# Strategic Withholding through Production Failures

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**ABSTRACT**

Anecdotal evidence indicates that electricity producers use production failures to disguise strategic reductions of capacity in order to influence prices, but systematic evidence is lacking. We use an instrumental variable approach and data from the Swedish electricity market to examine such behavior. In a market without strategic withholding, reported production failures should not depend directly on the market price. We show that marginal producers in part base their decision to report a failure on prices, which indicates that production failures are a result of economic incentives as well as of technical problems.

**Keywords:** Strategic withholding, Market power, UMMs, Production failures

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## 1. INTRODUCTION

-We decided the prices were too low... so we shut down.
- Excellent. Excellent.
- We pulled about 2,000 megs of the market.
- That's sweet.
- Everybody thought it was really exciting that we were gonna play some market power. That was fun!

Intercepted exchange between Reliant traders, June 2000, Weaver (2004)

A competitive and well-functioning market is one of the goals of modern, liberalized electricity markets. However, a commonly voiced concern has been that firms strategically reduce their generating capacity in order to increase the electricity price. Strategic withholding of electricity was, for example, observed during the electricity crisis in 2000–2001 in California, and has been determined to be one of the reasons why the crisis became so severe (Kwoka and Sabodash 2011, Weaver 2004). Theoretical studies have also shown how firms benefit from this behavior (Crampes and Creti 2005, Kwoka and Sabodash 2011). The studies of market power investigating the Nordic electricity market Nord Pool have so far been mostly inconclusive (Vassilopoulous 2003, Hjalmarsson 2000, Fridolfsson and Tangeras 2009). However, certain circumstances have been proven to enable exercising of market power like high demand, congestion in the market (Olsen et al. 2006; Mirza and Bergland 2015), and concentration of production (Amundsen and Bergman, 2002).

In this article we look at a previously under-researched method that electricity producers can use to withhold capacity in order to increase prices on the Nordic electricity market. We consider instances when generators shut down part of their production due to a failure, and we verify

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whether the decision to stop production and provide information about this failure depends on economic incentives rather than being the result of a technical problem. Market participants on Nord Pool are obliged to publicly inform about changes to consumption, generation or transmission that exceed 100MW and last longer than 60 minutes in so-called Urgent Market Messages (UMMs). We investigate whether spot prices on Nord Pool influence the probability of production failures being reported in UMMs. Production failures should not depend directly on prices, as failures should be irregular and difficult to foresee. The detection of a significant relationship between prices and market messages therefore indicates that market participants base decisions concerning reporting a failure not only on technical problems, but also on economic incentives.

We use text scraping methods to create a unique dataset containing information about UMMs released by market participants with information about unplanned reductions of production i.e. production failures. Our dataset permits us to examine how prices affect market participants' decisions about issuing failure messages and how these decisions vary by generator type. Since prices may directly influence how generators are operated an OLS regression would give biased results. In order to estimate a causal effect of prices on production failures we therefore use a linear two-step model and instrument for prices using temperature and precipitation levels. Temperature was chosen as an instrument because of its exogenous nature and because prices on the Nordic electricity market are highly correlated with temperature. Especially during the cold season, when electricity is used for heating, temperature and demand follow each other closely. Additionally, since Nord Pool is largely based on hydro generation we instrument prices with precipitation levels, since during a "wet" ("dry") year prices are in general low (high).

We distinguish messages issued by different types of baseload unit production (nuclear and hydro[1]), and marginal unit production (coal, gas and oil). When the demand is high, a small reduction in produced quantity can have a large impact on prices, and this reduction can be achieved by either a marginal or baseload unit. However, a producer with several types of generators primarily has an incentive to decrease production for marginal fuel types, as these production units have higher marginal costs. Hence, we expect larger effects for marginal fuel types which, in the case of Sweden, are oil, gas and coal.

We also separate the effects for new messages regarding failures and follow-up messages concerning already reported failures. This distinction is important as the incentives might differ depending on whether a producer decides to report a new failure or the prolongation of an existing outage. It is possible that a producer decides to report a new failure based on the encountered technical problems, but that the length of the failure depends on economic incentives. An increased number of follow up messages indicates that it takes longer to fix a failure, and the time it takes to fix a failure should not depend on prices in a competitive market.

To our knowledge, this is the first article studying strategic withholding that uses a quasi-experimental set up. The results indicate that there is a significant relationship between day-ahead electricity prices and the number of reported failures. The effect depends on the type of fuel used for generation. We find a positive effect of an increase in price on the number of reported failures in the case of oil and gas—marginal technologies. This is consistent with the hypothesis that it is more profitable to withhold capacity from generators with a high marginal cost. The results also

1. Although hydro generation, especially with reservoirs, can be thought of as marginal type of generation due to its fast response time and balancing characteristics, in this analysis we treat hydro as baseload. We make a distinction between types of electricity generation with regard to the level of marginal costs as low costs generators will face different incentives than high cost generators.

show that prices have a larger effect on follow-up messages as compared to messages reporting an initial failure.

We first describe the economic rationale for withholding capacity in Section 2, followed by a description of the Nordic electricity market in Section 3. The data used in the analysis is presented in Section 4. Section 5 presents the econometric strategy and results are discussed in Section 6. The last section concludes.

## 2. ECONOMIC RATIONALE FOR WITHHOLDING CAPACITY

In Sweden, the general EU transparency rules apply, in particular REMIT (2011)[2] a regulation penalizing market manipulation in wholesale energy markets across Europe. Strategic withholding is regarded as a way of exploiting market power on electricity markets. In economic literature whenever a generator would in expectation profit from the sale of an additional unit of electricity, assuming that the market price would not change, and the generator decides not to sell, it is believed he has exercised market power (Twowey et al. 2005). A multi-unit generator that wants to increase the market price can achieve it in two ways. It can either strategically bid all of its production, asking for high prices (above its marginal costs[3]), or it can physically keep some of its capacity away from the market.[4] This article deals with a specific version of physical withholding—the reduction in capacity through production failure. Here, and in the relevant literature, "strategic" is not defined as an interaction between multiple market players, but as a unilateral decision of one player to systematically influence prices (Wolfram 1998, Kwoka and Sabodash 2011).

### 2.1. Theoretical background

There are some pre-conditions that are thought to ease unilateral withholding of capacity: tight market conditions i.e. high demand, congestion in the market, and concentration of production.

Figure 1 illustrates physical withholding behaviour and its intended impact on prices. The graph depicts characteristics of a liberalized wholesale electric power market with inelastic demand (in the short run) and a hockey-stick shaped supply curve. The special shape of the supply curve is due to the merit order of electricity production, that is, the ordering of electricity production technologies according to their increasing marginal cost of production. Electricity is supplied by either baseload production with large starting costs but low, almost zero, marginal cost (for instance, through nuclear power plants), or by marginal production that starts producing when the baseload cannot fulfil the demand (for instance, coal or gas in Nord Pool). Moreover, different plants have some fixed capacity with steady costs that rise sharply when this capacity is exceeded.

