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Passive Balancing Through Intraday Trading: Whether Interactions Between Short-term Trading and Balancing Stabilize Germany's Electricity System

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ABSTRACT

Transmission System operators actively balance the electricity system by sending a dispatch signal to suppliers of balancing reserve. When market participants intentionally adapt their intraday positions based on the expected system state, they can also reduce the required dispatch of balancing reserves. This is called passive balancing. The German imbalance price system incites this behavior. This paper examines whether passive balancing prevails in Germany and how it affects the system stability. Our analysis indicates that intraday trading close to gate closure is highly affected by market participants reacting to the latest published system balance (SB). This behavior has a positive impact on system balancing. Intraday trading close to gate closure reduces both the required demand of balancing energy and high SBs up to 5% without causing a critical overshoot of the system.

Keywords: Electricity Market Design, Passive Balancing, Intraday Market, Electricity Portfolio Management, Strategic Behavior
JEL Classifications: C32; D47

1. INTRODUCTION

The liberalization of the electricity market caused a deconstruction of the integrated electricity value chain. Potentially competitive segments like marketing and operation of generation and load are separated from regulated segments such as operations of transmission or distribution grids (Joskow, 2008). This also changed the approach of balancing demand and supply in the electricity system. In Germany and many other liberalized countries, decentralized balancing responsible parties (BRPs) plan the production or consumption of their portfolio while the Transmission System Operators (TSOs) centrally coordinate the compensation of the remaining imbalances by the activation of balancing reserve.

The accuracy of BRPs' portfolio management determines the demand of balancing reserve. As time unfolds, BRPs have better predictions of their actual generation and consumption. Therefore, it becomes necessary to balance forecast deviations for renewables, load and power plant outages after the day-ahead market by either trade or dispatch of own assets. The most important platform to trade these deviations is the intraday market. The German continuous intraday market at EPEX SPOT opens at 3 pm of the previous day and products can be traded until 5 min before delivery (EPEX SPOT SE, 2017). The Nord Pool power exchange provides intraday trading even until delivery within the German TSO areas (Nord Pool, 2018).

The core incentive for BRPs to use the intraday market for portfolio balancing is the imbalance price. If the overall system is short – meaning that uptake exceeds infeed – the imbalance price must be higher than the intraday price and vice versa so that BRPs buy or sell additional volumes on the intraday market instead of using balancing energy. But what is about the BRPs whose imbalance is opposed to the overall system? In Germany, they are rewarded the same imbalance price as the BRPs pay that enforce the imbalance of the system. This symmetric pricing model incites BRPs to take a position that is opposed to (or to avoid a position that is congruent to) their expectation of the system balance (SB) to financially optimize their portfolio. This behavior is called passive balancing as it decreases, in case of success, the SB without activating balancing reserve capacity (Chaves-Ávila et al., 2014b; Hirth and Ziegenhagen, 2015). In Germany however, it is prohibited to take intentional imbalance positions. The German imbalance price system thus incites BRPs to deploy operations that are legally not allowed.

This study analyses whether market participants follow the financial incentive of the imbalance price and, if so, how this behavior affects the system stability. We extend the definition of passive balancing to be understood as intentional reactions to the expected SB by intraday trading. It is not relevant whether intraday trading reduces the BRPs imbalance congruent to the SB or increases the imbalance opposed to the SB as the overall effect on the system and the financial incentive is the same.

Our analysis is twofold: Firstly, we apply a regression model to estimate price changes of intraday trades close to gate closure. Hagemann (2015) and Wolff and Feuerriegel (2017) show that intraday prices are influenced by fundamental drivers such as forecast deviations and power plant outages. If the latest published SB is also a significant parameter, it will be an indication that market participants react to this information to optimize their own portfolio. We apply a quantile regression including third degree polynomial to address non-linear effects and to gain greater insights regarding the relations of the dependent and the independent variables. This approach has gained popularity in the literature of electricity price forecasting as inter alia the studies of Jónsson et al. (2014), Nowotarski and Weron (2015), Bunn et al. (2016) and Maciejowska et al. (2016) show. In a second step, we calculate the effect of intraday trading close to gate closure on different system stability indicators.

