Contract durations in the electricity market: Causal impact of 15 min trading on the EPEX spot market

Contract durations in the electricity market: Causal impact of 15 min trading on the EPEX SPOT market

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Abstract

The European Power Exchange (EPEX) introduced two new products in 2011 and 2014 which reduce the delivery duration of electricity from 1 hour to 15 min intervals. These changes to the market design aim to better reflect the intermittent power generation from renewable energy sources. However, little is known about trading in shorter intervals and its impact on the existing market. As a remedy, our evaluation first shows that the market has quickly adopted the new 15 min contracts. Second, we estimate a Bayesian structural time series, which measures a causal decrease of electricity prices. Depending on the model specification, our results indicate that the reduction can be as high as 28 % for existing hourly contracts subsequent to the introduction of 15 min trading. Third, the use of 15 min contracts coincides with intermittent power generation, as it incentivizes renewable energy providers to offer additional electricity. Altogether, our findings suggest that 15 min trading is used to balance the intra-hour volatility of renewable energy sources. Consequently, this presents a blueprint for policy-makers, who can attain similar price reductions and larger feed-ins from renewable energy

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sources without direct costs in all countries with high shares of renewable energy sources.

Keywords: Electricity market, 15 min trading, Market design, Contract duration, Bayesian structural time series, Policy implications

1. Introduction

The world is experiencing an unprecedented growth in carbon-free renewable energy sources, largely due to government initiatives (Bundestag, 2008; European Union, 2009; The White House, 2014). The volatile power generation of these renewable energy sources (Papavasiliou and Oren, 2014; Riesz and Milligan, 2015) challenges existing markets which were originally designed to trade electricity from controllable sources, such as nuclear, coal and gas power (EPEX, 2013; Weber, 2010). In contrast to the previous baseloads, renewable energy sources, such as solar and wind power, exhibit very different generation characteristics as their infeed strongly depends on weather conditions. For instance, feed-ins from solar power exhibit steep ramp-ups every morning followed by a sharp decline in the evening (Bunn and Muñoz, 2016; Dillig et al., 2016). Accordingly, policy-makers face the challenge of designing markets which allow for the efficient trading of renewable energy sources (Chao, 2011).

In an effort to improve the market design, the EPEX electricity exchange introduced two new products in the years 2011 and 2014 which reduce trading intervals to 15 min (EPEX, 2013). This represents a considerable decrease to only a quarter of the previous minimum duration, which was 60 min. The shorter contract duration specifically addresses the needs of market participants to handle the generation uncertainty of intermittent power sources, such as solar and wind power (EPEX, 2013; Kiesel and Paraschiv, 2017). While the market quickly adopted these products, policy-makers know little regarding the introduction of 15 min trading and its impact on the electricity market.

Hence, this paper analyzes the introduction of 15 min products beyond previous literature:

1. **Trading volumes.** We investigate the adoption of 15 min trading and show their trading volumes subsequent to the launch of these products. Both trading volumes increased quickly, now exceeding 1.000 MW, while the 15 min auction in 2014 experienced a sharper rise compared to the earlier introduction of 15 min continuous products in 2011. This highlights the need of electricity retailers and power producers for such shortened trading intervals.

2. **Causal impact on electricity market.** As a result, the price of 60 min contracts dropped considerably. For this purpose, we perform an innovative evaluation based on Bayesian structural time series to measure the causal impact of these products on the existing market. In fact, our causal analysis reveals significant price decreases, ranging in the spectrum of 11 % to 28 % in hourly contracts due to the introduction of shorter trading intervals. We perform multiple robustness checks to ensure the validity of our outcome, all supporting our primary finding of a causal impact. In contrast, we observe that the average trading volumes for 60 min products remains fairly stable.

3. **Cross-effects with renewable energies.** We show that these new contracts provide incentives to offer additional volatile electricity from intermittent power sources, which participants could not efficiently trade via the power exchange earlier. Hence, 15 min contracts are especially common during the ramp-ups and ramp-downs of solar power generation, as well as around peaks in wind power. Here they can be used

for balancing intra-hour demand and supply, which becomes also evident when performing a correlation analysis with feed-in from these electricity sources.

The previous results provide crucial insights for governments and policy-makers all over the world, but especially in countries with a high penetration of solar and wind power. Policy-makers also need to understand potential cross-effects, since benefits to some stakeholders come at the expense of others. At the same time, even little modifications to the market design may result in large shifts of revenue, causing current stakeholders to disappear and new ones to enter the market. Therefore, it is highly relevant for government agencies and policy-makers to carefully study the impact of changes in the market design.

This paper is organized as follows: Section 2 provides background on the electricity market design, with a focus on the combined electricity market in Germany and Austria. Then, Section 3 describes our time series data and our methodology for inferring the causal impact of market changes, followed by Section 4 which presents the results of this analysis. Based on these, Section 6 interprets our findings and derives policy implications, while Section 7 concludes with a summary and an outlook.

2. Background

Delivery duration presents an important parameter of electricity contracts and is usually determined by the corresponding market design. Therefore, we review previous works that investigate contract durations in electricity markets. We then describe the electricity market design in Germany and Austria before and after the introduction of 15 min trading.

2.1. Contract durations in electricity markets

In economics, it is well known that, in the absence of perfect information, mechanisms are required to ensure the efficient allocation of resources. Such mechanisms may be embodied by markets, which master complex allocation problems when knowledge is dispersed (e. g. McAfee, 1998). However, designing markets presents a challenging undertaking, as every detail of the design affects the strategy of market participants and, hence, an improper market design can easily fail to attain efficient allocation.

The design of markets introduces several parameters for adjustments, including contract duration as an integral lever (Saussier, 1999). In general, the optimal duration depends on two determinants, namely, market uncertainty and transaction costs (Gray, 1978). Markets with high uncertainty require shorter trading intervals, while higher transaction costs increase the incentive to use a longer contract duration. However, few econometric studies evaluate this proposition by empirical means (Saussier, 1999).

In the electricity market, various research papers advocate the introduction of contracts with shorter durations. Just (2011) identifies noticeable potential for improvement in the electricity reserve market based on a simulated equilibrium model. Neuhoff et al. (2016) analyze 15 min contracts from the perspective of optimal discretization. The authors explore auction and continuous trading with 15 min contracts but neglect to study the impact on the existing market and cross-effects with renewable power generation. Similarly, Milligan and Kirby (2010) study the likelihood of market stakeholders responding to low-resolution price signals. Furthermore, previous works expect a beneficial setting from an increased flexibility to accommodate feed-ins from renewable energy sources (Riesz and Milligan, 2015; Sioshansi, 2013). However, the previous works are frequently of a theoretical nature and thus cannot support their claims through empirical findings. In addition, discussions on demand response propose shorter trading intervals as a means of providing near-to-real-time incentives for demand adjustments (Feuerriegel et al., 2016; Hirst, 2001).

On the other hand, research also discusses potential benefits from a less granular discretization. For instance, Buechner and Tuerkucar (2005) favor longer trading intervals to ensure security of supply. Cramton and Stoft (2005) consider contract lengths in tertiary reserves, where longer contracts are beneficial for promoting investment incentives and avoiding the possibility of manipulation.

Altogether, the above works expose the challenge for policy-makers to determine an optimal discretization in electricity markets. On top of that, we are not aware of any research paper that empirically studies the impact of the market design change from the introduction of 15 min contracts.