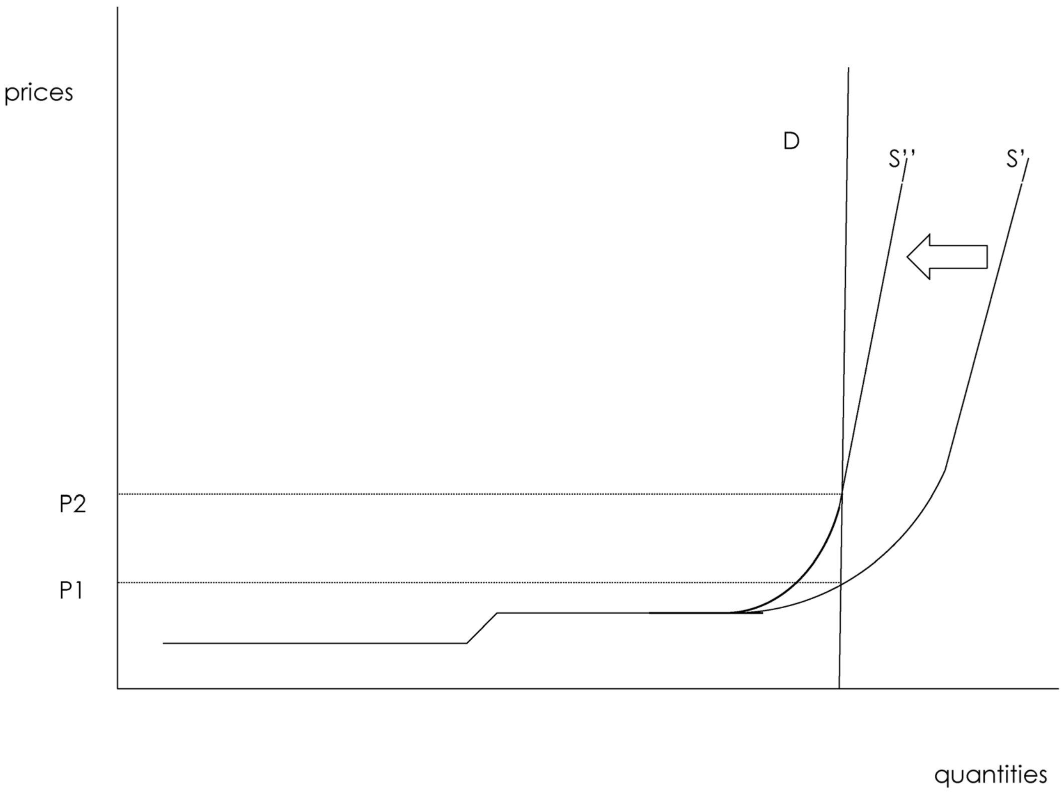
The electricity market of the Nordic Region operates as a uniform auction, resulting in a single equilibrium price for each hour. A reduction of supplied quantity shifts the supply curve to the left, which can result in big price changes, especially if the demand curve is close to the almost vertical part of the supply curve. At this very steep part of the supply curve, where more expensive units are required to match the rising demand, prices become very sensitive to changes in supply (Patton,

2. Regulation (EU) on wholesale energy market integriy and transparency.

3. This form of capacity withholding is often referred to as "economic withholding" Moss (2006).

4. For the first alternative see for e.g. Wolfram (1998) where it is shown that in England large suppliers bid strategically above their marginal costs and that all power plants submit higher bids if their owner has more low-cost capacity available. Wolfram (1999) has also evaluated prices in the spot market, comparing several price-cost ratios with the outcomes of theoretical oligopoly models and concluded that capacity withholding did not result in as high markups as the theory would suggest.

**Figure 1: Wholesale electricity market, capacity withholding**




2002), so even small output fluctuations might have a substantial impact on prices. Congestion can worsen the situation by helping to keep a high demand market tight.

Congestion can also directly facilitate exertion of market power when a large market due to congestion splits into several regions where only a few generators can provide electricity in each area thus creating conditions where some firms can use their dominant position to influence prices. Congested transmission lines causing a split of the market into zones and creating divergent prices in adjacent areas are indicated as a possible explanation of abnormally high prices in Western Denmark (Olsen et al. 2006) and southern Norway (Mirza and Bergland, 2015).

Another factor impacting the potential of exercising market power is the size of a producing firm. For a larger firm, an incentive to withhold is greater since in order for the strategy to be profitable, a producer needs to own several production units and the increase in profit after a production failure needs to be larger than the lost profit from the reduced output. In a 2002 study Amundsen and Bergman point out that a generating company becoming a minority owner in another generating firm might have incentives to reduce its own production this way increasing the market price of electricity and in fact exercising market power. However, even though strategic withholding is considered as uncompetitive behavior, and a form of market power abuse, a large market share is not a necessary condition for withholding to be advantageous. The condition on high demand when demand crosses supply at the upper part of the "hockey stick", together with the multi-unit structure of a generator explains why even producers with a small share of the market can gain from strategic withholding (Kwoka and Sabodash 2011, Kwoka 2012).

The type of generating technology also has an impact on the potential withholding decision. Different production technologies are expected to have different incentives for strategic withholding and we anticipate finding larger effects for marginal production technologies. Withholding marginal production is more profitable, as these units have higher marginal costs compared to baseload units. When demand is high and marginal production units set the price, even a small reduction of capacity can have a substantial impact on prices. Under these circumstances the market price is higher than the marginal cost of baseload production so it is in one's interest to utilize cheap, baseload production, since it is already earning high infra-marginal profits. For technical reasons, it is also easier to shut down a marginal production unit compared to a baseload production unit. In the electricity market of the Nordic region we, therefore, expect larger effects for coal, gas and oil, since these are considered marginal technologies in the studied market.

In summary, when demand is high and capacity utilization (including marginal capacity) is tight, generators possess considerable market power to increase prices. In such a situation even a small company may be able to exercise market power, in particular so if further electricity imports to the price area are prevented by transmission constraints.

## 2.2 Strategic withholding through failures

In contrast to the withholding literature that focuses on the bidding strategies of operators, we analyze the strategy of physical withholding of capacity. We assume that producers have an incentive for disguising withholding as failures. This strategy, as opposed to simply increasing bid prices, has the advantage of being more difficult to prove simply by looking and comparing bid curves of market participants and can always be explained as being undertaken due to technical reasons or security issues. Due to information asymmetry between a generator and a regulator it might be almost impossible to determine whether a generator reporting a "sick day" really cannot operate (Wolak, 2014). We assume that disguising capacity withholding as failures can allow firms to claim that they are doing their best in providing generating services under the circumstances. Physical withholding has been examined in the literature concerning price spikes but as pointed out by Kwoka (2012), the occurrence of extreme price spikes has gone down in most deregulated markets over the last few years.[5] It is possible that the attention that the media and research has brought to the subject has made market participants more careful. Wolak (2014) writes: "the treat of public scrutiny and adverse publicity is the regulator's first line of defence against market rule violations". There is, however, still the possibility for strategic withholding through production failures given that this strategy is difficult to prove and has been only sporadically investigated. Jaskow and Kahn (2002) analysed the case of California crisis and showed that outage rates of some plants increased during the crises.[6] Wolak and Patrick (2001) analyse the case of the England and Wales electricity power pool where they show that periodically two major generators where using notifications about available capacity in order to achieve prices substantially above their marginal cost. Patton et al. (2002) conducted a thorough analysis of the New England electricity market and did not find evidence of unilateral physical withholding of output. However, they observe that it is of importance to monitor these issues and suggest that random physical audits should be used as a

5. Kwoka and Sabodash (2011) develop a method to separate price spikes that are a result from demand shifts under inelastic supply from price spikes that result from strategic withholding. They do this by investigating whether supply systematically shifts down during periods of high demand. They conclude that there is evidence of strategic withholding for a brief period of time during 2001 on the New York wholesale electricity market. They also develop a model that shows that unilateral withholding for a company with two identical production units is profitable, as long as the price increase (resulting from reduction of capacity) is larger than the initial price-cost margin.

