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# Screening Instruments for Monitoring Market Power − The Return on Withholding Capacity Index (RWC)

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**Abstract**

*While markets have been liberalized all over the world, incumbents often still hold a dominant position, e.g. on energy markets. Thus, wholesale electricity markets are subject to market surveillance. Nevertheless, consolidated findings on abusive practices of market power and their cause and effect in these markets are scarce and non-controversial market monitoring practices fail to exist. Right now, the Residual Supply Index (RSI) is the most important instrument for market monitoring. However, a major drawback of this index is its focus on just one specific aspect of market power in wholesale electricity markets whereas different consequences of market power are possible. Hence, markets could be distorted in several ways and we propose the „Return on Withholding Capacity Index" (RWC) as a complementary index to the RSI. The index is a measure of the firms' incentive to withhold capacity. The benefits and practicability of the RWC is shown by an application on data for the German-Austrian electricity wholesale market in 2016.*

***Keywords:*** *Market Power, Electric Power Markets, Residual Supply Index*
***JEL classification numbers:*** *L11, L43, L94, K23, C13.*

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# 1 Introduction

Since the 1990s, energy markets have been liberalized in many countries all over the world. Wholesale electricity markets are a key part of the energy sector and many of these markets have reached a reasonable share of private competitors. Nevertheless, incumbents often still hold dominant positions due to their existing fleet of power stations. Thus, wholesale electricity markets are typically subject to market surveillance. In particular, specialized regulators, competition authorities and service operators are monitoring the market development to deduce substantial information about the degree of remaining market power.[1]

However, the most important development in electricity wholesale has been the increasing electricity production from renewable energies in recent years. In many countries, renewables have reached considerable market shares within a short time. In Germany, for instance, renewable energies accounted for already 40.36 percent of electricity production in 2018.[2] A special characteristic of renewable energies is that production is subsidized in many countries. In addition, the production volume of important technologies, such as wind and solar power, cannot be determined by the suppliers. With marginal costs close to zero, production is heavily dependent on meteorological factors. Therefore, cartel authorities generally regard renewable energies as a separate market, while conventional power plants compete for residual load (load minus generation from volatile renewables) (German Federal Cartel Office (2011)). Due to the rapidly increasing volume of renewable energies and the resulting overall increase in electricity generation capacity, market power problems on wholesale markets have recently been observed less frequently. Therefore only little research has been done in this field. However, due to the closure of power plants and increasing shortages a new focus is laid on this topic. In the German-Austrian bidding zone, the average day-ahead price for electricity rose from 30.23 Euro/MWh to 45.62 Euro/MWh between 2016 and 2018.[3] Most European countries are planning or even have already implemented government mechanisms to secure capacity (European Commission (2016)).

As conventional electricity becomes scarce again, monitoring of market power on wholesale markets is gaining importance. The results of this kind of monitoring are important for political and institutional actors to further develop the market design, e.g. in terms of capacity mechanisms. Moreover, the knowledge gained and the methods used in market monitoring to assess market power are important in quasijudical investigations conducted by competition authorities. For all these institutions, reliable screening tools are important to monitor markets with foresight. As

[1]Important examples of such a market monitoring include the European Commission (2016), Final Report of the Sector Inquiry on Capacity Mechanisms, COM(2016) 752 final, Nov 2016, `https://ec.europa.eu/energy/sites/ener/files/documents/com2016752.en_.pdf` and the German 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.

[2]Own calculations based on production data of the ENTSO-E transparency platform.

[3]This is the load-weighted average price for these years, calculated with data from the ENTSO-E Transparency Platform. Since October 1, 2018, the German und Austrian markets are separated, hence only data for the German bidding zone was taken into account for 2018.

screening of market power in wholesale electricity markets is subject to particular challenges, we are proposing a new instrument, the ”Return on Witholding Capacity Index” (RWC) and show its application on data for the German-Austrian electricity wholesale market in 2016. The RWC index is a measure which indicates the strategic incentive of capacity withholding by a supplier. Therefore, we consider the perspective of an electricity supplier: electricity markets are mostly organized via uniform price auctions. Hence, the market price can increase by a large amount in reaction to a small decrease in supply when demand is at a high level. Consequently, strategically withholding a fraction of running capacity leads to a net increase in profit if the earnings from the higher market price exceed the losses from the offset power plant.

The article is organized as follows: The subsequent section gives a literature review and describes the existing tools for monitoring market power. Section 3 presents the new instrument for market screening of market power, namely the RWC, whose benefits and practicability are shown by using data from the German-Austrian electricity wholesale market in section 4. We conclude in section 5.

## 2 Monitoring Market Power: Literature Review

Economic research provides a large set of indices to measure market power. They can generally be used by monitoring units in energy markets. By contrast to other markets, wholesale electricity markets have some distinctive characteristics which have to be taken into account when measuring market power. It is generally assumed that these markets are characterised by a mean reversion of the price, sudden fluctuations in load and supply without strong opportunities to storage and low elasticity in demand, which is reflected in price spikes (Cartea and Figueroa (2005)). Consequently, it can be shown that typical market share indices, such as the Herfindahl-Hirschman Index (HHI), are not well suitable to investigate market power in electricity markets (Newberry (2009))[4]. Thus, market monitoring as well as certain research has been focusing in particular on two methods: on the one hand emphasis is put on the Residual Supply Index (RSI) which is kind of a structural index and specialized for the needs of electricity markets. On the other hand more complex behavioral analysis is used. The latter is typically based on real cost data or cost estimation, such as the price-cost markup.

The RSI was initially introduced by Sheffrin (2002) who showed a strong relationship between the RSI and markups during the California Energy Crisis in 2001. The index was developed as a more differentiated extension of the Pivotal Supplier Index (PSI) which has been used for the first time by the US Federal Energy Regulator Commission (FERC) in 2000 as a measure called Supply Margin Assessment (SMA) to determine market power of electricity suppliers. Both, PSI and RSI measure on an hourly basis whether a supplier is pivotal in terms of its capacity being relevant for the market to serve total electricity demand. If this is the case, the supplier can determine

[4] Even though HHI and similar measures like the concentration rates are still used to determine market concentration on wholesale electricity markets, i.e. Frontier Economics (2010), European Commission (2012).

the price if demand is inelastic. Since pivotal market power has a significant impact, the RSI has gained considerable importance as a market power indicator. The RSI is also suitable for market monitoring, because it can be calculated with a reasonable amount of load and market share data.[5] Since its first application, the RSI has become an important predictor for market power in electricity markets (e.g. Chang (2007), Lang (2007), Asgari and Monsef (2010), Kamiński (2012), Mulder and Schoonbeek (2013)). Even more relevant seems to be the use of the RSI by market monitoring units of US regional transmission organizations (RTO).[6] Additionally, the RSI has gained importance in market surveillance by European competition authorities. In Europe, the RSI was crucial for assessing European energy markets by DG Competition (2007).[7] Furthermore, the German Federal Cartel Office applied an RSI calculation on an hourly basis for the years 2007 to 2008 in its sector enquiry (German Federal Cartel Office (2011)). More recently, the German Monopolies Commission conducted RSI analyses in their special reports on the German energy sector (Monopolies Commission (2013), (2015), (2017)).

As an alternative to the RSI calculation, the Lerner index as a well established measure of market power in economic research can be used. The Lerner index or likewise the very similar price-cost markup (PCMU) is specified as the proportional price-cost margin of a firm. Although these indices are usually considered as reliable to describe market power they do not serve as common screening instruments in market monitoring due to the limited availability of adequate cost data. Using the Lerner index in wholesale electricity markets requires hourly data – in particular regarding marginal costs – for each power generation unit. Only in quite extensive sector investigations it might be feasible for a competition authority to obtain this cost data directly from the suppliers. Despite the fact that the European Commission as well as the German Federal Cartel Office have retrieved this information from power generators once in their sector inquiries, this complex procedure seems to be unsuitable for continuous market monitoring.