2.2. EPEX SPOT market

The electricity market in Germany and Austria features three different ways to trade electricity, namely, (i) a derivative market, (ii) a spot market and (iii) over-the-counter trading.[1] In this paper, we focus on the spot market since only this market offers 15 min trading and it distributes the majority of renewable power. The spot market enables short-term purchases via day-ahead and intra-day trading. In Germany and Austria, it is operated by EPEX SPOT, a subsidiary of Powernext and EEX. Furthermore, electricity traders use the spot market to balance day-to-day, as well as intra-day,

[1] The derivative market allows participants to trade standardized electricity contracts up to 6 years in advance via the European Energy Exchange (EEX). Consequently, this market is predominantly used for long-term electricity purchases.Lastly, over-the-counter trading provides suppliers and purchasers with the possibility of trading electricity directly via bilateral agreements. While this form represents the highest flexibility, it increases transaction costs and might lack the efficiency and liquidity of an exchange.

variations in demand and supply. Accordingly, the spot market faces the most imminent challenge of incorporating highly volatile renewable energy sources.

The spot market in Germany and Austria, EPEX SPOT, features different product categories, namely, auction and continuous trading, which we discuss in the following. Figure 1 shows the bidding and delivery times of both products.

Auction trading allows one to trade electricity one day ahead to fulfill the demand forecast of the subsequent day. Here, offers may be placed multiple hours before the auction closes at 12:00 noon for 60 min products and at 3:00 pm for 15 min products. For this purpose, EPEX SPOT implements a combinatorial double-sided uniform price auction (Cramton et al., 2006; Neuhoff et al., 2016). Both auctions are separated by a time lag of 3 hours, which allows market participants in the 15 min market to incorporate the clearing price from the first auction into their bidding strategy. At the same time, they can forecast the liquidity of continuous auctions and refine their demand and supply planning for within-hour discrepancy.

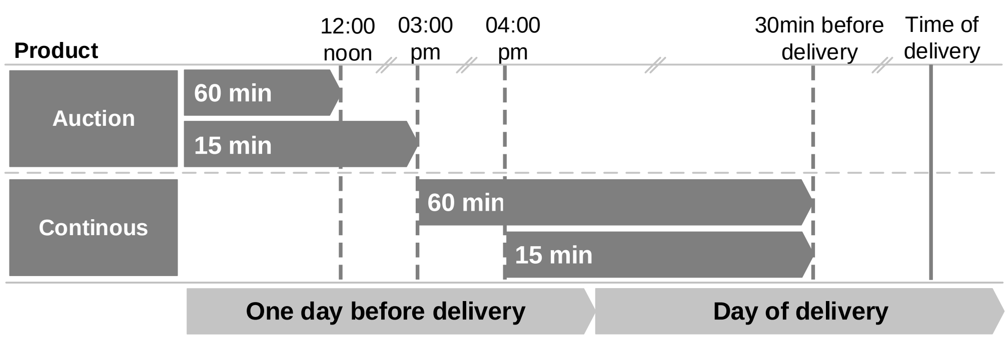

Figure 1: Overview of standardized electricity products available at EPEX SPOT. Stakeholders trade electricity in auctions the day before delivery, while continuous trading commences the day before and stops 30 min before delivery.

In contrast, intra-day continuous trading starts at 3:00 pm the day before delivery for 60 min products (and at 4:00 pm for 15 min products), but stops only 30 min before delivery. This facilitates continuous corrections if the actual demand or supply differs from earlier predictions. Trades occur whenever a bid meets or exceeds the asking price. Consequently, liquidity is stretched over the whole period and the clearing price may fluctuate throughout the process (Hagemann and Weber, 2015; Scharff and Amelin, 2016).

2.3. Introduction of 15 min trading

The spot market originally offered a minimum delivery duration of 60 min. Only recently has EPEX SPOT started to tender trading in 15 min blocks. This reduction of contract durations was implemented for two reasons (EPEX, 2013): first of all, the increasing market penetration of renewable energy sources entails greater fluctuations in power generation. Second, market regulations require electricity retailers and grid operators to settle their electricity demand in steps of 15 min.

EPEX SPOT introduced 15 min products to the combined German and Austrian electricity market in the form of intra-day continuous auctions on December 14, 2011. This form of trading was later extended to 15 min auctions on December 9, 2014. Figure 2 illustrates the corresponding timeline. Accordingly, 15 min auctions enable transparent price formation before intra-day trading commences. Earlier works have studied price models for these contracts, finding that the bidding behavior especially stems from production forecasts of renewable energies (Kiesel and Paraschiv, 2017), while empirical evidence on the cross-effects with the spot market is scarce.

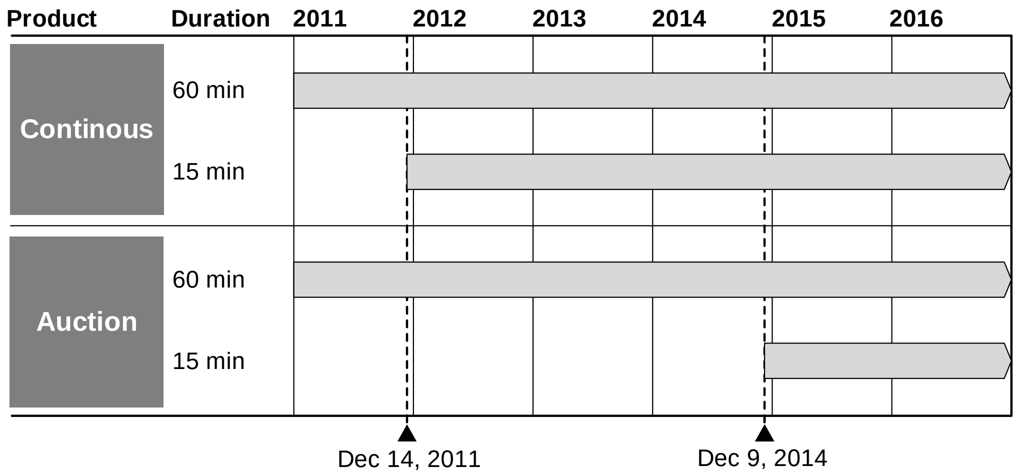

Figure 2: Trading in 15 min blocks started on December 14, 2011 for intra-day continuous trading and on December 9, 2014 for day-ahead auctions.

3. Methods and materials

This section presents our method for inferring the causal impact of market changes, followed by a description of our time series data.

3.1. Time series methodology for inferring causal impact

In the following, we motivate the need for a tailored methodology to infer the causal impact of changing the market design. In this regard, causal impact is defined as the difference between the actual observed output and the output that would have been observed had the event not taken place. This is also known as the effect of treatment on the treated (Collins et al., 2004; Morgan and Winship, 2014). In fact, several obstacles make it especially challenging to measure a causal response in our situation, since electricity prices are largely influenced by seasonal patterns, weather conditions and other confounding factors. As a result, one cannot just compare the average prices before and after the introduction of 15 min contracts in order to quantify the causal impact.

Many methods exist to statistically show that an event actually had a causal impact on the observed variable (Angrist and Pischke, 2014; Blundell and Dias, 2009; Imbens and Wooldridge, 2009; Varian, 2016). For instance, essential tools comprise randomized experiments (difference-in-differences), instrumental variable regression or regression discontinuity design. However, randomized experiments or difference-in-differences are impossible in an ex-post analysis where truly comparable markets are not present. Similarly, instrument variable regression and regression discontinuity design struggle to quantify the causal effect in the price variable. As a remedy, we utilize an innovative approach based on Bayesian structural time series (Brodersen et al.).

This method for causal inference relies upon three components as follows: (1) the response must exist in the form of a time series which changes its values due to the intervention. (2) Covariates, which provide a synthetic control model, are necessary. (3) A model specification is needed to explain the relationship between the observed time series and covariates prior to the event. In order to select only purposeful covariates, the model uses a spike-and-slab regression for variable selection. It then predicts the counterfactual market response that would have occurred if no event had taken place. Finally, the counterfactual model is estimated using Markov chain Monte Carlo sampling in order to calculate the posterior probability of a causal effect. We provide an in-depth description of this method in the following section.

In our case, we implement the above approach with weekly and daily seasonality of electricity prices. In addition, we choose feed-ins from wind and solar power as potential covariates together with a static regression model. This choice is validated by robustness checks in Section 5, respectively.