6. However, Hogan et al. (2004) give another explanation for the higher outage rate; they suggest that it was the higher utilisation of units that lead to this increased failures rate.

tool to verify the technical justifications which accompany forced outages. In our study, we provide a more systematic investigation of the potential for physical withholding through outages that can be used in markets where information about sudden outages is publicly available (as is the situation in EU since the implementation of the SPDEM Regulation (2013)).

It is possible that there is no systematic timing of failures, but that the time it takes to correct a failure depends on economic incentives. There has been anecdotal evidence of similar behavior played at the British electricity pool, where generators have occasionally prolonged the outage if doing so would allow them to receive a higher level of capacity payments (Newbery 1995; Green 2004). In this article, we distinguish between the failures reported for the first time and follow-up messages regarding already reported failures. More follow-up messages indicate that it takes longer to fix a failure. If the effects that we estimate are larger for follow-up messages as compared to reports of new failures, we can conclude that firms put more emphasis on prolonging failures compared to timing them strategically and announcing them for the first time.

### 2.3 Potential for withholding at Nord Pool: spot prices and timing

By the design of the Nordic electricity market, the next day's electricity prices are set on the previous day at 1 p.m. Prices are correlated over time and in case there are no shocks the expected price for tomorrow's electricity is equal to today's price. Therefore, we assume that a producer would base the decision of reporting a failure on today's price. A failure cannot influence the current spot price as this has already been fixed. It can however have an impact on the next day's price. Today's production failure will become common knowledge through UMMs. Tomorrow's prices will increase if other producers fail to compensate for this failure. Another scenario assumes that when a failure happens, a more expensive unit produces the missing capacity, which is likely to happen when demand is high. All this will result in today's failure pushing up tomorrow's prices. This effect can be shown empirically (see results in table A5 in the Appendix)[7].

In our framework, we focus only on the day-ahead market, the spot price, excluding from our analysis possible interactions between markets of different horizons, for instance balancing and future markets. Given our econometric set up we can only estimate how daily variations in price affect failure rates, which means that any long term withholding strategies are outside the scope of this article.

### 2.4 A Simple Example

In this section, we illustrate with simplified calculations how withdrawing of capacity from the market can be a profitable strategy. We use price numbers from our data that we will explore thoroughly later on in this article. We assume that marginal production costs are zero for all types of units.

Consider a producer A, who owns 1000MW production that can be divided into 10 units of 100 MW each. In the warm season, from the 15th of March until the 1st of October, the mean price in our sample is 36€. In order not to lose on withdrawing 100MW of capacity, the price in-

7. If we combine the estimates in table A5 with the back of the envelope calculation in section 2.4, we see that if the number of daily oil failures increases by 100% as compared with the average (0.14) then the price will increase with 19%. For gas an increase in failures with 100% compared to average (0.10) will result in a price increase of 17%. These numbers correspond to price increases of 7.6€ and 6.8€. However, these calculations are done on averages and abstract from that withholding is more profitable when prices are high.

crease as a result to this capacity reduction would need to be at least 4€. If the producer decides not to fail he can earn 36000 € [1000MW*36€]. However, if he decides to fail 100MW, the price would need to be 40€ in order for the producer to enjoy the same profit [900MW*40€=36000€]. The situation is almost the same in the cold period (1st of October—15th of March) when the mean price is 44€. In this season, the price would need to increase by 4.8€ for the producer to be indifferent to whether or not to reduce capacity by 100MW [44€*1000MW=44000€ vs. 49€*900MW=44100€].

In the time period analyzed, the mean of the difference between today's price and yesterday's price is almost zero and the standard deviation is 5.51€. This indicates that the minimal price change from day to day that is necessary for producer A to not lose on withdrawing capacity (4–5€) is realistic. Moreover, the maximal day to day average price difference observed for the analyzed time frame is 33€.

## 3. MARKET DESCRIPTION

The Nordic Region electricity market is one of the first deregulated electricity markets in the world and one of the largest European electricity market both in turnover and geographical area. It consists of seven countries belonging to the Nordic and Baltic region (Sweden, Norway, Finland, Denmark, Lithuania, Estonia and Latvia[8]). The market is also connected with other countries including Germany and Poland. It consists of physical and financial markets. Two physical markets form the Nord Pool Spot, and enable trading, one day before the delivery of electricity, on the day-ahead market Elspot, and between 1 to 36 hours before the delivery on the intra-day market Elbas. In 2012[9] the total traded volume on Nord Pool reached 432 TWh.[10] Out of this, 334 TWh were traded on Elspot, which was a 13 percent increase as compared to the volume traded in 2011. 77 percent of the total consumption of electrical energy in the Nordic market in 2012 was traded through Nord Pool Spot. The Nordic market enables trade to many market participants; there are 370 companies from 20 countries trading on Nord Pool.[11]

The day-ahead market is the main arena for electricity trading. Based on bids and offers, a uniform auction determines a unique price that clears the market for each hour. The gate closure for the trades, with delivery for the next day, is 12:00 CET. At around 13:00 CET, prices for the next day are known, and contracts start to be delivered at 00:00 CET. If there is no congestion between the zones, the entire Nord Pool area gets the same system price, often called the spot price[12].

Sweden constituted one price area until the 1st of November, 2011, when it was divided into four price zones as a result of an antitrust settlement between the European Commission and the Swedish network operator.

8. http://www.nordpoolspot.com/How-does-it-work/Bidding-areas/.

9. http://www.nordpoolspot.com/Global/Download%20Center/Annual-report/annual-report_Nord-Pool-Spot_2012.pdf.

10. This is including the day-ahead auction at N2EX in the UK.

11. Data from 2012 Nord Pool's yearly rapport.

12. However, in case of congestion, the market can be divided into up to 15 zones. Each zone can have its own price, which is calculated from the bids and offers submitted to the exchange after taking into account transmission constraints. The split of the market into different areas changes the competitive landscape of Nord Pool, as in cases of congested transmission lines the market decreases from the one spanning several countries into a very local one, often with a dominant generating company. Such dominant local players have been shown to actively shape the transmission between areas in order to profit from high prices (Mirza and Bergland, 2015; Olsen, 2006).

### 3.1 Market structure

There are 29 power plants that are larger than 100MW in Sweden.[13] We summarize their characteristics in Table 1.