Instead of gathering information on real marginal cost from suppliers one can estimate costs using a synthetic model of electricity dispatch. These kind of models simulate the market by combining behavioral assumptions with available information about input prices and power generation units. Regarding the measurement of market power only few studies make use of those models. For example Lang (2007) analyze the German wholesale electricity market using a simulation model. Additionally, Möst and Genoese (2009) investigate the exercise of market power with an agent-based simulation model, that uses detailed German wholesale power market data. In a more recent study Mulder (2015) tests whether the intensity of competition in the Dutch

[5] The Residual Supply Index has reasonable requirements for the data which are necessary for calculation. However, load and other data should be available (at least) on an hourly basis. If data is used on a more aggregated level a lot of explanatory power is lost by this way of RSI calculation.

[6] In RTO the use of PSI/RSI or similar indicators can be intensive as they can be part of local market power mitigation mechanisms. E.g. the California Independent System Operator (CAISO) applies the Three Pivotal Supplier Test. In order to prove the appropriateness of the test a surveillance report is published CAISO (2013).

[7] On behalf of DG Competition (2007) London Economics undertook a study in which the RSI was calculated for several European countries. Their results showed substantial market power of huge electricity suppliers in the observed countries.

electricity wholesale market changed over the period 2006–2011. The marginal costs per firm are based on actual plant-level data, using engineering-cost estimates. However, the synthetic simulation of dispatch is usually not used by market monitoring units presumably due to missing confidence in appropriate estimation techniques and hence, the lack of empirical work.

While at least the RSI offers a prospective way of measuring market power in wholesale electricity markets there is still little empirical research on its appropriate application. Since Sheffrins initial idea, there have been very few attempts to provide evidence on the quality and appropriate quantification of the RSI. An exemption is the study of London Economics (2007) and subsequent research of the authors Swinand *et al.* (2010). They show, that market structure, as measured by the RSI, is a significant explanatory factor for markups, even when scarcity and other explanatory variables are included.

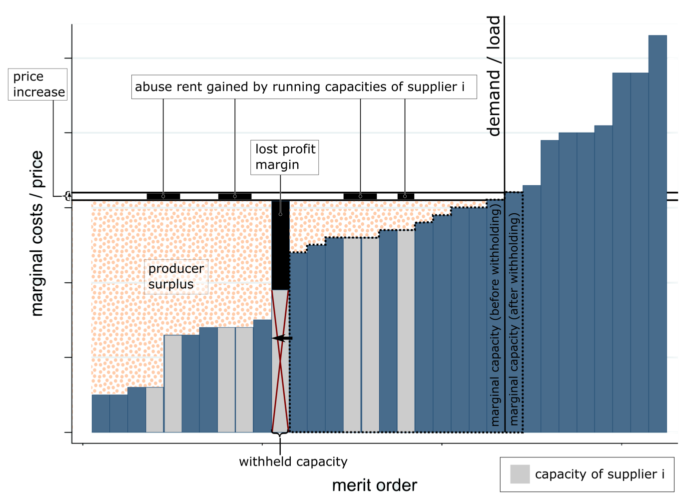
One major drawback of the RSI is that it does not fully consider suppliers' incentives to influence the market price. The RSI aims at the degree of pivotality of a supplier and thus, its ability to manipulate the price, but not its incentive to do so. As the RSI does not consider different technologies of electricity production and their related costs it cannot capture these incentives which are due to different technologies of each supplier. The consideration of incentives for abusive strategies constitutes an important advantage of behavioral indicators: these measures are more suitable to capture possible capacity withholding strategies. The dispatch model, for instance, reveals further details about the marginal cost structure of the analyzed coal and gas fired power plants. With the information on the ownership structure of each generating unit one can calculate markups for the total installed capacity of every supplier and then determine incentives to withhold specific generating units. A weakness of dealing with this information is, however, that the results are decisively depending on the accuracy of the estimated cost level. Therefore, a market power index, such as the Lerner index, which is sensitive to the absolute cost level is more vulnerable to possible impreciseness. In fact, this is a serious problem, because market monitoring and even more investigations by competition authorities need feasible and reliable monitoring techniques.

# 3 A Method for Monitoring Capacity Withholding Incentives

Although a market can be distorted in several ways, generally two strategies are considered as important for abusive practices in power generation (Twomey *et al.* (2006), Helman (2006), Biggar (2011)). Both strategies aim at rising prices by reducing supply, such that the cost of the marginal power plant increases: on the one hand this can be achieved by physical withholding of capacity (reducing output), e.g. a supplier temporarily reduces its capacity by claiming a unit is not operational. On the other hand market power is exercised by financial withholding (raising the price of output), i.e. a supplier raises its bidding price above the marginal cost of a generation unit. Either strategy generates specific cost and price effects depending on the technology mix of the electricity supplier.

Physical withholding behavior restrains capacities from the market for strategic reasons, which results in a reduction of output. Electricity units are not provided, although they could be offered at a price that exceeds the marginal cost. The strategy can be implemented through planned outages or throttling (Twomey *et al.* (2006)). In a normal competitive market situation any capacity that exceeds its short-term marginal costs is expected to be sold in order to achieve a positive contribution margin. In the market for electricity generation, however, this behavior is not always profit-maximizing due to special price generation on the electricity spot market.[8] Abusive practice can be identified if a supplier withholds capacity that he could sell above marginal cost in the short term. This is profitable as the supplier expects that the shortage of supply volume leads to a shift in the merit order. As a result of the price mechanism in electricity wholesales market, the price increases which leads to additional profits due to higher contribution margins for the remaining power plants in the portfolio. However, in order to maximize profits with this strategy, additional profits must exceed losses due to withheld capacity (German Federal Cartel Office (2011)). This mechanism is illustrated in figure 1:

**Figure 1:** *Rational Calculation for Capacity Withholding*




Strategic withholding played an important role during the California Energy Crisis in 2001 and was a reason for the severity of this crisis (Kwoka and Sabodash (2011)). One of the best-known empirical studies in the field of capacity withholding incentives is that of Joskow and Kahn (2002), whose goal is to explain the sharp price increase in Californian energy wholesale in 2000 compared to previous years. They first examine whether the increase was caused by exogenous market changes, such as the rise in gas prices, demand or lower imports. In a further step, they investigate whether the increase in cost of emission rights led to higher prices in the wholesale energy sector. In their analysis, however, they conclude that a large part of the increased costs cannot be explained by changed market conditions and emission rights certificates. Finally, they

[8]For theoretical work see for example Crampes, C., Creti, A. (2005), as well as LeCoq (2002).

analyze capacity withholding behavior as a reason of the price increase. They distinguish between actual scarcity caused by planned failures or transmission limitations and strategic withholding to increase profits. They limit their analysis to peak load periods in order to determine reasonable quantities by comparing the actually produced capacity with the maximum installed capacity. The maximum installed capacity serves as a proxy for the amount of quantity produced in a competitive benchmark during peak load periods. Joskow and Kahn (2002) show that the behaviour of capacity withholding in the Californian spot market during summer 2000 can at least partly explain the observed price increase. The California Public Utilities Commission also comes to the conclusion that five Californian electricity producers have withheld the capacity of their plants (Joskow and Kahn (2002)).

Prior to Joskow and Kahn (2002), Patrick and Wolak (2001) investigated possible strategies to raise prices in the wholesale energy sector. In their empirical analysis of the UK wholesale electricity market during April 1991 to March 1995, they found that National Power and PowerGen strategically withheld capacity in the market to achieve higher prices.

The pivotality of a supplier, as well as a diversified power plant portfolio increases the probability of capacity withholding. However, the strategy of physical capacity withholding is difficult to identify for regulators as it can be easily declared as necessary maintenance or technical failure. More recently, Fogelberg and Lazarczyk (2014) and Bergler *et al.* (2017) have found evidence that so-called unplanned power plant outages (defined as strategic failures by the authors) increase with rising prices in the Swedish or German-Austrian-wholesale market. In conclusion, Bergler *et al.* (2017) recommend extended monitoring by public authorities.

In fact, capacity withholding may be a serious problem in liberalized energy markets and reliable monitoring techniques are needed. Hence, we develop an indicator detecting abusive use of market power in terms of capacity withholding which is more suitable for practical use. It is quite important that the indicator addresses the incentives for capacity withholding on the one hand, but is not sensitive to the absolute level of costs.