3.2. Specification of the causal impact methodology

In order to quantify the impact of shorter contracts on electricity prices and volumes, we use an innovative approach based on Bayesian structural time series (Brodersen et al.). This method has recently been propagated as a means of inferring the impact of an event or change on an observed variable by using a set of one or more control variables. The methodology entails several advantages: it includes an automated variable selection to choose appropriate covariates, it is specifically tailored to time series properties (such as trend or seasonality) and it infers causality while also measuring the effect size.

This method succeeds in quantifying the causal effect by constructing the counterfactual time series $\tilde{y}_t \in \mathbb{R}^N$ for the period $t_{\text{post}} = m+1, \ldots, n$ after the event where the pre-period is given by $t_{\text{pre}} = 1, \ldots, m$. We then calculate the causal impact

$$\Phi_t = y_t - \tilde{y}_t, \tag{1}$$

where $y_t \in \mathbb{R}^N$ represents the actual observed time series and $\Phi_t \in \mathbb{R}^N$ gives the impact at time t. This methodology also returns a posterior probability of the causal impact Φ_t being different from zero, as well as the accumulated causal impact

$$\sum_{t=m+1}^{n} \Phi_t. \tag{2}$$

We create $\tilde{y}_t$ using a structural time series model comprising of an observation equation and a state equation. The former consists of a local trend $\mu_t \in \mathbb{R}^N$, seasonality $\gamma_t \in \mathbb{R}^N$ and covariates $x_t \in \mathbb{R}^N$. This is given by

$$\tilde{y}_t = \mu_t + \gamma_t + \beta^T x_t + \varepsilon_t \tag{3}$$

with additional state equations as follows: trend $\mu_t = \mu_{t-1} + \delta_{t-1} + u_t$, increment $\delta_t = \delta_{t-1} + v_t$, seasonality $\gamma_t = -\sum_{s=1}^{S-1} \tau_{t-s} + w_t$ and coefficients

β. The term $\eta_t = (u_t, v_t, w_t)^T$ contains independent random Gaussian noise components; the variable $\varepsilon_t \sim \mathcal{N}(0, \sigma_t^2)$ denotes the observation error.

To simplify the above notation, we incorporate all state equations into one latent d-dimensional state vector $\alpha_t \in \mathbb{R}^d$. Then, the whole system in state space form can be expressed via

$$y_t = Z_t^T \alpha_t + \varepsilon_t \qquad \text{and} \qquad \alpha_{t+1} = T_t \alpha_t + R_t \eta_t \tag{4}$$

where the observation y_t depends on the state vector α_t, an output vector $Z_t \in \mathbb{R}^d$ and an observation error ε_t. Here, the state vector α_{t+1} is calculated from the previous state and system inputs $R_t \eta_t$.

Moreover, the coefficients $\beta \in \mathbb{R}^d$ follow a spike-and-slab prior. The *spike* describes the probability of a non-zero coefficient and the diffuse *slab* represents the distribution of the coefficient. We obtain both posterior probability distributions by repeatedly drawing samples from these two priors using Markov chain Monte Carlo. Here, we run 2.000 model iterations to calculate the posterior probability. As a result, the spike-and-slab prior implicitly performs variable selection of potential covariates.

Finally, the Bayesian estimation procedure obtains a *posterior probability* which quantifies the causal effect. That is, it gives the probability that the accumulated causal impact is non-zero, i. e.

$$P\left(\sum_{t=m+1}^{n} \Phi_t \neq 0 \;\middle|\; y_1, \ldots, y_m, x_1, \ldots, x_m \right). \tag{5}$$

3.3. Time series data

This paper utilizes electricity prices from the EPEX SPOT market[2], for which we analyze the two main product categories: auction day-ahead and intra-day continuous trading. For both, we analyze the change in price and

[2]EPEX SPOT: Market data. URL: `http://www.epexspot.com/`

volume due to the introduction of 15 min trading. Furthermore, our causal impact analysis also incorporates wind and solar power feed-ins from EEX Transparency[3]. Where necessary, we aggregate this data from 15 min to hourly time resolution.

3.4. Descriptive statistics of electricity prices

Table 1 reports descriptive statistics for prices of hourly and 15 min contracts in the year 2015. This enables us to understand how prices have evolved to the present day.

First of all, the mean prices for all four contracts range from 31.63 EUR/MWh to 31.80 EUR/MWh. Similarly, their medians lie between 30.54 EUR/MWh and 31.78 MWh. All prices are thus in close proximity and 15 min products come at marginal premiums as 15 min contracts cost, on average, 0.03 EUR/MWh more than in the case of an auction, while the premium amounts to 0.09 EUR/MWh in the continuous market.

Furthermore, the standard deviation between auction and continuous prices differs by up to 2.94 EUR/MWh. Altogether, this highlights a similarity of prices between different products. In addition, the slightly negative skewness of all prices indicates a larger tail for prices below mean. Furthermore, prices for hourly and 15 min continuous contracts entail a high kurtosis of 7.04 and 5.05 respectively, thus suggesting a larger preponderance of outliers.

[3] European Energy Exchange: Transparency Platform. URL: `http://www.eex-transparency.com/`

Product type	Duration	Mean	Std. dev.	Median	Min.	Max.	Skew.	Kurt.
Auction	15 min	31.66	12.06	31.12	−45.38	89.78	−0.21	1.41
	60 min	31.63	12.66	30.54	−79.94	99.77	−0.31	2.77
Continuous	15 min	31.80	14.91	31.78	−88.72	180.85	−0.28	7.04
	60 min	31.71	13.98	31.43	−81.04	121.66	−0.62	5.05

Table 1: Descriptive statistics of electricity prices in EUR/MWh during the course of the year 2015 (source: own analysis).

We now investigate the intra-hour trading volume of 15 min contracts. Table 2 serves this purpose by presenting descriptive statistics for all four 15 min slots within an hour, i. e. 0–15 min, 15–30 min, 30–45 min and 45–60 min. Interestingly, we observe large trading volumes in the first and last quarter of every hour. In 2015, the electricity traded in each 15 min auction averages to 451.67 MW, while the first and last quarter feature volumes that are 159.62 MW and 155.04 MW above this average, respectively. In the second and third quarter of every hour, the average volume is roughly 157 MW below the hourly mean. Notably, the standard deviation of the first and last quarters considerably exceeds that of the second and third quarters. Moreover, 15 min continuous trading exhibits a similar pattern.

Product	Deviation from hourly mean	Mean	Std. dev.	Median	Min.	Max.	Skew.	Kurt.	Hourly quarter
15 min auction	Q1 (00 – 15)	611.29	309.33	561.3	29.0	4956.0	1.04	4.61	159.62
	Q2 (15 – 30)	294.19	123.48	278.2	16.9	1358.7	0.71	0.87	−157.48
	Q3 (30 – 45)	294.49	127.14	274.6	23.6	1761.2	1.06	4.30	−157.18
	Q4 (45 – 00)	606.71	310.00	550.8	38.1	3110.1	0.80	0.57	155.04
15 min continuous	Q1 (00 – 15)	487.79	308.21	446.6	4.2	2984.2	1.24	3.31	33.44
	Q2 (15 – 30)	318.69	196.01	286.4	5.1	1431.6	1.02	1.42	−135.66
	Q3 (30 – 45)	376.89	232.27	340.2	11.0	1851.6	1.10	1.89	−77.46
	Q4 (45 – 00)	634.03	360.68	597.2	2.9	2937.1	0.86	1.21	179.68

Table 2: Intra-hour variation in the trading volume in MWh of 15 min auction and continuous products in 2015 (source: own analysis).