**Table 1: Summary characteristics of Swedish electricity production**

| | Number of power plants | Number of units | Main fuel | Installed capacity in MW | Average size of a unit |
|---|---|---|---|---|---|
| SE1 Luleå | 12 | 21 | Hydro | 3,764 | 170 |
| SE2 Sundsvall | 2 | 5 | Hydro | 705 | 141 |
| SE3 Stockholm | 12 | 24 | Oil, Bio, Coal, Nuclear, Gas | 11,846 | 493 |
| SE4 Malmö | 3 | 6 | Oil, Bio, Gas | 1,581 | 263 |
| Total: Sweden | 29 | 56 | | 17,566 | 313 |

*Source:* Based on the data from (Nord Pool, b)
*Note:* State as on the 4th of December 2012.

Power plants are spread unequally across Sweden. There are 12 power plants in the Luleå area—SE1; 2 in the Sundsvall area—SE2; 12 in the Stockholm area—SE3; and 3 in the Malmö area—SE4. The largest installed capacity—11,846MW—is in the Stockholm area, as this is where Swedish nuclear power plants are based. The number of units is different from the number of power plants as one power plant has between 1 and 4 generating units. There are 6 power plants that have only 1 generating unit in area SE1, 1 in SE2, 4 in SE3, and 2 in SE4.

In Sweden 79% of electricity is supplied by three biggest companies: Vattenfall, E.ON and Fortum (EI, 2013). The concentration ratios measured with the Herfindahl-Hirschman Index (HHI) indicate that the market is relatively concentrated[14]. The HHI value for Sweden[15] alone is 1,989 (EI, 2013)[16].

## 4. DATA

In our analysis we investigate whether market participants report a failure based on the electricity price for the day, t. We examine two years of daily data from the 1st of January, 2011, to the 31st of December, 2012, describing the day-ahead Nordic electricity market Nord Pool. We analyse the Swedish average day-ahead price and we instrument for this price using daily average temperatures in Sweden and Swedish average precipitation levels. The information on all unplanned failures larger than 100MW and lasting for more than 60 minutes was extracted from the Urgent Market Message (UMM) text files that are available upon request from Nord Pool's server. Text scraping methods were used to create an UMM dataset containing information on the number of failures per hour by fuel type. We can also separate between newly reported failures and UMMs that are sent out as updates on already reported failures. The price data also come from Nord Pool's server. Temperature and precipitation data come from the Swedish Meteorological and Hydrological Institute (SMHI). To get results that are more easily interpreted, we collapse the hourly data to daily data. The results for hourly data are however consistent with the results we report for daily data.

13. State on the 4th of December 2012, (Nord Pool, b).
14. In Europe markets thought to be moderately concentrated have HHI values between 1,000 and 2,000.
15. The HHI which we report (EI, 2013) is for installed capacity and does not include transfers between zones.
16. Inclusion of the other Nordic countries (Finland, Denmark and Norway) decreases the ratio, but it is still above 1,000.

### 4.1 Price, temperature and precipitation level data

The evolution of the Swedish average day-ahead price is depicted in Figure 2.[17] The data sample starts with high prices above 80€/MWh during the winter of 2011. The price gradually decreases before peaking again in February 2012 when prices for two days exceeded 90€/MWh. Prices rose again in December 2012. From the 1st of November, 2011, Sweden has been divided into four price areas. Hence, for the purpose of the analysis in this article we construct and use an average price for the whole country. Table 2 reports summary statistics describing price distribution.

**Figure 2: Swedish average Elspot price, January 2011–December 2012**

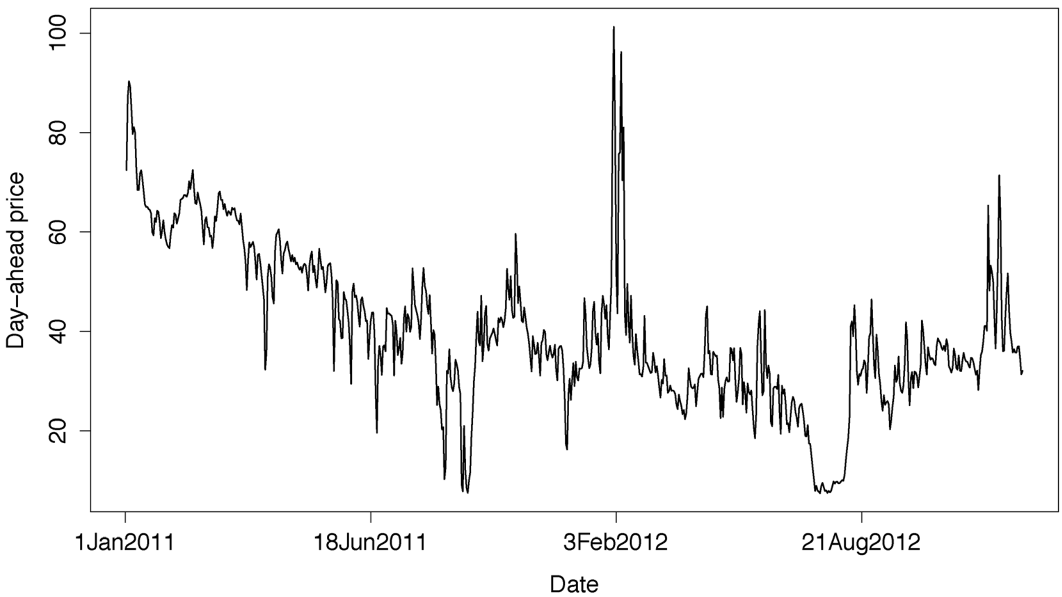



**Table 2: Summary statistics describing the Swedish average day-ahead price**

| Variable | Heating Season | Obs | Mean | Std Dev. | Min | Max |
|---|---|---|---|---|---|---|
| Price | | 731 | 40.08 | 15.60 | 7.37 | 101.26 |
| Price | Yes | 333 | 44.29 | 15.96 | 7.46 | 101.26 |
| Price | No | 398 | 36.55 | 14.39 | 7.37 | 68.16 |
| Log of Price | | 731 | 3.60 | 0.46 | 2.00 | 4.62 |
| Log of Price | Yes | 333 | 3.72 | 0.38 | 2.01 | 4.62 |
| Log of Price | No | 398 | 3.50 | 0.49 | 2.00 | 4.22 |

*Note:* This table presents summary statistics for the day-ahead Swedish electricity price from the Nordic electricity market Nord Pool during the period from the 1st of January 2011 to the 31st December 2012. Variable Swedish price is reported in Euros per megawatt hour. Variable Log of Swedish price is a natural logarithm of Swedish price. The heating season is defined as the period between the 1st of October and 15th of March.

The overall mean price for Swedish electricity traded at Nord Pool is 40€/MWh. The difference between the highest and the lowest price is around 94€/MWh. The cold season, between October and the middle of March, is characterised by higher mean prices that oscillate around 44€/

17. Scrutinizing the price graph could raise doubts whether the price time series is stationary. Therefore we test the null hypothesis that the price data follows a unit root process with the use of the Dickey-Fuller test. We reject the null hypothesis and conclude that the series is stationary.