### 3.1 The Return on Withholding Capacity Index (RWC)

To measure the incentive for capacity withholding, the costs and benefits of withholding for any supplier have to be examined: the lost profit margin on the one hand and the abuse rent due to a price increase on the other hand. The RWC takes into account that the supplier will induce a higher price if capacity is withheld due to the increasing scarcity (e.g. caused by the use of a more expensive power plant), without this price increase necessarily having to be particularly high. A corresponding unilateral effect can also occur if the provider does not have a pivotal position. Incentives for capacity withholding outside peak load hours also depend in particular on the power plant portfolio, which is considered by the RWC, contrary to other frequently used indicators, such as the RSI. Therefore, the RWC is suitable for assessing the risk of abusive capacity reduction.

Data on hourly produced quantities per plant type and the portfolio structure of each supplier enables us to derive the total capacity each power supplier provides per hour. Hence, multiplying these value with the induced increase of the market price, yields the profits any supplier can gain by withholding a capacity of one MWh. This value can be considered as the incentive for the abusive strategy of withholding physical capacity to increase prices. For interpretational reasons it is helpful to relate this rent to the actual market price. This yields an alternative measure of market power on firms incentive for abusive behaviour which we label as the Return on Withholding Capacity Index (RWC). It is defined as follows:

$$RWC_{i,t} = \frac{\Delta p \times (runningcapacity_{i,t} - 1)}{marketprice_t}$$

with $\Delta p$ as the estimated value for the price premium expected by the supplier i for withholding one MWh capacity at time t. For calculation of the RWC, information on suppliers' running capacity is essential though. Therefore, we will discuss the approximation of this figure in more detail in the following section.

The RWC works as a standardized indicator to quantify the incentive of a certain power supplier to withhold capacity. However, to interpret the results of a comprehensive RWC calculation, some aspects have to be considered: the calculated return on withheld capacity has to be compared with the lost profit margin due to reduced production (see Figure 1). An incentive for strategic withholding is given if the RWC is higher than the proportional profit margin for withheld capacity. At maximum the proportional profit margin equals one if the withheld capacity has marginal costs of zero.

Thus, the following rule can be applied:

**RWC $\geq$ 1** the supplier has a strong incentive to withhold capacity since the lost profit margin is always smaller than the abuse rent gained if the supplier runs other capacities.

**RWC $<$ 1** interpretation of this indicator is limited since it can solely provide information on the relative likelihood of strategic withholding (e.g. by inter-temporal, inter-market or inter-firm comparison). For further interpretation of an RWC below one, extended in-depth data about the hourly profit margins of generation units would be necessary.

### 3.2 Data Requirements for the Index Calculation

The purpose of our market power index is to provide an instrument for a wide range of users, such as monitoring units. The index is designed to provide information about the incentives of suppliers to withhold capacity with reasonable effort. Thus, it is important that data for the calculation of the RWC is publicly available.[9] Information to calculate the running capacity of a provider, as well as price and demand (load) data to estimate the price premium $\Delta p$ are necessarily required.

[9]While most of the data is available for free, exceptions are the commercial ORBIS database of Bureau van Dijk and information on price data.

For EU countries, the ENTSO-E transparency platform offers detailed information on production and load data.[10] To determine the incremental price increase $\Delta p$, data on the demand for electricity from price-setting power plants in the bidding zone under examination is required. Since we use day-ahead prices for the later estimation, it is further suitable to use day-ahead forecasts for the load and production values accordingly. Total demand is available as (forecasted) "total load" on the ENTSO-E platform. To calculate the incremental price increase, however, only demand for the production volume of power plants that produce electricity dependent on the market price is considered. This is the case if the output of the power plants can be controlled by the supplier and power plants are also working at marginal cost above zero. Power plants that do not meet these criteria are usually volatile renewable energy plants that produce electricity depending on meteorological factors. These plants feed into the grid independent of the current market price. As a result, they shift the residual demand for electricity from power plants that set prices.[11] While the production volume of ordinary power plants is weakly or strongly positively correlated with the price, inflexible power plants reduce the residual demand for price-setting plants and are negatively correlated with the price.[12] Hence, the appropriate residual demand value results from the difference of (forecasted) "total load" and (forecasted) production volume of inflexible power plants. In our case solar, wind power and run-of-the-river hydroelectricity plants in the German-Austrian price zone.[13]

There is often no precise data for the specific power plants of a supplier that produce at a certain point in time. However, the running capacity can be approximated quite well from data which is publicly available. For this purpose, production data from ENTSO-E differentiated by power plant type can be used. Within a power plant technology, marginal costs usually differ only slightly. By allocating data on hourly produced quantities per plant type to the corresponding supplier's market share of the existing capacities, it is possible to deduce the running capacity of each supplier.[14] Therefore, the market share of suppliers, differentiated by type of generation, has to be determined.

[10] See `https://transparency.entsoe.eu/` for hourly load (including day-ahead-forecast) and production data.

[11] One issue in this calculation of the quantity in demand could be that the value for "total load" includes electricity trading (limited by the transmission volume) with suppliers and buyers from neighboring bidding zones. However, the non-price-setting power plants in these neighboring markets cannot simply be adjusted in value for the total load. The resulting distortion can be critical if smaller markets are examined in which supply by neighboring countries accounts for a considerable part of supply in the bidding zone under consideration. Thus, in these cases it can be an advantage to approximate the demand quantity instead of the adjusted "total load" by the accumulated supply of the price-setting power plants in the bidding zone under consideration.

[12] Significant negative price-generation correlation values for 2016 are: solar (-0.11), wind power (-0.41) and run-of-the-river hydroelectricity (-0.14).

[13] In consequence, subtracting non-controllable renewable energy plants leads to a substantially higher explanatory power on the effect on prices. This effect is shown by a R2 of 0.745 with adjusted load compared to a R2 of 0.325 in case of non-adjusted load.

[14] Capacity of production facilities should not be taken into account if they feed in at fixed subsidized prices and therefore do not (or only marginally) benefit from an increase in the market price. In Germany and Austria, this accounts for wind power and solar installations that receive a feed-in tariff or a market premium.

To do so, we use data for the installed capacity in Germany from the periodical power plant survey of the German Federal Network Agency.[15] The survey provides detailed information regarding e.g. the normal maximum operating capacity (MW), energy source (type of power plant), supplier (owner) company etc. for all German generation units with a net nominal output of at least 10 MW.[16] According to the Federal Network Agency the survey covers more than 95% of the total installed capacity produced by conventional power plants in Germany or rather in the German control areas.[17] In total, we observe 875 generation units with a total installed capacity of 110,346 MW. In order to determine the ownership structure for these generation units, or rather the total installed capacity, survey data on the respective owner companies was merged with Bureau van Dijks ORBIS database. ORBIS provides information about the global ultimate owner for most of our sample firms. Firms which were not covered by ORBIS were manually researched by checking company websites and company reports. This enables us to identify which firms in our sample data belong to one of the four big generators in Germany. As a result, we obtain the market share in the production capacities of the individual generator companies, both for the overall market and for the individual types of power plant. The added production volumes of the individual power plant types from the ENTSO-E transparency platform multiplied by the respective market shares leads to the approximated running capacity of each supplier.

Moreover, energy carrier prices, such as gas, coal and carbon oxide were used as control variables for estimating the supply curve. Gas prices and carbon oxide as well as coal prices are provided by Energate. Spot market prices (day-ahead prices) for electricity can be observed on an hourly basis e.g. on the ENTSO-E transparency platform.

### 3.3 Estimation of the Incremental Price Increase $\Delta p$

For the estimation of the price premium, i.e. the incremental price increase $\Delta p$, expected by the supplier for withholding one MWh capacity, we make use of the relationship between residual load and the price level. This relationship is used to estimate the supply function.