We conducted expert interviews with traders of major German electricity retailers to shed light on the intra-hour pattern: apparently, these fluctuations originate from a very specific trading strategy. Stakeholders in the electricity market usually sell or buy electricity in the form of hourly contracts based on the average demand or supply of each hour. Afterwards, they need to make intra-hour adjustments for the individual quarters. This strategy is utilized when selling e. g. solar power (which is regarded as the predominant source of electricity for 15 min contracts). However, the supply of solar power steeply increases in the morning and then sharply decreases in the afternoon. Both gradients thus result in a larger deviation in the first and fourth quarter of an hour (see Figure 3 for a visualization of this pattern). Thus, this reinforces the intra-hour variation of 15 min trading volumes.

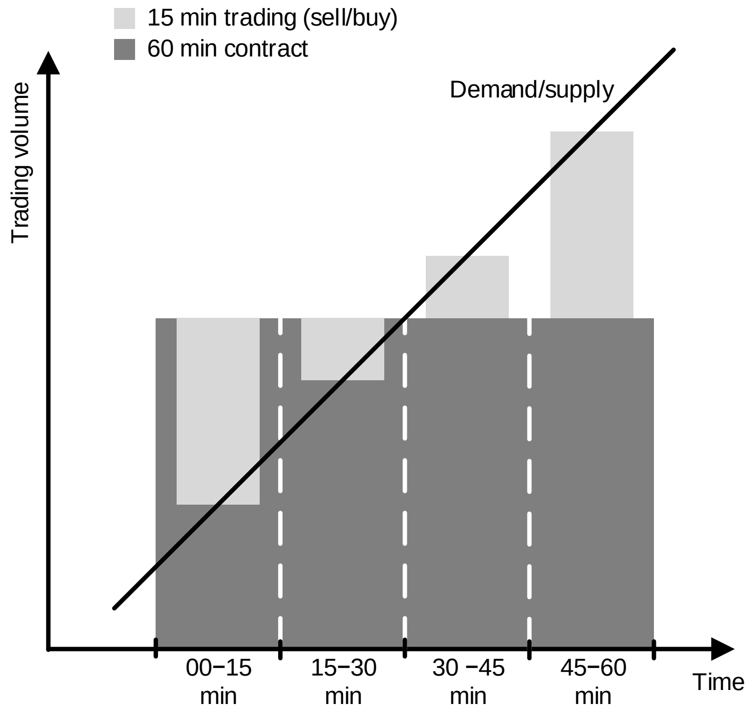

Figure 3: Illustration shows trading volumes of hourly and 15 min products during a ramp-up phase of solar power. The average supply is traded in hourly products, also representing the majority of the trading volume. Averages of quarter hour volumes are then traded in 15 min contracts to balance intra-hour variations. The volumes traded in the first and fourth quarter are the highest.

4. Results

This section first provides descriptive statistics concerning the adoption of 15 min contracts as measured by their trading volumes (Section 4.1). We then compare the electricity market before and after their introduction (Section 4.2). Section 4.3 quantifies the causal impact on the electricity market, finding an economically significant reduction of prices for 60-min contracts. In addition, we discuss the main reason for the price reductions, which is given by a considerable increase in power generation from intermittent electricity sources (Section 4.4).

4.1. Trading volumes of 15 min contracts

The introduction of 15 min continuous trading on December 14, 2011 marked the first possibility to trade electricity on the German-Austrian spot market at intervals shorter than hourly blocks. Nonetheless, trading volumes of the 15 min continuous products picked up slowly, as shown in Figure 4 (left). Average trading volumes often remained at zero during the first three weeks, while they stabilized at approximately 200 MW six months after the introduction.

In contrast, 15 min auctions experienced a much faster adoption as average trading volumes exceeded 400 MW less than half a year after the launch. According to Figure 4 (right), the volume amounted to around 500 MW in subsequent months.

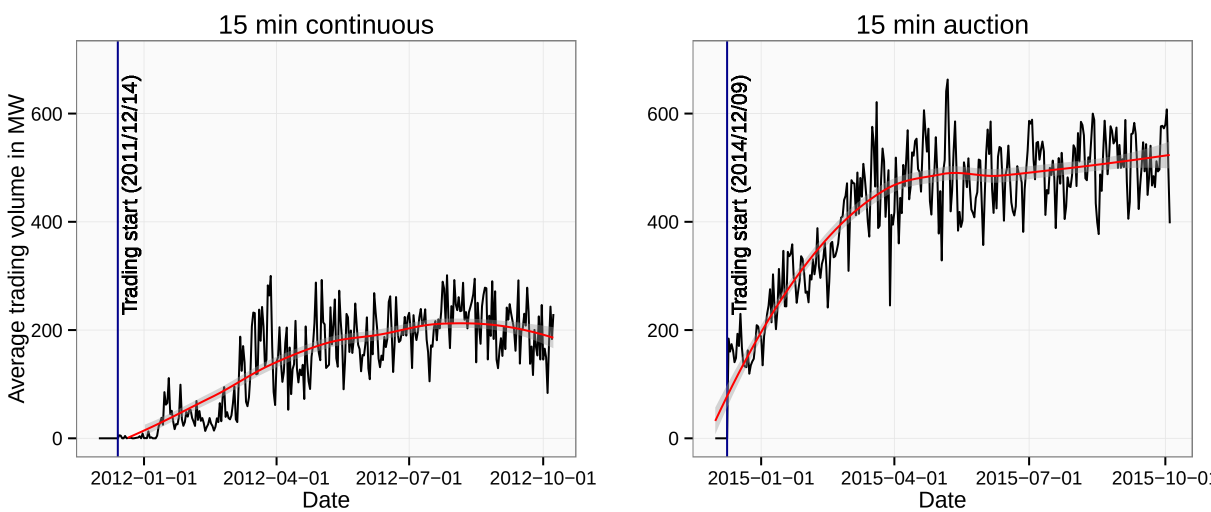

Figure 4: Plots compare the daily average trading volumes of 15 min products after their introduction. The left figure shows the adoption of 15 min continuous trading in 2011 while the figure on the right reflects the volumes of 15 min auctions in 2014. The red line visualizes the smoothed trend of daily average volumes via LOESS regression (source: own analysis).

4.2. Pre/post comparison around the introduction of 15 min contracts

We now aim at a better understanding of the market before and after the introduction of shorter contracts. To this end, Table 3 reports several statistics comparing prices and trading volumes before and after the market change.

We observe the following patterns for the introduction of 15 min intra-day continuous trading on December 14, 2011:

- After the launch, auction prices decreased considerably in absolute numbers by 26.61 %, while prices for continuous trading similarly dropped by 27.95 %. At the same time, the standard deviation of prices increased by 17.07 % for auctions and 14.14 % for continuous trading – thus raising price fluctuation and possible price risk.

- In the case of trading volumes, we recognize an increase especially in auction (12.41 %), but also in continuous trading (6.21 %). We thus conclude that 15 min contracts made additional power generation available to the market which couldn't be leveraged before. In contrast to prices, the standard deviation of traded auction volumes decreased – thus resulting in more steady trading.

Similar characteristics can be observed for 15 min auction day-ahead trading starting on December 9, 2014:

- Prices decreased strongly, i. e. hourly auctions by 29.24 % and hourly continuous contracts by 27.61 %. In addition, we also observe a considerable reduction in prices for 15 min continuous contracts, amounting to 25.59 %.

- Average trading volumes exhibited a growth of 16.92 % for the hourly auctions and 9.62 % for hourly continuous trading. In contrast, 15 min continuous trading declined by 20.69 %. This accounts for an absolute drop of 0.12 GW. Apparently, market participants partially shifted trading activities from 15 min continuous to 15 min auctions as a substitute market (Section 4.4 visualizes this substitution effect between 15 min continuous and auction trading later).

A simple pre-post comparison reports changes in absolute figures. However, the true underlying change needs to be corrected for confounding effects, such as seasonality or external influences. Therefore, we isolate and quantify the causal impact in the next section.