MWh. In the rest of the year, average prices are lower, at around 36€/MWh, with the highest mean price of 68€/MWh registered in the second part of March 2011. As we use the natural logarithm of price instead of levels, in Table 2 we also report the summary statistics for the transformed price variable—the natural logarithm of the Swedish price. Figure A1 in the appendix plots the log of the day-ahead Swedish spot price.

In our analysis we use an average temperature for Sweden to instrument for the price. The mean temperature in the analysed period is 4.26 Celsius. The coldest period was in February 2011 when the average temperature dropped to –21 Celsius. Table 3 presents summary statistics for the temperature data for the Swedish average temperature recorded between the 1st of January, 2011 and the 31st of December, 2012.

**Table 3: Summary statistics of the Swedish average temperature**

| Variable | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| Temperature | 731 | 4.26 | 8.16 | –21.18 | 19.56 |
| Average precipitation | 731 | 2.06 | 2.27 | 0 | 12.17 |

*Note:* This table presents summary statistics for the Swedish average temperature and average precipitation levels (in millimetres) recorded between the 1st of January 2011 and the 31st December 2012.

There is an expected negative correlation of –0.47 between the price variable and the temperature indicating that when the temperature drops the electricity price increases.

Since Nord Pool is largely based on hydro generation, as a second instrument for price we use Swedish precipitation data. The raw data were downloaded from the Swedish Meteorological Office webpage for more than 2000 measuring stations and subsequently were averaged to get an overview measure for the entire country (Table 3). There is a negative correlation (–0.2) between price and precipitation level indicating that during a "wet" season electricity prices drop[18]. Precipitation levels are considered important exogenous indicators of price levels in hydro dominated systems (Weron et al. 2004; Torro, 2007).

### 4.2 The UMM dataset

The Urgent Market Messages dataset is composed of messages providing information about all planned and unplanned outages exceeding 100MW and lasting for more than 60 minutes that were recorded in the Nord Pool area. We measure the number of failures (the unplanned outages per day) as the variable "$Failure_t$". Based on the information extracted from the UMMs we were able to identify the area that would be most affected by the event that the message was informing about. The affected area is identified by the issuer of the message. In our two-year sample there are 1,327 messages announcing unplanned failures affecting Sweden; out of these, 612 are hydro failures, 341 are nuclear failures, 99 are gas failures, 75 are oil failures, 41 are biofuel failures, and only 4 are coal production failures.

In the Nordic area the demand for electricity rises as it becomes colder. The calendar year can be roughly divided into two seasons: the heating season from the 1st of October to the 15th of March, and the warmer season without heating, covering the rest of the year. As the demand increases, the production required to meet this demand also rises. Marginal types of production are not constantly employed but are started when the high level of demand requires additional capacity.

18. Depending on the amount of snow and rain-fall that fill water reservoirs hydro generators adjust their production plans for the whole year (Mirza and Bergland, 2015) thus impacting the electricity prices.

Therefore, it is possible that certain types of production report unplanned outages only in winter when the heating is turned on. To show that this is not the case in Table 4 we report the number of registered messages informing about failures during the heating season (when prices are generally high) and in the off-heating season (when prices are, on average, low).

**Table 4: Number of messages reporting failures per fuel type**

| Variable | Heating Season | | | Off Heating Season | | | Whole year | Heating Season | Off Heating Season |
|---|---|---|---|---|---|---|---|---|---|
| Production type | All failures | New failures | Follow-up failures | All failures | New failures | Follow-up failures | All failures | % of follow-ups | % of follow-ups |
| All | 734 | 264 | 470 | 593 | 200 | 393 | 1327 | 64 | 66 |
| Nuclear | 151 | 39 | 112 | 190 | 39 | 151 | 341 | 74 | 79 |
| Hydro | 333 | 144 | 189 | 279 | 118 | 161 | 612 | 56 | 58 |
| Coal | 4 | | | 0 | | | 4 | | |
| Oil | 56 | 24 | 32 | 19 | 9 | 10 | 75 | 57 | 53 |
| Gas | 58 | 19 | 39 | 41 | 13 | 28 | 99 | 67 | 68 |

*Note:* The heating season is defined as the period between the 1st of October and 15th of March.

The data indicates that failure messages were reported in both seasons with the exception of coal fuelled electricity generation that has issued only 4 messages informing about problems affecting Sweden. Subsequently we dropped coal failures from further analyses.

An important remark is that the number of UMMs informing about failures is not necessarily equal to the number of actual failures. Market participants can issue multiple UMMs addressing the same failure, defined as so-called follow-up messages. In such a case, each message will bring additional information about the same event. Therefore, in order to make a distinction between the number of actual failures and messages that describe the same failure several times, we created "$\text{NewFailure}_t$" and "$\text{FollowupFailure}_t$" variables. The first counts the actual number of failures, and the latter counts the number of follow-up messages. In the studied sample 464 new failures were registered by different types of electricity production; the rest (863) were follow-ups. Out of all follow-up messages 485 (56%) inform about a lengthening of the outage time, 16% about shortening and 28% bring some other information. In the dataset we had 464 sudden outage events that affected electricity generators; each outage event had on average one lengthening follow-up and around 20% of events had more than one follow up message. The messages shortening the time of sudden outages were less frequent with only four events that had two shortening follow-ups issued.

## 5. EMPIRICAL STRATEGY

We are interested in studying the causal effect of price on production failures reported by electricity producers. For an OLS regression to give us an unbiased result we would require that $\text{E}\left(\text{error\_term}_t|\text{Price}_t\right) = 0$. However, even though $\text{Price}_t$ is set on the day before a failure is reported, there is a clear risk that different omitted variables such as market players' bidding strategies or technical considerations affect both prices set yesterday and the number of failures today. For instance, high prices could encourage producers to run their generators above the recommended capacity levels, which would increase the risk of failures. We therefore instrument for prices using daily average temperature for Sweden and precipitation levels. We estimate our results using Poisson regressions, whereas corresponding results using a log-log OLS set-up are reported in the appendix.

First stage:

$$Price_t = \beta_1 Temperature_t + \beta_2 PrecipitationLevels_t + \sum_{i=1}^{4} \beta_{3i} BidProduction_t + \sum_{j=1}^{6} \gamma_j W_j + \epsilon_t \quad (1)$$

Second stage:

$$Failure_t = \exp(\hat{\beta}_3 Price_t + \sum_{i=1}^{4} \beta_{4i} BidProduction_t + \sum_{j=1}^{6} \delta_j W_j) + \varepsilon_t \quad (2)$$

In our estimations we control for different weekdays and for Swedish aggregated bid production, which is the market clearing aggregated production level for day t based on t-1 bids. We use aggregated bid production for each day, instead of that day's realized production, because real time production is endogenous in relation to failures. In order to capture any potential non-linear effects we use a set of dummies for different levels of bid production. We use HAC standard errors in all specifications in order to account for potential heteroskedasticity and autocorrelation issues.

To test whether economic incentives affect the timing of new failures or whether economic incentives primarily affect the duration of maintenance after a failure we repeat our two-step procedure and estimate separate effects for the newly reported failures and the follow-up messages. In the analysis of follow-up failures, we only consider the messages that inform about a prolongation of an outage.