The general shape of the supply function depends on the market under consideration and has to be adjusted accordingly. In the German-Austrian bidding zone, the technological merit order and the fluctuations of residual load support a cubic shape. A cubic relationship is assumed as a result of the typical mixture of different power plant technologies, which differ in their fixed and marginal costs (Crew *et al.* (1995)). Base load power plants (e.g. lignite, nuclear) have low marginal costs, but a limited flexibility. For this reason, shutting down base load power plants

[15] Version 31.03.2017. An updated version of the survey can be found here:`https://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Sachgebiete/Energie/Unternehmen_Institutionen/Versorgungssicherheit/Erzeugungskapazitaeten/Kraftwerksliste/Kraftwerksliste_2016.html`

[16] Note, that the survey also includes industrial generation units. However, they react differently on market signals, such as energy prices since they are operating as required to meet demand of the respective industrial company. Hence, all industrial power plants are discarded from our analysis.

[17] There are generation units not located in Germany, but in the border region of Austria, Switzerland, France and Luxembourg which feed power into the German grid. Hence, they are regarded as part of the German control area.

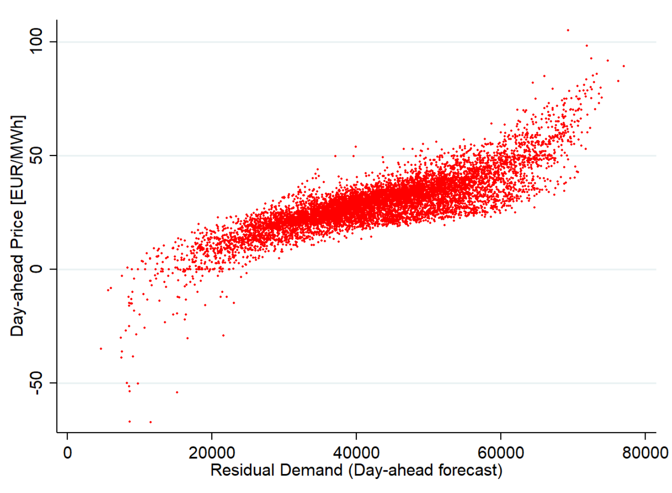
is only profitable in case of sharp price jumps to negative prices. Meanwhile, peak-load power plants, such as gas-fired ones, are only used during peak demand, have high marginal costs and have to finance these with short running times. This suggests that price jumps are stronger with fluctuations in base load and peak load ranges than with medium loads. The German-Austrian market is characterised by precisely these technological characteristics, which are reflected in price peaks and negative prices. The cubic shape of the supply curve is also confirmed by Figure 2 which shows the relationship between residual load and market price in 2016.

Since we intend to estimate the price increase expected by suppliers for the withdrawal of one unit of capacity, the appropriate investigation period has to be adjusted accordingly. A study of at least several months would be more appropriate if a period that is too short may give an incomplete picture of the different seasonal load situations. A period, that is too long, on the other hand, does not consider structural changes on the energy markets (e.g. construction or dismantling of power plants) and thus, attenuates the correlation of load and price. Therefore, for our study of the German-Austrian market, we consider the calendar year to be a suitable period of investigation. Nevertheless, in case of other markets or study years examined, the supply conditions may also fluctuate considerably during a calendar year, requiring the model to be adjusted in such cases accordingly.[18]

We are able to show, that the calculated residual demand or load explains electricity prices to a great extent. We focus on the period of 2016, for which running capacity was measured likewise and which serves as the basis for determining the RWC in Section 4.

[18]Fluctuations, that can blur the relationship between price and residual load during a calendar year are, for example, the seasonal nature of certain price-setting power plant types (e.g. downtimes in the event of overheating in summer months), large-scale power plant shutdowns during the year or significant changes in fuel prices. Instead of dividing the investigation period into periods of less than one year, seasonal dummy variables (e.g. monthly) could also be considered in such cases. However, it should be pointed out that using such dummy variables may lead to the disappearance of seasonal effects from the price/load relationship. The price premium expected by providers during capacity holdbacks may therefore deviate from the estimate in these periods.

**Figure 2:** *Relationship of residual load and market price in 2016*




To investigate the incremental price increase $\Delta p$, we further quantify this effect as we estimate a regression model. A key point in our analysis is the estimation method, as we make use of wholesale electricity price as the dependent variable and (residual) load as a regressor. One could argue that such a model suffers from an endogeneity bias due to reverse causality since demand and price are usually simultaneously determined. However, this may not be the case here, as demand in wholesale energy markets is highly price inelastic. Our main focus lies on the real-time price elasticity of demand,[19] since the theory of capacity withholding is an unpredictable event for consumers. This means, that one can only react to the withholding price effect in real time. But a large proportion of electricity consumers are generally unaware of the real-time fluctuations in wholesale electricity prices (Knaut A. und Paulus S. (2016), German Federal Cartel Office (2011); Gelabert *et al.* (2011)). Hence, they have no incentive to adjust their consumption in real-time, but may only react on price changes in the long run. However, elasticity of demand plays a decisive role, particularly with regard to the increased amount of volatile renewable energy which poses new challenges to electricity grids.

Due to the huge amount of data required, there are only a few studies that deal with the analyses of real-time elasticities of overall demand. Nevertheless, they come to similar conclusions. Lijesen (2007) measures the real-time elasticity of demand for electricity in the Netherlands for 2003. To address possible endogenity due to the simultaneity of demand and supply, lagged prices are used as instrument variables. Lijesen (2007) shows a price elasticity of -0.0014 in the linear model specification and -0.0043 in the log-linear model specification. He concludes that according to his study, consumers are not prepared to react to real-time prices because the elasticity of demand is low. Knaut A. und Paulus S. (2016) estimate a similar model for the German energy market in 2015 and come to similar results. They show that demand reacts only slightly to price

[19]Real-time elasticity is defined as the price elasticity of demand on an hourly basis.

changes. Elasticity varies between -0.004 and -0.006. These results are in line with Lijesen (2007). Genc (2014) chooses a different approach. He uses detailed power generation and market data from 2007 and 2008 to investigate market power in the wholesale energy sector in Ontario, Canada. He estimates the responsiveness of demand only for wholesale customers. However, the hourly elasticities are rather small. They lie within an interval -0.144 and -0.013 for 2007 and within -0.083 and -0.019 for 2008.

Thus, we conclude that real-time elasticity of demand is rather small in all these cases. If, in a specific wholesale market for which the RWC is calculated, an (almost) completely inelastic demand can be assumed, there is no problem with endogeneity. In the following, we use data for the German-Austria-wholesale market and perform both, simple OLS as well as IV regressions.

### 3.4 OLS Estimation Approach

In a first step we use the wholesale electricity price (day-ahead price) as the dependent variable and residual demand (day-ahead forecast) as a regressor to perform OLS estimations.[20] As we have already emphasized in the previous chapters residual demand $L_{resid}$ enters the equation as a cubic function. Furthermore, we use control variables for input prices, namely fuel prices for coal, gas and CO2, to control for supply shocks. Augmented Dickey-Fuller test reveal that neither the wholesale electricity price nor residual demand and our control variables show a unit root. That is, they are stationary and consequently enter the regression model in levels. Thus, the following equation is estimated:

$$p_t = \beta_0 + \beta_1 * Lresid_t + \beta_2 * Lresid_t^2 + \beta_3 * Lresid_t^3 + \beta_4 * pcoal_t + \beta_5 * pgas_t + \beta_6 * pCO2_t + \epsilon_t \quad (1)$$

By deriving the estimated model with respect to $Lresid_t$, it is possible to calculate the price increase $\Delta p$ that occurs when load is changed by one unit.

Our results in Table 1 show that in the full sample residual load (i.e. residual demand), as well as changes in gas and coal prices have a significant effect on the wholesale electricity price, while changes in CO2 price show no significant effect. This result is also confirmed if we split our sample into peak and off-peak hours. From a theoretical point of view, commodity prices can have an impact on electricity prices as they influence the marginal costs of power plants. Due to the technology mix in a merit order, the influence on the price depends on how much a certain technology is used at a certain load phase and how much the marginal power plant provides. Therefore, the influence of certain fuel prices on the market price is not linear, but depends on load.[21] Consideration of fuel prices may distort the estimate, as the linear influence in the model will have an effect even if this is not actually the case due to the load situation.[22] Hence, in a

[20] We took the day-ahead price, as it is the most important spot market price and all hourly prices for a day can be determined at the same time. Accordingly, we also use the day-ahead forecast for the demand data.