Market event	**Variable (unit)**	**Product**	**Duration**	**Mean**			**Median**			**Std. deviation**		
				Pre	**Post**	**Change in %**	**Pre**	**Post**	**Change in %**	**Pre**	**Post**	**Change in %**
15 min continuous (December 14, 2011)	Price (EUR/MWh)	Auction	60 min	52.54	38.56	−26.61	50.89	41.21	−19.02	14.00	16.39	17.07
		Continuous	15 min	—	43.11	—	—	44.33	—	—	14.46	—
			60 min	52.91	38.12	−27.95	51.49	40.87	−20.63	16.13	18.41	14.14
		Average		52.72	38.17	−27.60	51.13	40.94	−19.93	14.60	16.42	12.47
	Hourly volume (GWh)	Auction	60 min	26.10	29.34	12.41	25.56	28.94	13.22	4.43	4.14	−6.55
		Continuous	15 min	—	0.02	—	—	0.00	—	—	0.05	—
			60 min	1.45	1.54	6.21	1.36	1.35	−0.74	0.76	0.91	19.74
		Total		27.55	30.89	12.12	27.13	30.52	12.5	4.88	4.52	−7.38
15 min auction (December 9, 2014)	Price (EUR/MWh)	Auction	15 min	—	25.54	—	—	27.15	—	—	14.89	—
			60 min	36.77	26.02	−29.24	33.61	28.17	−16.19	13.31	15.77	18.48
		Continuous	15 min	36.46	27.13	−25.59	34.79	28.12	−19.17	13.56	15.28	12.68
			60 min	36.55	26.46	−27.61	34.66	27.66	−20.20	13.88	15.60	12.39
		Average		36.59	26.45	−27.71	34.63	27.54	−20.47	13.28	14.93	12.42
	Hourly volume (GWh)	Auction	15 min	—	0.20	—	—	0.18	—	—	0.10	—
			60 min	30.44	35.59	16.92	30.05	35.29	17.44	3.71	5.32	43.40
		Continuous	15 min	0.58	0.46	−20.69	0.57	0.45	−21.05	0.31	0.21	−32.26
			60 min	2.39	2.62	9.62	2.14	2.48	15.89	1.21	1.10	−9.09
		Total		33.41	38.86	16.31	32.84	38.81	18.18	4.50	5.74	27.56

Table 3: Comparison of electricity prices and trading volumes before and after the launch of 15 min products in 2011 and 2014. The pre-period comprises an 80 day time window before the event and the post-period a 40 day time period after the market change. In addition, the table lists the average electricity price, as well as the total trading volume, to better assess the combined effect on 15 min and hourly contracts (source: own analysis).

4.3. Causal impact of 15 min products on electricity trading

We now adapt the innovative methodology from Section 3.1 to estimate the causal effect of 15 min trading on the electricity market. The estimated effects are corrected for potential confounding influences, such as seasonality and weather dependency. In addition, Section 5 provides a variety of further robustness checks in order to rule out confounding effects.

To this end, Figure 5 depicts the causal impact of launching 15 min auction trading on the electricity prices of the already-existing hourly auction. Here, the vertical line indicates the event date. The upper figure shows the actual electricity price (solid line) and its corresponding counterfactual (dashed line). Evidently, prices and counterfactual both decrease after the event, even though the decline is stronger for the observed prices. Hence, the middle plot shows this effect in detail by visualizing the difference between counterfactual and observed price. As the counterfactual mirrors the hypothetical situation in which no event occurred, the gap between both reflects the causal impact evoked by the event. Finally, the bottom graph visualizes the accumulated difference between observed prices and counterfactual. It reveals a considerable decrease in the accumulative price, since its 95 % confidence reaches values below zero. Hence, we note a statistically significant causal reduction of hourly auction prices.

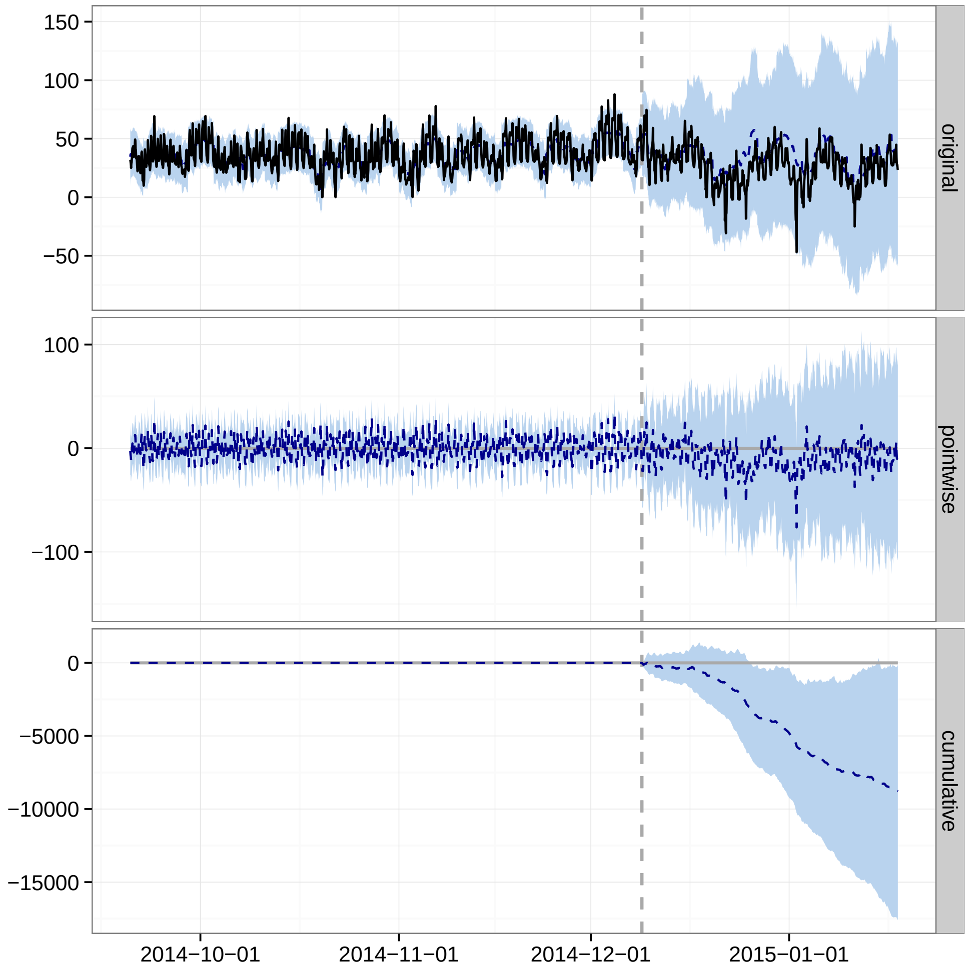

Figure 5: Plots show the causal impact of launching 15 min auctions on hourly auction prices with 95 % confidence intervals. The vertical line denotes the timing of the actual event. The observation period contains 80 days before the event and 40 days thereafter. The solid line in the upper plot represents the observed price and the dashed line its counterfactual. The middle plot measures the difference between the actual price and the counterfactual, while the bottom diagram visualizes the accumulative sum of these differences (source: own analysis).

We now extend our previous analysis and compare the causal impact on prices and trading volumes of different market products. Table 4 thus details the effect size and the posterior probabilities for launching both forms of 15 min trading.

As a result of 15 min continuous contracts, prices of hourly continuous and auction trading dropped by 22.05 % and 22.70 %, respectively. These reductions entail a posterior probability above 95 %, which indicates that this observation is of a causal nature. As we are correcting for exogenous influences, the estimated change is slightly weaker compared to the one observed in Table 3; however, it gives the underlying magnitude that can purely be attributed to the introduction of 15 min continuous trading without confounding seasonal effects. With regards to trading volumes, all posterior probabilities remain below 95 % and, hence, we cannot assume a causal change. Additionally, the relative effects are marginal and cannot even be clearly related to an increase and decrease.