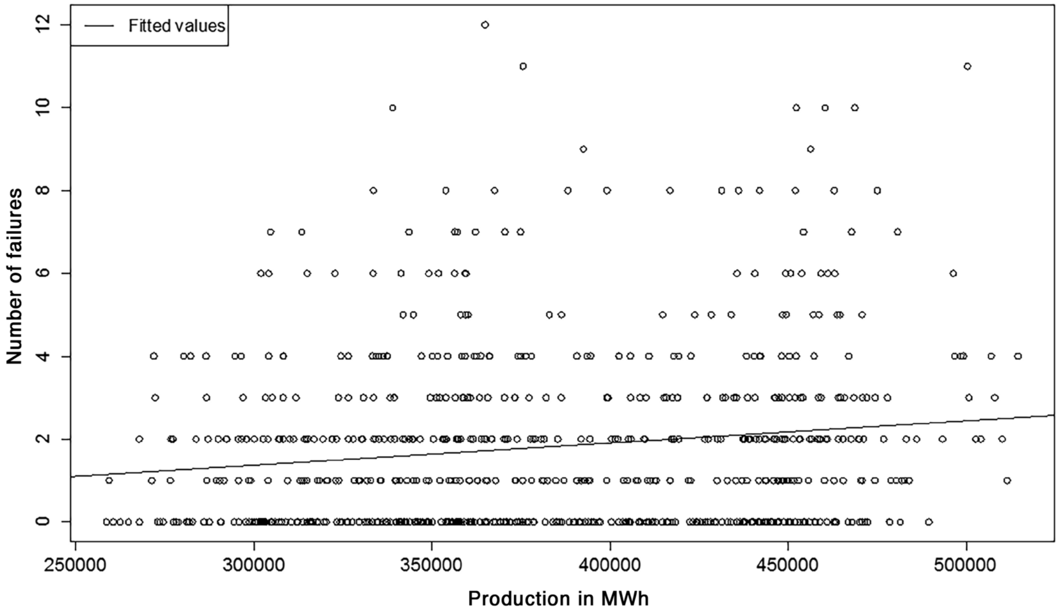
Since we believe that producers using different production fuels and therefore occupying different places in the merit order have different incentives for withholding capacity, we want to investigate the effects for separate fuel types of particular interest. We therefore create four dependent variables that count the number of messages issued by nuclear, hydro, oil and gas generators every day. This division is done for all messages, as well as for the new failures and the follow-up messages. We think that it is interesting to compare the effects of price on the baseload technologies of hydro and nuclear to the (in a Swedish setting) marginal technologies of gas and oil.

The key identifying assumption in order for our instrument to be valid is that conditioned on the control variables, there should be no correlation between temperature and the error term in the equation we wish to correctly estimate. This condition should be satisfied because temperature is strictly exogenous. It is also necessary that there is no direct effect of temperature on the probability of production failures. In the period studied, we did not observe any extreme temperatures that would be unfamiliar to Scandinavia. Power plants in the Nordic Region are constructed with the aim of withstanding the normal weather conditions and should not be affected by a normal range of temperatures.

We have identified several potential threats to our identification strategy. First, since there is no publicly available real time data on the number of operating units in Sweden our outcome variables are not normalized. This means that the number of failures could naturally increase with the production level, and the production level is also correlated with price. It is also the case that when temperature decreases, additional production units might have to start up in order to cover the increased demand. It is possible that these start-ups influence the probability of failures (a problem that would not affect the results for follow-up messages) or that units that start up when demand is very high are in worse shape, which could potentially influence both failure rates and the time it takes to repair a failure.

We try to handle this problem by controlling for different levels of bid production in the estimations. This should control for the fact that units of different quality might be used at different levels of production. Further, as can be seen in Figure 3, the relationship between production level and the number of failures is only weakly positive. The relationship also seems to be monotonic with no sudden jumps at the highest production levels. It is hence reasonable to expect that controlling for bid production levels can compensate the absence of data for the number of operating units.

**Figure 3: The relationship between bid production and failures**




*Note:* The x-axis shows bid production in MWh and the y-axis shows the number of failures per day registered as affecting Sweden. The black line indicates linearly fitted values.

Another issue is linked to water temperature. When temperature goes up, there is also a rise in water temperature, which might affect the cooling systems of power plants, potentially reducing a unit's efficiency. The implication of this would be an increased number of failures when temperature increases. In Scandinavia, there is an inverse relationship between temperature and prices of electricity; as electricity is used for heating, demand reaches very high levels when it is cold. Our results indicate that strategic withholding is primarily used when demand is high. This means that any direct effect of warmer water on failure rates would attenuate the results reported in this paper.

An additional concern about the issue of water temperature is linked to the freezing of water reservoirs, which potentially increases the probability of failure of hydro-fuelled generators. However, as every UMM contains a description of the reported problem we were able to scan the dataset for outages that were caused by special weather conditions such as freezing. We have not identified any such cases in the data.

The last potential problem that we have identified is linked to the follow-up messages and the length of an outage. If the temperature influences the length of failures (as it might be harder to repair failures when it is cold, due to, for example, transportation constraints), we would expect the share of the follow-up messages to be larger during the heating season as compared to the warmer off-heating period. However, the percentage of follow-ups announced by nuclear, water, oil and gas-fuelled production is constant over the year and there are no large differences between the two seasons (Table 4).

Additionally, since Swedish generation is largely based on hydro, we use Swedish average precipitation levels as another instrument for price. During a wet year the prices in the market are in general low, in a dry year, the prices in the market are in general high.

The results of the first stage regression (equation 1) are reported in Table A1 in the Appendix. The high F-statistic of 48.69 indicates that both instruments are not weak.

## RESULTS

Below we present results of our investigation, focusing on the relationship between the Swedish day-ahead price and messages about sudden outages. We are particularly interested in the messages issued by different type of generating plants as we expect that generating units using different fuels (and therefore facing different marginal costs) might have different incentives when it comes to reporting messages. We also compare the results for novel announcements and those which extend an on-going outage.

### 6.1 Results from all messages informing about failures affecting Sweden

The results from the second stage regressions investigating the relationship between the Swedish day-ahead electricity price and the announcement of failure messages are presented below. In Table 5 we focus on messages reporting failures that were coded as affecting Sweden, issued by Nordic producers.[19] The results indicate that a 1 euro increase in price is associated with a 1.3 percent increase in the number of reported failures. Thus, a price increase of 15 euros would increase the number of reported failures by 19.5 percent increasing the number of daily failure messages by 0.4 messages. As we assume that particular technologies used for producing electricity might face different incentives, we disaggregate the failures into outages reported by different fuel types.