[21] The correlation between the residual load and the coal and gas prices amounts to 0.23 and is statistically significant in each case.

[22] If there is a huge differential of fuel-prices during the calender year, it could be preferable to catch the effect by monthly dummy variables.

**Table 1:** *Regression result of spot price on load*

| | Full sample I | Peak hours II | Off-Peak hours III | Full sample IV |
|---|---|---|---|---|
| L_resid | 0.0056*** | 0.0057*** | 0.0055*** | 0.0055*** |
| | (0.0004) | (0.0001) | (0.0001) | (0.0004) |
| L_resid2 | <-0.0001*** | <-0.0001*** | <-0.0001*** | <-0.0001*** |
| | (<-0.0001) | (<-0.0001) | (<-0.0001) | (<-0.0001) |
| L_resid3 | <0.0001*** | <0.0001*** | <0.0001*** | <0.0001*** |
| | (<0.0001) | (<0.0001) | (<0.0001) | (<0.0001) |
| pcoal | 0.1670*** | 0.1740*** | 0.1700*** | |
| | (0.0074) | (0.0130) | (0.0100) | |
| pgas | 0.4330*** | 0.6830*** | 0.2150*** | |
| | (0.0482) | (0.0800) | (0.0617) | |
| pCO2 | -0.0863 | 0.1140 | -0.1880 | |
| | (0.0831) | (0.1310) | (0.1000) | |
| _cons | -80.18*** | -85.43*** | -76.47*** | -63.21*** |
| | (4.8530) | (1.9310) | (1.7050) | (4.7730) |
| Observations | 8,687 | 4,345 | 4,342 | 8,687 |
| $R^2$ | 0.800 | 0.804 | 0.785 | 0.745 |

Standard errors in parentheses

$^{*}$ $p < 0.05$, $^{**}$ $p < 0.01$, $^{***}$ $p < 0.001$

further specification we simplify our model by omitting these control variables. As Table 1 shows omitting all control variables only led to a small decline in the goodness of fit measure R2 and - even more important - coefficient values of residual load. Since our goal is to develop a very simple measure of market power, that can be calculated and applied easily, this simplified model provides a very sound foundation. Although using the coefficient value of residual load of the simplified model may come at the cost of a small bias, it has the huge advantage that considerable less data is needed. Besides, omitting control variables allows for defining a standardized procedure for calculating the RWC. Thus, we propose using the result of the simplified regression model as the foundation of the RWC and build on this within the following analysis. Furthermpore, the simplified regression model yields to a rather high adjusted R2 of 0.75.[23]

All our results show a highly significant relationship between residual load and the spot market price. If we take the first derivative of equation (1) with respect to $Lresid_t$ we receive

$$\frac{\delta p_t}{\delta Lresid_t} = \beta_1 + 2\beta_2 Lresid_t + 3\beta_3 Lresid_t^2 = \Delta p \tag{2}$$

[23]As an robustness check, we show that this strong relationship is also present in 2017 (adjusted R2 of 0.87) and in 2015 (adjusted R2 of 0.78). This is also shown in the graphs presented in the appendix section A.3.

**Table 2:** *Summary statistics* $\Delta p$

| | Mean | Std.Dev. | Minimum | Maximum | Observations |
|---|---|---|---|---|---|
| I | 0.0839 | 0.0510 | 0.0457 | 0.4708 | 8,687 |
| II | 0.0872 | 0.0557 | 0.0431 | 0.4791 | 4,345 |
| III | 0.0752 | 0.0443 | 0.0437 | 0.3906 | 4,342 |
| IV | 0.0899 | 0.0517 | 0.0511 | 0.4637 | 8,687 |

in Eurocent

Hence, by inserting the residual load we are able to calculate $\Delta p$, namely the price increase if residual load is raised by one MWh or rather the price increase if one MWh of capacity is withheld by the supplier, for each each hour t of the period examined. Table 2 shows the summary statistic of $\Delta p$.

It can be seen that in the full sample withholding of one MWh unit leads to a price increase of 0.084 Eurocent, on average. At first glance, this value may seem rather small, but it in fact, it is of great importance if one recalls, that, for example, RWE has a plant portfolio of 46,411 MW in Germany.[24]

The results of the subsamples reveal that another unit of residual load leads to an average price increase of 0.087 Eurocent during peak hours and to 0.075 Eurocent during off-peak hours. However, a Wald test on the difference of the coefficients of residual load during peak and off-peak hours shows that the coefficients are not significantly different from each other making the full sample model the preferred specification. Tabel 2 also shows that, if we use the simplified model, withholding one unit of capacity leads to an average price increase of 0.090 Eurocent.

### 3.5 Instrument Variable Approach

As mentioned before, depending on the specific situation in a market, the OLS model may suffer from an endogeneity bias. To address this issue, we estimate an instrument variable approach in the following. We use lagged residual load as one instrumental variable. To ensure that the instrument captures the same time of the day as in the OLS model, residual load should be lagged by 24 hours. However, since demand for electricity may differ between weekdays and weekends, residual load is not lagged by 24, but by (7*24) 168 hours. Intuitively, the dynamics of the energy market ensure the exogenity of our instrument, as it seems reasonable that today's EEX spot market price is not directly dependent on demand decisions from the previous week.[25]

Since the amount of electricity produced by conventional power plants is highly dependent on the amount of renewable electricity, we use the production values of renewable electricity by

[24]Own calculations based on the periodical power plant survey of the German Federal Network Agency (Version 31.03.2017) linked with ORBIS ownership Data.

[25]This instrument variable approach with lagged instruments is also in line with the estimation of Lijesen (2007) who uses lagged prices to estimate the real-time elasticity of demand.

wind, solar and run-of-the-river hydroelectricity as another instrument. One may argue, that these renewable technologies are determinants for the prices on the supply side rather than on the demand side, but this channel is rather indirect due to an intersection of lower remaining demand for conventional electricity and the merit order. In fact, wind and solar power plants operate at zero marginal cost. Their electricity is fed into the grid, regardless of the current market price. Their production quantity is determined based on exogenous weather conditions. In addition, wind and solar power are subsidized by fixed prices in many countries.[26] Therefore, the production of wind and solar power can be considered as an exogenous parameter, that influences the residual demand for electricity conventional power plants. Performing a Stock and Yogo test leads to partial F-values of the instrumental variables of 1564.10, 2946.3, 2156.6.[27] According to Staiger and Stock (1997) a partial F-value of the instrumental variable in the first stage regression should exceed the value of ten. Hence, we can conclude that the instruments are relevant and the IV-regressions will not suffer from a possible weak instrument bias. Furthermore, we test whether our instruments are exogenous employing the Sargan test. The statistic does not reject the null hypothesis of validity of instruments (Sargan $p = 0.8753$).

Hence, the model to be estimated can be written as follows:

$$p_t^{iv} = \beta_0 + \beta_1 * \widehat{Lresid_t} * \beta_2 * \widehat{Lresid_t^2} + \beta_3 * \widehat{Lresid_t^3} + \beta_4 * pcoal_t + \beta_5 * pgas_t + \beta_6 * pCO2_t + \epsilon \quad (3)$$

As in the OLS-model this econometric framework enables us to determine $\Delta p$. We also conducted IV-regression without the control variables on input prices in order to define a standardized procedure to calculate the RWC. Results of the estimations are displayed in table 3.

[26]Since the German Renewable Energy Act (EEG) electricity from renewable sources has dispatch priority leading to a decreasing demand for conventional power plants.

[27] Detailed results can be found in the Appendix in section A.1.