We observe a similar pattern for the introduction of 15 min auction trading. Prices decrease causally with posterior probabilities above 95 % for all electricity products under study. The strength of the effect varies between −25.68 % and −28.15 %, of which continuous trading exhibits the largest decline. Altogether, these cost reductions accumulate to savings of €9.3 million per day in the observed period after the introduction of 15 min trading. Again, we cannot observe a causal effect on trading volumes.

In summary, the introduction of 15 min trading has resulted in a causal reduction of prices for hourly contracts. In addition, the volumes of hourly trading have remained fairly constant, while additional power generation has been harnessed by the market via 15 min trading. The next section provides evidence that this additional power originates from renewable energy sources.

Market event	Variable (unit)	Product	Duration	Obs. value	Pred. value	Abs. effect	95 % Conf. interval Low	95 % Conf. interval High	Rel. effect	Post. probability: non-zero causal impact
Continuous (Dec 14, 2011)	Price (EUR/MWh)	Auction	60 min	38.56	49.46	−10.90	−20.29	−1.22	−22.05 %	98.28 %*
		Continuous	60 min	38.12	49.32	−11.19	−23.29	1.18	−22.70 %	96.39 %*
	Hourly volume (GWh)	Auction	60 min	29.34	28.61	0.72	−33.19	37.15	2.53 %	51.14 %
		Continuous	60 min	1.54	1.64	−0.10	−1.75	1.04	−6.37 %	56.75 %
Auction (Dec 9, 2014)	Price (EUR/MWh)	Auction	60 min	26.02	35.71	−9.69	−19.26	0.50	−27.14 %	97.11 %*
		Continuous	15 min	27.13	36.51	−9.38	−19.79	1.39	−25.68 %	95.89 %*
			60 min	26.46	36.83	−10.37	−20.96	0.90	−28.15 %	96.61 %*
	Hourly volume (GWh)	Auction	60 min	35.59	31.74	3.85	−30.04	39.65	12.12 %	59.74 %
		Continuous	15 min	0.46	0.51	−0.05	−0.24	0.17	−9.05 %	67.96 %
			60 min	2.62	2.75	−0.13	−1.47	1.12	−4.89 %	58.91 %

Probability threshold: * 95 %

Table 4: Causal impact of the introduction of 15 min continuous and auction trading on existing products. Observation period contains 80 days before and 40 days after the event. The posterior probability denotes the confidence of the observed effect. Hence, this value specifies the probability that of a non-zero causal effect, where we highlighted values above the probability threshold of 95 % (source: own analysis).

4.4. Intermittent electricity sources as a driver of 15 min trading

Renewable energy sources are subject to highly volatile power generation and it is thus pertinent to study the relationship between renewables and 15 min trading. Accordingly, Table 5 details the correlation between electricity prices and feed-ins from wind and solar power. We observe a clear negative correlation, which suggests that prices tend to be lower with larger feed-ins from wind power. The infeed from solar power reveals a similar relationship, albeit of less magnitude, as the correlation coefficient is considerably smaller.

Table 5 also depicts the relationship between trading volumes and the change in renewable electricity generation, where we specifically replace the absolute volume with its gradient, since 15 min trading is supposed to better balance the ramp-ups and ramp-downs of renewable energy sources. Here we note a stronger correlation between the change in solar power than for wind power. In addition, the correlation coefficient appears to be larger for 15 min trading than for 60 min blocks. This provides evidence that 15 min products are predominantly used to balance the variations in solar infeed.

Variable (unit)	**Product**	**Duration**	**Correlation with wind power**	**Correlation with solar power**
Hourly price (EUR/MWh)	Auction	15 min	-0.54^{***}	-0.02^{**}
		60 min	-0.54^{***}	-0.05^{***}
	Continuous	15 min	-0.47^{***}	-0.07^{***}
		60 min	-0.51^{***}	-0.05^{***}
Variable (unit)	**Product**	**Duration**	**Correlation with Δwind power**	**Correlation with Δsolar power**
Hourly volume (GWh)	Auction	15 min	0.06^{***}	0.72^{***}
		60 min	0.20^{***}	0.30^{***}
	Continuous	15 min	0.13^{***}	0.61^{***}
		60 min	0.10^{***}	0.33^{***}

Statistical significance levels: *** 0.001, ** 0.01, * 0.05

Table 5: This table reports the correlation coefficients between electricity prices and the volume of renewable power generation in the top section. The bottom part studies the correlation between trading volume and the gradient of power generation. The underlying dataset spans the year 2015, with P-values from Pearson's correlation test (source: own analysis).

The previous correlation analysis underlines the considerable influence of weather on electricity prices and trading volume. We observe a strong link between renewables and electricity prices, while 15 min trading specifically increases with larger infeeds from solar power.

Hence, we further investigate 15 min contracts as a vehicle to balance fluctuations in solar power generation. Feed-ins from solar power experience a sharp rise in the morning until noon and then quickly drops again in the afternoon. Accordingly, we visualize this pattern in Figure 6 and compare it to the daily trading activities of 15 min contracts. The left plot thus shows the absolute change in solar power, while the two others display the trading volumes of 15 min contracts. As we can see, all curves feature two peaks during the course of the day. This thus suggests that 15 min products indeed represent a tool for electricity traders to balance ramp-ups and ramp-downs of solar power generation.

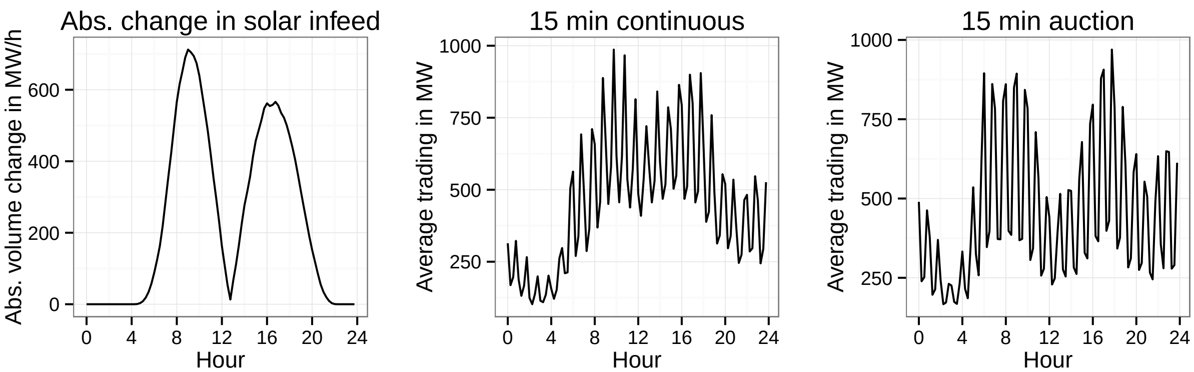

Figure 6: The left plot visualizes the change in solar power generation, while the middle and right graphs illustrate the trading volumes of 15 min contracts in 2015 (source: own analysis).

We finally examine the seasonality of 15 min trading across the year. Our outcome provides evidence that 15 min contracts present a common vehicle by which to exchange (excess) power from renewable energy sources. For this purpose, Figure 7 depicts the trading volume of 15 min contracts and relates it the average feed-in from solar power. Both curves reveal a similar and strong seasonality, with large peaks during the summer. Evidently, 15 min contracts are largely adopted by market participants to trade additional and hitherto unused solar power, given the similar periodicity. This validates the original intention behind changing the market design (EPEX, 2013).

We also observe a gradual increase in 15 min trading volumes during the years 2011 to 2016. However, the actual trading was apparently distributed among continuous and auction products after the launch of 15 min auctions in 2014. This is also followed by a slight decline in continuous trading, which is likely to be replaced by the newly available auction products. Based on this, we note that the market had a strong demand for 15 min auction contracts, which allowed for a reliable price settlement due to the concentration of liquidity during the auction.