**Table 5: IV—Poisson estimates of the effect of prices on failures by fuel type. Estimates in levels**

| | All Failures | Nuclear | Hydro | Oil | Gas |
|---|---|---|---|---|---|
| Price | 0.0131*** | –0.00215 | –0.00258 | 0.0626*** | 0.0516*** |
| | (0.00447) | (0.00909) | (0.00664) | (0.0188) | (0.0118) |
| Production 300–400 GWh | 0.345** | –0.0278 | 0.473* | 1.140 | –0.649 |
| | (0.156) | (0.296) | (0.284) | (1.492) | (0.516) |
| Production 400–500 GWh | 0.374** | –0.395 | 0.542** | 1.353 | –0.401 |
| | (0.156) | (0.320) | (0.275) | (1.469) | (0.474) |
| Production 500–600 GWh | 0.715** | –0.218 | 0.134 | 2.496 | –19.95*** |
| | (0.285) | (0.503) | (0.490) | (1.557) | (0.556) |
| Observations | 731 | 731 | 731 | 731 | 731 |

*Note:* Robust standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$ The regressions include day of the week dummies.

There are positive and significant result for gas and oil, where a 1 euro increase in price increases the number of reported failures by 5.2 percent in case of gas fuelled generation and by 6.3 percent in the case of oil[20]. Thus, if price would increase by 15 euros the number of oil failure messages would increase almost by 100%. There are no significant effects for nuclear or hydro.

### 6.2 Results from new and follow-up messages affecting Sweden

Results for new and follow-up failures (Tables 6 and 7) indicate that the initial announcement of an outage depends less on the encountered price at a particular day as compared to the joint

19. In the Appendix table A2 reports results for the same variables of interest estimated with OLS.

20. While testing the overidentifying restrictions, we do not manage to reject the null that the overidentifying restrictions are valid.

effect of new and follow-up messages (Table 5).[21] The results for reporting a failure for the first time are significant for oil and gas fuelled plants, for the former type a 1-euro price increases rises the number of reported failures by 6.4 percent (Table 6). The effect is smaller for gas, in which case a similar increase in price rises the number of failures by 4 percent.

**Table 6: IV—Poisson estimates of the effect of prices on new failures by fuel type. Estimates in levels.**

| | All new failures | Nuclear | Hydro | Oil | Gas |
|---|---|---|---|---|---|
| Price | 0.00567<br>(0.00459) | 0.00105<br>(0.0119) | 0.00363<br>(0.00704) | 0.0644***<br>(0.0211) | 0.0402***<br>(0.0140) |
| Production<br>300–400 GWh | 0.436**<br>(0.179) | –0.0392<br>(0.508) | 0.368<br>(0.290) | 0.949<br>(1.412) | –0.0719<br>(0.763) |
| Production<br>400–500 GWh | 0.514***<br>(0.175) | 0.0204<br>(0.501) | 0.364<br>(0.282) | 1.053<br>(1.377) | 0.270<br>(0.731) |
| Production<br>500–600 GWh | 0.438<br>(0.403) | –0.174<br>(1.068) | 0.321<br>(0.467) | 2.120<br>(1.493) | –13.60***<br>(0.785) |
| Observations | 731 | 731 | 731 | 731 | 731 |

*Note:* Robust standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$ The regressions include day of the week dummies.

The effects on the follow-up messages which extend the initially announced failure are larger in magnitude compared to the effects on failures reported for the first time. The general semi-elasticity effect on all follow-up failures is 1.3 and the effects for oil and gas are 6.1 and 5.7[22] respectively (Table 7) which indicate that in order to see a doubling of the number of messages, the price would need to rise by 20 euros (which occasionally may happen as the mean values of prices are around 40 euros and price spikes in the analysed period go above 100 euros (Table 2)).

**Table 7: IV—Poisson estimates of the effect of prices on follow-up failures by fuel type. Estimates in levels.**

| | Extended follow-up failures | Nuclear | Hydro | Oil | Gas |
|---|---|---|---|---|---|
| Price | 0.0130***<br>(0.00469) | –0.00315<br>(0.01) | 0.00281<br>(0.00715) | 0.0614***<br>(0.0180) | 0.0572***<br>(0.0128) |
| Production<br>300–400 GWh | 0.242<br>(0.174) | –0.0715<br>(0.318) | 0.540*<br>(0.290) | 1.205<br>(1.420) | –0.968<br>(0.627) |
| Production<br>400–500 GWh | 0.266<br>(0.177) | –0.507<br>(0.345) | 0.653**<br>(0.281) | 1.447<br>(1.419) | –0.837<br>(0.588) |
| Production<br>500–600 GWh | 0.687**<br>(0.318) | –0.227<br>(0.491) | –0.100<br>(0.572) | 2.652*<br>(1.522) | –17.17***<br>(0.681) |
| Observations | 731 | 731 | 731 | 731 | 731 |

*Note:* Robust standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$ The regressions include day of the week dummies.

These findings confirm our hypothesis that the economic incentives are more important when deciding on the scope of a failure—that is, the size and duration of the failure measured through follow-up messages—as compared to the decision of whether to report a new failure.

21. In the Appendix in tables A3 and A4 we report results for the same variables of interest estimated with OLS.
22. The overidentification test confirms that the instruments used in that estimation are valid.

The effects for both scenarios that we test do not indicate that economic incentives matter for reporting failures in the case of the baseload production. The results for both nuclear and hydro generation are not significant. This finding is not surprising as, due to low marginal costs, the baseload production can recover high infra-marginal profits if the electricity price is established by the marginal units. Reporting a failure when other, more expensive, types of production set the price is not in the economic interest of a cheap producer.

## 6. CONCLUSIONS

In this article we investigate whether producers supplying electricity to the Swedish market base their decision of whether to report a failure on economic incentives or on purely technical reasons. The results indicate that prices affect failures reported through Urgent Market Messages in different ways depending on the type of electricity generation. We find no significant effects for the baseload technologies (nuclear and hydro), which suggests that failure risks for baseload technologies do not depend on the daily variations in spot prices. However, we do observe a positive and significant effect of spot prices on the number of reported failures in the case of marginal production generators, which in case of Sweden are oil and gas.

These findings support the hypothesis that economic incentives might play a role when marginal producers decide to report a failure. Small changes to marginal production in periods of high demand can have potentially larger effect on the price levels as compared with similar changes to baseload production in low demand periods. Moreover, producers who own both types of electricity generation (infra-marginal and marginal) are interested in recovering high infra-marginal profits while at the same time decreasing production costs. A strategy to withdraw expensive marginal capacity disguising it as a failure could accomplish these goals.

We see that the effect on follow-up messages is slightly larger in magnitude compared to the effect on failures reported for the first time. This indicates that economic incentives might to a greater degree affect the duration of a failure compared to the probability of reporting a new failure.

This analysis has shown that there is some evidence of strategic failures being used in order to affect prices in the Nordic Region market. Since the results reported in this paper are of relevance for all electricity markets that use uniform auctions in the day ahead market, similar analysis should be carried out in order to investigate the potential existence of this type of behavior in other markets.