**Table 3:** *Regression results IV-estimation*

| | Full sample I | Full sample II |
|---|---|---|
| L_resid | $0.0056^{***}$ | $0.0063^{***}$ |
| | (0.0004) | (0.0004) |
| L_resid2 | $<$-0.0001$^{***}$ | $<$-0.0001$^{***}$ |
| | ($<$0.0001) | ($<$0.0001) |
| L_resid3 | $<$0.0001$^{***}$ | $<$0.0001$^{***}$ |
| | ($<$0.0001) | ($<$0.0001) |
| pcoal | $0.1740^{***}$ | |
| | (0.0086) | |
| pgas | $0.4600^{***}$ | |
| | (0.0525) | |
| pCO2 | -0.0465 | |
| | (0.0864) | |
| _cons | $-79.56^{***}$ | $-70.92^{***}$ |
| | (4.400) | (4.927) |
| Observations | 8,687 | 8,687 |

Standard errors in parentheses

$^{*}$ $p < 0.05$, $^{**}$ $p < 0.01$, $^{***}$ $p < 0.001$

All our results of the IV-regressions show a highly significant relationship between residual load and the spot market price. This is in line with our results obtained by the OLS-regressions in the previous chapter. Table 4 shows the summary statistics of $\Delta p$, i.e. the price increase if residual load is raised by one MWh. It can be seen, that withholding of one MWh unit leads to an average price increase of 0.079 Eurocent. In the model without the input price control variables $\Delta p$ amounts to 0.090 Eurocent, on average and thus, confirms ours results obtained with the OLS model.[28]

**Table 4:** *Summary statistics first derivative - IV estimates*

| | Mean | Std.Dev. | Minimum | Maximum | Observations |
|---|---|---|---|---|---|
| I | 0.0786 | 0.0513 | 0.0401 | 0.4690 | 8,687 |
| II | 0.0891 | 0.0629 | 0.0418 | 0.5266 | 8,687 |

in Eurocent

Finally we perform a Hausman-Wu-test ($pvalue = 0.0501$) which supports our assumption that we do not face an endogeneity problem in this case. Hence, the Hausmann's test null

[28]The similarity of the estimated relationship between OLS and IV estimation is also clearly shown by the graphical illustration in Section A.3. Furthermore, as a robustness check we show that our model is robust by estimating the proposed model for the years 2015 and 2017. Results can be found in section A.3

hypotheses that OLS and IV lead to the same estimates cannot be rejected. Furthermore, we have conducted several robustness checks with alternative instruments, which lead to the same conclusion (see section A.2). Intuitively, this can be explained by the low real-time elasticity of demand as also shown by Graf and Wozabal (2013), as well as Lijesen (2007). However, higher elasticity is generally observed in peak load periods (Patrick and Wolak (2001)) which is quite essentiell for the estimation of the RWC since withholding incentives may be even higher at the steep part of the merit order. It is also not clear that real-time elasticity of demand will remain low in the future. For example, with increasing digitization, consumer devices may automatically control their load according to the price level. Thus, demand elasticity would further increase which would bias OLS estimates. It is therefore particular important, that the RWC index can be calculated for high demand elasticity as well. Hence, we suggest to use the IV estimator rather than the OLS-estimator for market monitoring, as the results are more reliable for the whole range of hours and the volume of demand.

# 4 Results and Application Proposal for Market Monitoring Units

By using estimation techniques as described in the previous chapter we are able to calculate RWC values for the German-Austrian market for 2016. In total, we receive 8,687 RWC values (i.e. for (almost) every hour of the year 2016) for the four largest providers in Germany. The values indicate how high the incentives of the individual providers were to withhold capacities on the spot market in the respective trading hour.

In order to interpret the values with regard to each suppliers' market power, it is necessary to adjust the calculated RWC values for off-peak periods. If load is low, the market price is low and the incremental price increase ($\Delta p$) is high. Hence, the RWC may show relatively strong incentives for withholding capacity in this situation. However, abusive capacity withholding is rather unlikely at very low market prices. In fact, baseload power plants are operated in low load phases at (even negative) prices, that do not cover short-term variable costs, because technical reasons prevent these baseload power plants from being completely shut down at short notice. Since the ability to control output represents a technological limitation, that can hardly be verified, the market price can be used as an indicator. We therefore clear the measured values for the RWC by those hours in the lower load range in which the price is very low and the possible price jumps are at the same time particularly high. To do this, we calculate the average incremental price increase $\Delta p$ for the load values below the turning point of our function. For 2016 this gradient value corresponds to an estimated market price of 21.67 euros. We presume, that in cases where the market price is actually lower, electricity is potentially produced although the short-term variable costs of production are not covered. Although the hours below this threshold are taken into account for the subsequent calculation of the percentiles, the RWC value is set to zero in these cases. This procedure ensures that the number of hours with the highest RWC values, whose limit is indicated by the percentile value, does not fluctuate significantly. Therefore, these values remain comparable for different tests. Finally, there remain 6.858 out of 8.784 hours for which the RWC can be interpreted.

In order to assess market power of individual providers for a specific year, we suggest to consider the upper 90 or 95 percentile values of the RWC. These values indicate how high the incentives to withhold capacity are for the 5 or 10 percent of hours with the highest values. Using these thresholds is in line with the monopolist test (SSNIP test) from European antitrust law. The SSNIP test asks the question whether a hypothetical monopolist would be able to profitably increase prices by 5 or 10 percent.[29] Table 5 shows the calculation of the 90 and 95 percentile values as well as the mean for the OLS and IV estimates. Moreover, Figure 3 shows seasonal variations of the RWC values received by IV-estimations.

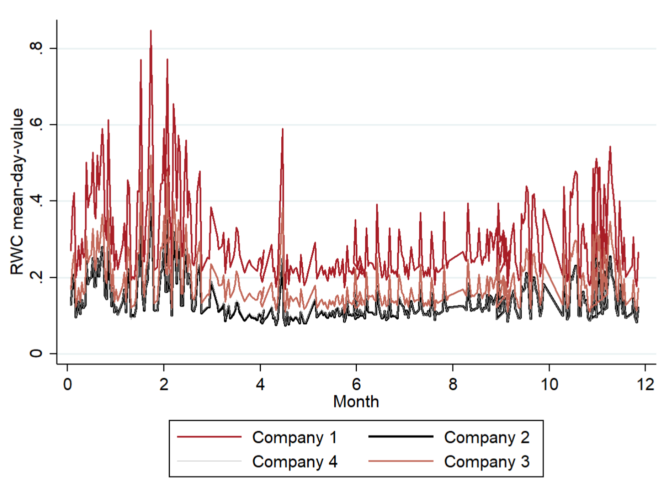
**Table 5:** *Mean and fringe values for the RWC in 2016*

| | Mean | | 90% Percentil | | 95% Percentil | | Hours> 1 | |
|---|---|---|---|---|---|---|---|---|
| | OLS | IV | OLS | IV | OLS | IV | OLS | IV |
| Company 1 | 0.3103 | 0.2968 | 0.4551 | 0 .4719 | 0.5455 | 0.5851 | 4 | 12 |
| Company 2 | 0.1457 | 0.1396 | 0.2154 | 0.2240 | 0.2590 | 0.2775 | 0 | 0 |
| Company 3 | 0.1946 | 0.1860 | 0.2868 | 0.2958 | 0.3429 | 0.3661 | 0 | 0 |
| Company 4 | 0.1466 | 0.1403 | 0.2176 | .2228 | 0.2609 | 0.2785 | 0 | 0 |

The results of the OLS and IV estimates for the incremental price increase are similar on average as well as for the percentile values. We conclude from this that the elasticity of demand in the market under examination is low. This fact as well as our tests conducted in the previous section lead us to the conclusion that the endogeneity problem in the market under consideration is not that serious. Nevertheless, we still suggest to use the IV-estimator for market monitoring, as the results are more reliable if demand elasticity is elastic. One advantage of the presented IV-estimator is that the required data (lagged residual load and renewable infeed) are usually quickly accessible through public sources, such as ENTSO-E. Thus, RWC values can be very well determined and standardized using the simplified form of our model (with the residual load as the only regressor) by market monitoring units. The standardization of the model also simplifies intertemporal comparisons of the calculated RWC values making changes of withholding incentives visible in market monitoring.

[29]Note, however, that this is quite a general comparison since the RWC only measures the incentive for capacity withholding and does not make a statement about a price increase.