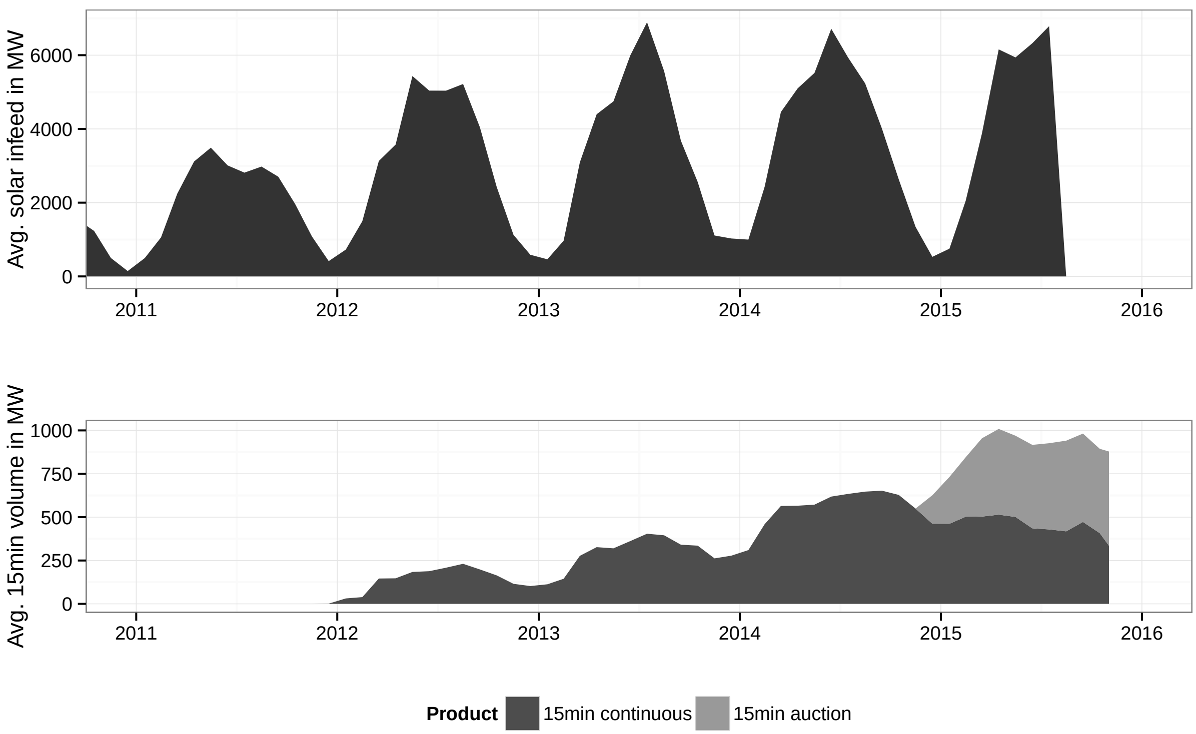

Figure 7: Plot shows the similar seasonal patterns of both monthly average solar power and trading volume of 15 min continuous and auction products. The bottom plot prints the stacked trading volumes due to substitution effects between auction and continuous trading (source: own analysis).

5. Robustness checks

We now conduct a sensitivity analysis to test and validate the methodology by monitoring the robustness of the output when facing varying input parameters. In our case, we study different parameters, such as other covariates, time duration and the hypothesized time of the event. All of the checks confirm that the posterior probability of a causal effect points in the desired direction. Moreover, we obtain further insights regarding the magnitude of the effect, where the size of the relative effect ranges between 11 % and 28 % depending on the individual setting, type of 15 min contract and variable of interest. However, an exact estimate of the effect is difficult infer due to the complexity of the market

5.1. Sensitivity analysis of observed causal impact

When exchanging covariates, we test other possible variables (e. g. electricity demand) or use only wind or solar exclusively. As a matter of fact, all combinations of covariates result in very similar effect sizes, as well as probabilities of above the common significance threshold of 95 % as shown in Table 6. However, we find that the combination of wind and solar performs best across all models, while also being strongly backed by how the electricity market functions.

Response variable	Covariates	Average relative effect (80 d, 40 d)	Average relative effect (28 d, 14 d)	Posterior prob. of a causal effect (80 d, 40 d)	Posterior prob. of a causal effect (28 d, 14 d)	Causal impact detected
Intraday	Wind & solar	−22 %	−21 %	97 %	98 %	✓
electricity	Wind	−22 %	−23 %	97 %	100 %	✓
price	Solar	−20 %	−18 %	94 %	98 %	✓
Auction	Wind & solar	−21 %	−19 %	99 %	99 %	✓
electricity	Wind	−21 %	−21 %	98 %	100 %	✓
price	Solar	−18 %	−16 %	96 %	97 %	✓
Intraday	Wind & solar	0 %	10 %	51 %	78 %	✗
volume	Wind	−2 %	6 %	53 %	69 %	✗
buy	Solar	29 %	2 %	54 %	55 %	✗

Table 6: Sensitivity analysis for our evaluation of the causal impact with varying response variables and covariates. Effect is measured on 60 min market subsequent to the introduction of 15 min continuous trading. Both the relative effect and probability of causal effect (i. e. the posterior probability) are calculated for two different time frames of pre-event and post-event periods. These are given a 28 d and 80 d pre-period, as well as 14 d and 40 d post-periods, respectively. Seasonality settings are calibrated to 7 days of 24 hours, each to fit hourly data. Check marks indicate that the posterior probabilities of both time frames under study exceed the critical threshold of 95 %. This thus refers to the detection of a non-zero causal impact, which here again yield the expected outcomes.

Choosing the time duration of the analysis is subject to a trade-off: a longer time window t_{post} allows us to capture a more profound effect as the market participants slowly adapt over time to the new electricity contract. However, it becomes harder to predict the counterfactual precisely for longer time windows, thus resulting in a lower posterior probability. Hence, we have experimented with numerous time spans ranging from 42 days to a full year. We find that a total of 120 days with a pre-period of 80 days and post-period of 40 days obtains a favorable trade-off between magnitude of the observed effect and reliability of the result. To account for seasonal variations, we also perform the analysis with pre- and post-periods of one full year each.

We repeat this analysis for the years 2011 through to 2014, but only find causal events in 2011 and 2014 as shown in Table 7.

Year	**Obs. value**	**Pred. value**	**Abs. effect**	**Rel. effect**	**Post. probability: non-zero causal impact**
2011	33.26	39.66	−6.40	−16.13 %	99.95 %*
2012	26.91	32.48	−5.57	−17.15 %	90.50 %
2013	24.97	28.08	−3.11	−11.07 %	87.30 %
2014	24.01	26.91	−2.90	−10.81 %	98.83 %*

* Above probability threshold of 95 %

Table 7: Sensitivity analysis for the years 2011 to 2014 using hourly auction prices (EUR/MWh) and a pre-/post-periods of one year each. Here the posterior probability refers to the probability of a non-zero accumulated causal impact. Hence, values marked by an asterisk highlights years in which the probability of a non-zero causal impact exceeds 95 %. Here the critical threshold of 95 % is exceeded only for the true market changes in the years 2011 and 2014.

We also control for the time of the event by varying it. This helps us to identify at which point in time the majority of traders adjust their behavior to the new products. Our analysis assumes a market design change at midnight between December 13 and December 14, 2014. However, the true change of the market occurred at 11:00 am on December 14, 2014, after which 15 min contracts were activated. Our choice is justified by the fact that traders are likely to adjust their training behavior not throughout the day but from one day to another. Nonetheless, we are able to replicate all evaluations for both timings with similar outcomes. When using 11:00 am as event time, the impact decreases by roughly 5 %. Simultaneously, the posterior probability also declines by a few percent – hence justifying midnight as the more likely event.