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## APPENDIX

**Figure A1. The logarithm of the Swedish average Elspot price**

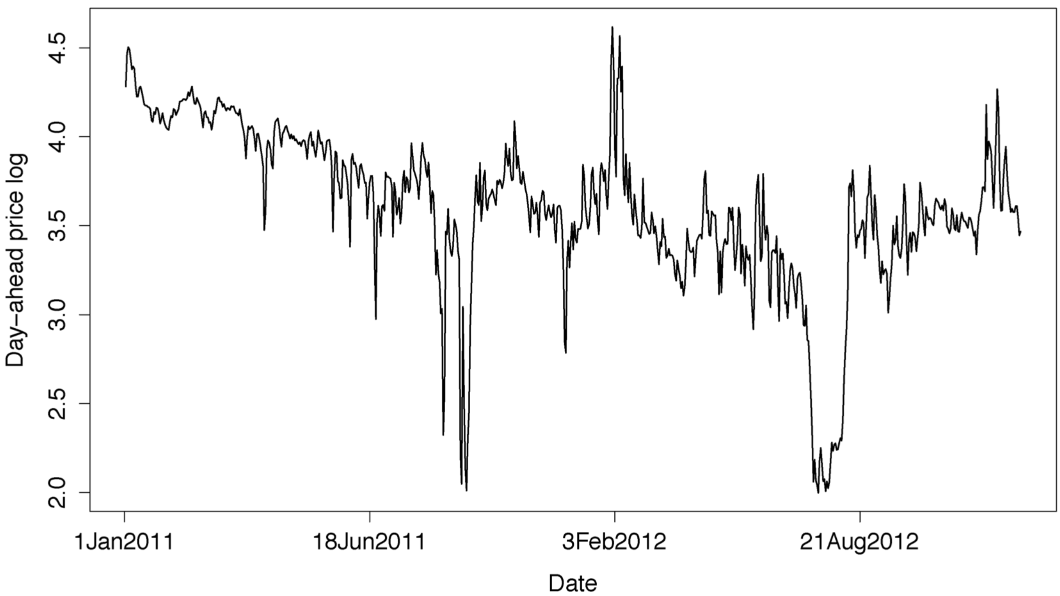


**Table A1: First stage regression with reported F-stat.**

| | Price |
|---|---|
| Temperature | –1.71*** |
| | (0.08) |
| Precipitation | –0.61*** |
| | (1.79) |
| Production 300–400 GWh | –18.18*** |
| | (1.63) |
| Production 400–500 GWh | –32.64*** |
| | (2.11) |
| Production 500–600 GWh | –35.43*** |
| | (4.32) |
| F stat | 48.69 |
| Observations | 731 |

*Note:* Robust standard errors in parentheses.
* p < 0.1, ** p < 0.05, *** p < 0.01

**Table A2: OLS estimates. Failures by fuel type. Log-log models.**

| | All failures | Nuclear | Hydro | Oil | Gas |
|---|---|---|---|---|---|
| Price | –0.0155 | –0.0958** | –0.0703 | 0.0565** | 0.0648*** |
| | (0.0615) | (0.0448) | (0.0503) | (0.0232) | (0.0238) |
| Production 300–400 GWh | 0.0526 | –0.0364 | 0.0706 | 0.0284 | –0.0432 |
| | (0.0850) | (0.0663) | (0.0705) | (0.0245) | (0.0397) |
| Production 400–500 GWh | 0.142 | –0.121* | 0.165** | 0.0619** | –0.00540 |
| | (0.0873) | (0.0672) | (0.0724) | (0.0267) | (0.0410) |
| Production 500–600 GWh | 0.589*** | 0.000248 | 0.0709 | 0.248* | –0.130*** |
| | (0.160) | (0.140) | (0.172) | (0.143) | (0.0407) |
| $R^2$ | 0.0525 | 0.0408 | 0.0358 | 0.0467 | 0.0342 |
| Observations | 731 | 731 | 731 | 731 | 731 |

*Note:* Robust standard errors in parentheses. * p < 0.1, ** p < 0.05, *** p < 0.01 The regressions include day of the week dummies.

**Table A3: OLS estimates. New failures by fuel type. Log-log models.**

| | All new failures | Nuclear | Hydro | Oil | Gas |
|---|---|---|---|---|---|
| Price | 0.00665 | -0.0199 | -0.0396 | 0.0333** | 0.0305*** |
| | (0.0398) | (0.0196) | (0.0321) | (0.0147) | (0.0116) |
| Production 300-400 GWh | 0.0969* | -0.00126 | 0.0351 | 0.0156 | 0.00209 |
| | (0.0560) | (0.0291) | (0.0462) | (0.0157) | (0.0182) |
| Production 400-500 GWh | 0.145** | -0.00420 | 0.0660 | 0.0318* | 0.0171 |
| | (0.0572) | (0.0295) | (0.0470) | (0.0164) | (0.0190) |
| Production 500-600 GWh | 0.228 | -0.0104 | 0.0913 | 0.120 | -0.0371** |
| | (0.158) | (0.0700) | (0.114) | (0.0867) | (0.0177) |
| $R^2$ | 0.0258 | 0.0112 | 0.0218 | 0.0325 | 0.0197 |
| Observations | 731 | 731 | 731 | 731 | 731 |

*Note:* Robust standard errors in parentheses. * p < 0.1, ** p < 0.05, *** p < 0.01 The regressions include day of the week dummies.

**Table A4: OLS estimates. Follow-up failures by fuel type. Log-log models.**

| | All follow-up failures | Nuclear | Hydro | Oil | Gas |
|---|---|---|---|---|---|
| Price | –0.0252 | –0.0867** | –0.0520 | 0.0396** | 0.0497** |
| | (0.0524) | (0.0411) | (0.0366) | (0.0161) | (0.0201) |
| Production 300–400 GWh | 0.0295 | –0.0291 | 0.0513 | 0.0213 | –0.0259 |
| | (0.0730) | (0.0604) | (0.0483) | (0.0164) | (0.0374) |
| Production 400–500 GWh | 0.0979 | –0.105* | 0.120** | 0.0431** | –0.01 |
| | (0.0752) | (0.0610) | (0.0500) | (0.0184) | (0.0386) |
| Production 500–600 GWh | 0.496*** | 0.0163 | –0.0216 | 0.163 | –0.09** |
| | (0.160) | (0.119) | (0.115) | (0.114) | (0.0397) |
| $R^2$ | 0.0557 | 0.0430 | 0.0415 | 0.0457 | 0.0357 |
| Observations | 731 | 731 | 731 | 731 | 731 |

*Note:* Robust standard errors in parentheses. * p < 0.1, ** p < 0.05, *** p < 0.01 The regressions include day of the week dummies.

**Table A5: OLS estimates of the impact of failures on prices. Log-log models.**

| | Price | Price | Price | Price | Price |
|---|---|---|---|---|---|
| All failures | –0.00635 | | | | |
| | (0.0252) | | | | |
| Nuclear | | –0.0854** | | | |
| | | (0.0412) | | | |
| Hydro | | | –0.0404 | | |
| | | | (0.0292) | | |
| Oil | | | | 0.191*** | |
| | | | | (0.0656) | |
| Gas | | | | | 0.167*** |
| | | | | | (0.0499) |
| $R^2$ | 0.0798 | 0.0872 | 0.0823 | 0.0896 | 0.0897 |
| Observations | 731 | 731 | 731 | 731 | 731 |

*Note:* Robust standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$ The regressions include day of the week dummies and bid production