**Figure 3:** *RWC results for 2016 monthly pattern*




# 5 Conclusion

Withholding production capacity is a widely discussed economic problem of wholesale electricity markets. Antitrust authorities and market monitoring units are engaged in this issue since the liberalisation of these markets. We have developed and tested the Return on Withholding Capacity Index to analyse the risk of abusing market power by capacity withholding. The index should be available to market monitoring units, but also to antitrust authorities and academics as a new screening instrument. The RWC is also suitable as a complement to the Residual Supply Index, which, unlike the RWC, only reflects a certain (but important) type of market power by individual suppliers.

The proposed RWC index is based on the assessment of a power plant operator prior to its decision to hold back capacity. The power supplier maximises its profit by withholding capacity if the lost contribution margins of a power plant (or a unit of capacity) held back is at least offset by the triggered price increase and the resulting contribution margins at other power plants. An RWC value of one or higher indicates that the capacity withholding might be profitable for a supplier, regardless of which power plant is held back. To interpret values below one in terms of absolute market power, further analyzes of individual costs are necessary. However, these results show the relative incentives for capacity withholding and are suitable, for example, for intertemporal comparisons of market situations.

An important requirement for the construction of the RWC is the calculation with reasonable effort from available data. Using an application example with data for the day-ahead market in the German-Austrian bidding zone in 2016, it is shown how the calculation can be optimized and standardized. An important component of the index calculation is the estimation of the price increase in the case of holding back one unit of capacity. In particular, market data on constant day-ahead prices on the one hand and hourly load forecasts on the other hand were used. The price increase was determined by using both, OLS and IV estimation models. In order to address the possible issue of endogeneity in case of an elastic demand function, we recommend that monitoring units determine the incremental price increase preferably with the IV-estimator. We also suggest to evaluate the data on the basis of a 90 and 95 percentile, on which the assumption of market power of individual suppliers could be based.

## References


Angrist, J. D. and Krueger, A. B. (2001). Instrumental variables and the search for identification: From supply and demand to natural experiments. *Journal of Economic Perspectives*, **15** (4), 69–85.

Asgari, M. H. and Monsef, H. (2010). Market power analysis for the iranian electricity market. *Energy Policy*, **38** (10), 5582–5599.

Bergler, J., Heim, S. and Hüschelrath, K. (2017). Strategic capacity withholding through failures in the german-austrian electricity market. *Energy Policy*, **102**, 210–221.

Biggar, D. (2011). The theory and practice of the exercise of market power in the australian nem, australian competition and consumer commission, melbourne.

CAISO (2013). Report on the appropriateness of the three pivotal supplier test and alternative competitive screens.

Cartea, Á. and Figueroa, M. G. (2005). Pricing in electricity markets: A mean reverting jump diffusion model with seasonality. *Applied Mathematical Finance*, **12** (4), 313–335.

Chang, Y. (2007). The new electricity market of singapore: Regulatory framework, market power and competition. *Energy Policy*, **35** (1), 403–412.

Crampes, C., Creti, A. (2005). Capacity competition in electricity markets. economia delle fonti di energia e dell'ambiente 2,. pp. 59–83.

Crew, M. A., Fernando, C. S. and Kleindorfer, P. R. (1995). The theory of peak-load pricing: A survey. *Journal of Regulatory Economics*, **8** (3), 215–248.

DG Competition (2007). Report on energy sector inquiry, sec(2006)1724.

European Commission (2012). Energy markets in den european union in 2011, publications office of the european union.

European Commission (2016). Final report of the sector inquiry on capacity mechanisms, com(2016) 752 final, nov.

Fogelberg, S. and Lazarczyk, E. (2014). Strategic withholding through production failures. *SSRN Electronic Journal*.

Frontier Economics (2010). Market concentration in the german engery wholesale market.

Gelabert, L., Labandeira, X. and Linares, P. (2011). An ex-post analysis of the effect of renewables and cogeneration on spanish electricity prices. *Energy Economics*, **33**, S59–S65.

Genc, T. (2014). Market power indices and wholesale price elasticity of electricity demand. *Technical report*.

German Federal Cartel Office (2011). Sector enquiry wholesale energy sector, b10-9/09.

Graf, C. and Wozabal, D. (2013). Measuring competitiveness of the epex spot market for electricity. *Energy Policy*, **62**, 948–958.

Helman (2006). Market power monitoring and mitigation in the us wholesale power markets. *Energy, Vol. 31, issue 6, 877-904*.

Joskow and Kahn (2002). A quantitative analysis of pricing behavior in california's wholesale electricity market during summer 2000. *The Energy Journal, Vol 23, Nr. 4.*, pp. 1–35.

Kamiński, J. (2012). The development of market power in the polish power generation sector: A 10-year perspective. *Energy Policy*, **42**, 136–147.

Knaut A. und Paulus S. (2016). Hourly price elasticity pattern of electricity demand in the german day-ahead market. . *EWI Working Paper, Nr. 16/07.*

Kwoka, J. and Sabodash, V. (2011). Price spikes in energy markets: "business by usual methods" or strategic withholding? *Review of Industrial Organization*, **38** (3), 285–310.

Lang, C. (2007). Marktmacht und marktmachtmessung im deutschen großhandelsmarkt für strom, wiesbaden.

LeCoq, C. (2002). Strategic use of available capacity in the electricity spot market. sse/efi working paper series in economics and finance 496.

Lijesen, M. G. (2007). The real-time price elasticity of electricity. *Energy Economics*, **29** (2), 249–258.

London Economics (2007). Structure and performance of six european wholesale electricity markets in 2003, 2004 and 2005, http://www.londecon.co.uk/le/publications/recent_reports.shtml.

Monopolies Commission (2013). Special report 65: Energy 2013.

Möst and Genoese (2009). Market power in the german wholesale electricity market. *Journal of Energy Markets 2*, pp. 47–74.

Mulder, M. (2015). Competition in the dutch electricity market: An empirical analysis over 2006-2011. *The Energy Journal*, **36** (2).

— and Schoonbeek, L. (2013). Decomposing changes in competition in the dutch electricity market through the residual supply index. *Energy Economics*, **39**, 100–107.

Newberry, D. (2009). Predicting market power in wholesale electricity markets. eui working papers, rscas 2009/03.

Patrick, R. and Wolak, F. (2001). *Estimating the Customer-Level Demand for Electricity Under Real-Time Market Prices*. Cambridge, MA: National Bureau of Economic Research.

Sheffrin, A. (2002). Predicting market power using the residual supply index. ferc market monitoring workshop, http://www.caiso.com/docs/2002/12/05/2002120508555221628.pdf.

Swinand, G., Scully, D., Ffoulkes, S. and Kessler, B. (2010). Modeling eu electricity market competition using the residual supply index. *The Electricity Journal*, **23** (9), 41–50.

Twomey, P., Green, R. J., Neuhoff, K. and Newbery, D. (2006). A review of the monitoring of market power the possible roles of tsos in monitoring for market power issues in congested transmission systems.

# A Appendix

## A.1 Robustness check IV results

Due to the cubic shape of the residual demand (*Lresid*) the first stage of the IV-model can be written as:

$$Lresid_t = \gamma_0 + \gamma_1 * Lresid_{t-168} + \gamma_2 * Lresid^2_{t-168} + \gamma_3 * Lresid^3_{t-168} + \gamma_4 * unflex_t + \gamma_5 * z + \mu \quad (4)$$

$$Lresid^2_t = \gamma_0 + \gamma_1 * Lresid_{t-168} + \gamma_2 * Lresid^2_{t-168} + \gamma_3 * Lresid^3_{t-168} + \gamma_4 * unflex_t + \gamma_5 * z + \mu \quad (5)$$

$$Lresid^3_t = \gamma_0 + \gamma_1 * Lresid_{t-168} + \gamma_2 * Lresid^2_{t-168} + \gamma_3 * Lresid^3_{t-168} + \gamma_4 * unflex_t + \gamma_5 * z + \mu \quad (6)$$

where $Lresid_{t-168}$ is the residual load lagged by 168 hour and $unflex$ is the forecasted load of unflexible power plants e.g. solar and wind generation.