Altogether the above sensitivity analysis demonstrates that our results are very stable even when changing individual model parameters. Consequently, this sensitivity analysis contributes to our evaluation by showing that our methodology produces reliable results.

5.2. Validity of inferring the causal impact

In addition to the above sensitivity analysis, we also validate the posterior probability in the following ways: (1) to demonstrate that the model works and no event is detected where none exists and (2) to demonstrate the absence of a confounding effect on covariates. To do so, we apply our methodology to arbitrary time frames, consistent with Brodersen et al..

We select time frames close to the actual event to have a comparable time frame with similar behavior of the parameters. We then test potential event timings closely before and after the actual event, as well as several random time periods (e. g. July 2011). As expected, all tests yield posterior probabilities below 80 % as illustrated by Table 8 and thus confirm that no causal effect is present.

Relationship to event (15 min continuous trading)	**Times frames**		**Relative effect**	**Posterior probability: non-zero causal impact**
	Pre-period	**Post-period**		
One day before original event	80 d	40 d	8 %	79 %
	28 d	14 d	−7 %	80 %
One day after original event	80 d	40 d	32 %	52 %
	28 d	14 d	−17 %	66 %
Event on 01/07/2011	80 d	40 d	−24 %	67 %
(arbitrary "false" event)	28 d	14 d	2 %	61 %

Table 8: Empirical assessment of the causal impact with arbitrary periods before and after the event, as well as a test run with a random event date (i. e. July 1, 2011) where no market change occurred. Again, posterior probabilities of above 95 % indicate a causal impact; however, none of these exceed the threshold. Hence, all values point in the expected directions and do not report an effect where no event occurred.

Furthermore, we test the method one year later than the actual launch to obviate that we erroneously captured a seasonal artifact. As before, we obtain posterior probabilities below 80 % and thus detect no evidence of causal effect. Hence, we conclude that our model works as expected and does not detect causality where no effect exists based on common statistical thresholds.

6. Discussion

6.1. Interpretation of findings

Our analysis reveals that the market has successfully adopted both types of 15 min products, with average trading volumes exceeding 1.000 MW, and is using them to balance intra-hour demand and supply. It seems that market participants have gained considerable experience in the trading of 15 min contracts and, as a result, have incorporated 15 min auctions in 2014 more quickly into their trading strategies as compared to the first market change in 2011. We also observe a substitution effect between both contracts, since 15 min trading partially shifted from continuous to auction products. Hence, this could raise the issue that market participants might have favored an even earlier introduction of 15 min auctions. In late 2015, average trading volumes were distributed almost evenly across both 15 min continuous and auction trading.

Furthermore, we confirm the importance of 15 min trading for balancing renewable energy sources. Our findings indeed suggest that 15 min contracts absorb renewable electricity – and solar power in particular – which was hitherto unused due to inflexible contract durations. Hence, morning and afternoon hours experience considerable trading volumes of 15 min contracts in which solar power generation undergoes its ramp-up and ramp-down phases. Due to the higher liquidity, market participants trade the majority of electricity demand in hourly contracts. This even holds true for solar power, where stakeholders trade the hourly average electricity demand in 60 min contracts and then use 15 min products to balance deviations from this average. In this regard, Kiesel and Paraschiv (2017) further detail the bidding behavior around 15 min contracts, finding that prices adjust to forecasting errors of both wind and solar power generation.

Economic theory stipulates that a larger supply results in price reductions when demand remains fixed. Interestingly, we see supporting evidence based on our analysis: consistent with theoretical justifications, we observe that a larger supply of electricity results in decreasing prices. In addition, the causal price decline subsequent to the launch of 15 min auctions exceeds the decrease from 15 min continuous trading. A possible reason might stem from faster adoption rates of 15 min auctions. Altogether, the immense cost reductions stress once again the importance of market design.

This investigation provides a unique example of how to empirically evaluate the impact of a market design change. Consequently, our methodology might be beneficial for further studies regarding changes in electricity market design across the world. In our case, the change enabled stakeholders to trade volatile renewables thanks to the greater flexibility of the market design.

6.2. Policy implications

Electricity generation has historically been a major source of greenhouse gases all over the world. As a remedy, policy-makers in many countries are searching for opportunities to augment the market share of renewable energy sources, such as solar or wind power. However, their intermittent nature makes them subject to considerable fluctuations in power generation. Thus, the trading of such volatile sources may also require modifications of the market. At the same time, more attractive markets for trading renewable energy sources also incentivize renewable energy providers to offer additional electricity on the stock exchange.

In fact, the trading of energy from renewables requires different market design properties than conventional baseload electricity sources. Due to their volatility, shorter contract durations allow electricity producers to sell even short-term peaks in power generation. Shorter contracts thus present an interesting opportunity for policy-makers and regulators to implement improvements to their electricity market design. Furthermore, the reduction of minimum contract durations allows for a more precise balancing of demand and supply and thus reduces friction in the market. Hence, shorter contracts can also provide a chance for policy-makers to simultaneously strengthen market dynamics (Weber, 2010).

Our findings lead market participants to expect a decrease of electricity prices following the introductions of 15 min trading. This gives electricity retailers the possibility to reduce costs and, if savings are passed on to end-customers, the latter can also benefit from cheaper electricity. At the same time, offering these additional products comes at almost zero marginal cost, with the exception of potential transaction costs.

What is left unanswered is whether a further reduction of contract durations could increase the share of renewable energy sources even more. For instance, a smaller resolution requires adjustments to the market of tertiary control reserves and the mechanism of balancing energy – both of which are largely operating in blocks of 15 min in Germany. In addition, shorter delivery periods simultaneously extend the range of available contract types and, therefore, such an introduction could further increase transaction costs for market participants.

As an immediate implication for policy-makers, 15 min trading can increase carbon-free power generation from renewable energy sources while also lowering electricity prices. Therefore, 15 min contracts present a powerful leverage for policy-makers from areas with high shares of renewable energy sources, such as Sweden, Austria, Denmark, Latvia and Portugal, all of which still trade in minimum intervals of 60 min.

7. Conclusions

This paper investigates the introduction of 15 min contracts in the German-Austrian spot market and potential cross-effects on prices and trading volume of existing electricity products. This launch represents a considerable change in the market design, which aims to improve trading of electricity from intermittent renewables.

Our results reveal a similar price distribution for 15 min contracts in comparison to their hourly blocks, with mean and median prices being highly similar. Evidently, electricity producers charge a minor premium of up to 0.09 EUR/MWh for 15 min contracts when comparing average prices with their hourly contracts. We note a larger standard deviation for continuous than for auction trading because of the later market clearing.

We further utilize an innovative approach based on Bayesian structural time series to infer the causal impact on other electricity products. Our empirical results uncover a significant reduction in prices for hourly contracts. As our primary contribution, we find that the price drop is of causal nature. Depending on the model specification, the analysis indicates that prices of hourly continuous and auction trading have plummeted by 11 % to 28 % due to this changed market design, yet an exact number is difficult infer because of the complexity of the market. We further see that the trading volumes for 60 min contracts remains fairly stable. Consequently, we provide evidence that 15 min products promote additional energy – predominantly from solar power – being made available to the electricity exchange. Together with the more flexible trading scheme, this results in an immense decrease in the prices of existing products.

Empirical studies related to the discretization of electricity trading present an intriguing and relevant field for further work. In this regard, future research should put an emphasis on the optimal duration of contracts. For instance, decreasing the delivery duration further increases transaction costs but might be an effective tool with which to balance electricity demand and fluctuating feed-ins from renewable energy sources. In addition, our analysis merely focuses on the ramifications of 15 min contracts in Germany and Austria. However, there might be spill-over effects in other countries due to market coupling in Europe. In this regard, policy-makers could benefit from estimations of prospective cost savings that might be achieved by introducing 15 min trading to other countries. Furthermore, it would be interesting to study the relationship between 15 min products and control reserves in terms of price and offered volume.

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