**Table A.6:** *Stock and Yogo weak instruments test*

| | (1) | (2) | (3) |
|---|---|---|---|
| | L_resid | L_resid2 | L_resid3 |
| da_gen_sum_unflexibel | -0.6450*** | -52924.8*** | -3.54495e+09*** |
| | (0.0100) | (803.6) | (59473659.3) |
| lag168L_resid | -0.8850*** | -117181.3*** | -9.41889e+09*** |
| | (0.1400) | (10511.3) | (775585064.9) |
| lag168L_resid2 | <0.0001*** | 3.5140*** | 253491.3*** |
| | (<0.0001) | (0.2690) | (20532.8) |
| lag168L_resid3 | <-0.0001*** | <-0.0001*** | -1.490*** |
| | ( <0.0001) | ( <0.0001) | (0.1700) |
| _cons | 50153.8*** | 3.24295e+09*** | 2.10003e+14*** |
| | (1856.2) | (133734979.3) | (9.53591e+12) |
| Observations | 8,687 | 8,687 | 8,687 |
| $F$ | 1564.10 | 2946.3 | 2156.6 |
| $R^2$ | 0.581 | 0.576 | 0.551 |

Standard errors in parentheses

$^{*}$ $p < 0.05$, $^{**}$ $p < 0.01$, $^{***}$ $p < 0.001$

## A.2 Robustness check with other instruments

The use of lagged values as an instrument is not always seen as unproblematic in the economic literature. It is argued that in terms of prices and quantities there may be a strong correlation of the realizations of the variables over time (Angrist and Krueger (2001) ). This is often the case in markets where long-term negotiations take place, as certain delivery conditions, such as in food retailing, are clearly determined on the basis of the previous period. By contrast, futures trading at the dynamic spot market for energy quantity takes place on an hourly basis. On this basis, a lag of 168 hours no longer appears to be directly dependent on the offer and an exogeneity seems plausible. In order to meet the criticism of Angrist and Krueger (2001), however, a modified specification is also tested to exclude a potential misinterpretation of the test results due to possible endogenous instruments. The specification is defined as follows:

$$Lresid_t = \gamma_0 + \gamma_1 * unflex_t + \gamma_2 * publichol_t + \gamma_3 * precipitation_t + \gamma_4 * Monday + \gamma_5 * Friday + \gamma_6 * z + \mu$$
$$Lresid_t^2 = \gamma_0 + \gamma_1 * unflex_t + \gamma_2 * publichol_t + \gamma_3 * precipitation_t + \gamma_4 * Monday + \gamma_5 * Friday + \gamma_6 * z + \mu$$
$$Lresid_t^3 = \gamma_0 + \gamma_1 * unflex_t + \gamma_2 * publichol_t + \gamma_3 * precipitation_t + \gamma_4 * Monday + \gamma_5 * Friday + \gamma_6 * z + \mu$$

and second stage as

$$p_t = \beta_0 + \beta_1 * \widehat{Lresid_t} * \beta_2 * \widehat{Lresid_t^2} + \beta_3 * \widehat{Lresid_t^3} + \beta_4 * pcoal_t + \beta_5 * pgas_t + \beta_6 * pCO2_t + \epsilon$$

where $unflex$ is the forecasted produced load of unflexible power plants e.g. solar and wind generation, $publichol$ is a dummy variable which takes the value of one on German national public holidays and $precipitation$ is the weighted daily amount of precipitation. [30]

Instruments are relevant (F-value: 586.74, 499.68, 423.73) and exogenouson a 10% level (Sargan test: $p = 0.2894$). By applying the econometric framework we are able to estimate the elasticity of supply and perform a Durbin-Wu-Hausman Test (Model I $p = 0.6831$ and model II $p = 0.4640$)[31]. Results of the estimation are displayed in table A.7. Summary statistics of the first derivative can be found in A.8.

[30] To capture precipitation for whole Germany, we weight precipitation with the number of inhabitants of all large German cities with more than 100,000 inhabitants which are assigned to the closest weather station.

[31] We also conducted the IV regression without taking supply inputs into account. In order for defining a standard procedure, as explained in the previous section.

**Table A.7:** *Robustness check other IVs*

| | Full sample | Full sample |
|---|---|---|
| | I | II |
| L_resid | 0.0076* | 0.0082* |
| | (0.0030) | (0.0038) |
| L_resid2 | <-0.0001* | <-0.0001 |
| | (<0.0001) | (<0.0001) |
| L_resid3 | <0.0001 | <0.0001 |
| | (<0.0001 ) | (<0.0001 ) |
| pcoal | 0.1700*** | |
| | (0.0219) | |
| pgas | 0.5100*** | |
| | (0.0977) | |
| pCO2 | -0.0758 | |
| | (0.2530) | |
| _cons | -104.1*** | -92.14* |
| | (31.11) | (39.06) |
| Observations | 8,687 | 8,687 |

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

**Table A.8:** *Summary statistics first derivative - IV robustness check estimates*

| | Mean | Std.Dev. | Minimum | Maximum | Observations |
|---|---|---|---|---|---|
| I | 0.0790 | 0.0737 | 0.0238 | 0.6355 | 8,687 |
| II | 0.0887 | 0.0874 | 0.0228 | 0.6837 | 8,687 |

in Eurocent

## A.3 Relationship of residual load and market price OLS and IV for 2015, 2016 and 2017

**Figure 4:** *Relationship of residual load and market price OLS (black) and IV (blue) in 2015*

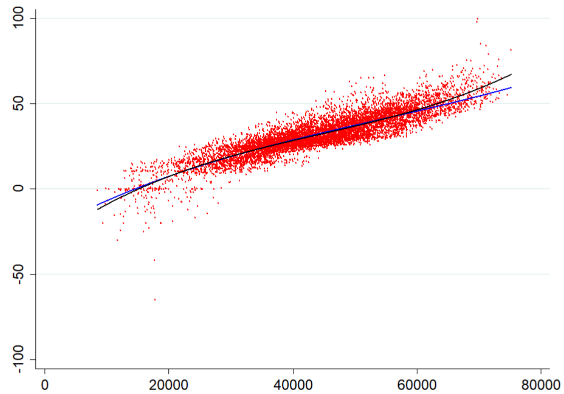



**Figure 5:** *Relationship of residual load and market price OLS (black) and IV (blue) in 2016*

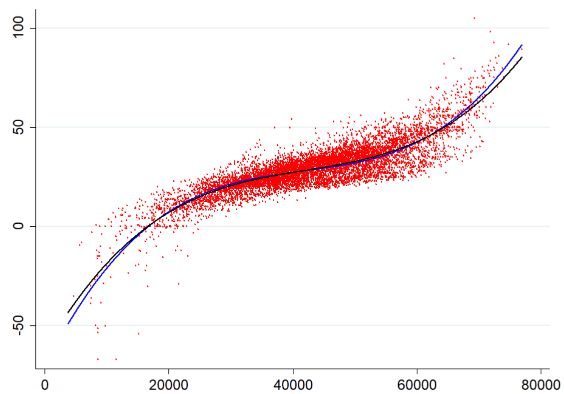
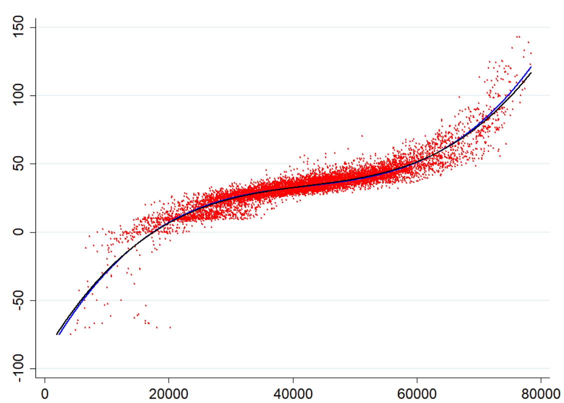



**Figure 6:** *Relationship of residual load and market price OLS (black) and IV (blue) in 2017*



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