The research relates to several studies discussing the theoretic approach of passive balancing (Chaves-Ávila et al., 2014a; Zapata Riveros et al., 2015; Brijs et al., 2017; Hu et al., 2018; Joos and Staffell, 2018; Röben and Schäfers, 2018). None of them apply a specific case study. We fill this gap with our analysis about the interactions of the intraday and balancing market in Germany. There are other research papers studying the financial incentive to use balancing energy for portfolio balancing (Möller et al., 2011; Just and Weber, 2015). Tanrisever et al. (2015) examine the influence of spot price incentives on the SB for the Dutch market. But all these papers do not address the topic of passive balancing. The paper also relates to studies analyzing the main drivers of intraday prices (Karanfil and Li, 2017; Kiesel and Paraschiv, 2017; Frade et al., 2018). The difference of our approach is that we use the model to test our hypothesis that market participants react to the SB to financially optimize their portfolio.

The paper is structured as follows: Section 2 provides background information about the balancing system and the idea of passive balancing. Section 3 gives an overview of the methodical approach and the used data. Section 4 examines whether the information of the SB influences intraday trading close to gate closure and Section 5 analyzes the impact on system stability. The results are discussed in Section 6. Section 7 concludes.

2. BACKGROUND

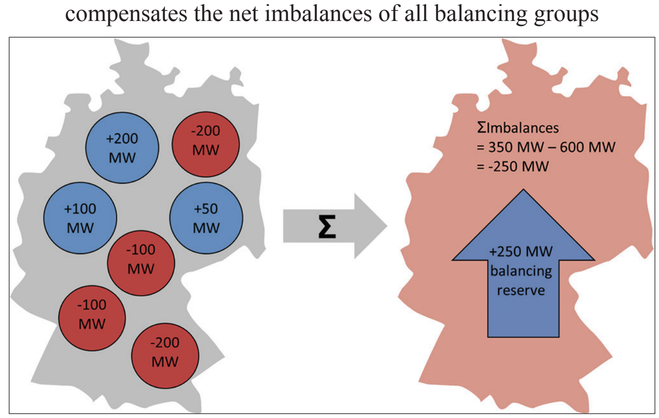
2.1. The Balancing System

One special characteristic of electrical energy is the requirement to ensure the balance between demand and supply at every point of time to maintain a stable frequency. If the system is physically short of energy, the frequency drops. Large deviations from nominal frequency can cause disconnections, damage equipment and lead to rolling blackouts. These situations shall be prevented by an elaborate system of regulations, processes and markets to which we collectively refer to as the "balancing system."

In Germany, the market participants have the responsibility to ensure that their portfolio is in balance. Each electricity market actor takes the role of a BRP. Each physical connection point of the grid is associated with one balancing group of one BRP. There are more than one thousand BRPs in Germany (50Hertz Transmission GmbH, 2019; Amprion GmbH, 2019; TenneT TSO GmbH, 2019; TransnetBW GmbH, 2019). They can balance their portfolio of generation and/or load through dispatch of physical assets or through trade. BRPs provide their schedules to the associated system operator. The remaining deviations between schedules and actual physical positions are called imbalances. They are compensated by system wide balancing energy being activated by the TSO. Positive and negative imbalances offset each other so that the final activation of balancing reserve is only determined by the net balancing group imbalances. Figure 1 illustrates the general principle for the German grid cooperation. If the sum of all balancing group deviations is negative, there is a shortage of supply in the system and the TSOs must activate positive balancing reserve.

The imbalance settlement period in Germany is 15 min. For each period, the average net imbalance of all balancing groups is called SB. It includes all measures used to compensate imbalances such as the activation of automated and manual Frequency Restoration Reserve (*aFRR* and *mFRR*) and additional measures

Figure 1: Explanation of the balancing system. Balancing reserve compensates the net imbalances of all balancing groups



as well as emergency measures for or from foreign TSOs (EM). Furthermore, there are international balancing cooperation to exchange balancing energy within the International Grid Control Cooperation and the aFRR cooperation with Austria (50Hertz Transmission GmbH et al., 2017).

$$SB_t = \left(P_{aFRR+} - P_{aFRR-}\right)_t + \left(P_{mFRR+} - P_{mFRR-}\right)_t + \left(P_{AM+} - P_{AM-}\right)_t + \left(P_{EM+} - P_{EM-}\right)_t + \left(P_{IGCC,im} - P_{IGCC,ex}\right)_t + \left(P_{aFRR,im} - P_{aFRR,ex}\right)_t \quad (1)$$

A positive SB corresponds to a shortage of supply in the national grid, a negative system represents a power surplus. It can be seen as indicator for the system stability. If the absolute SB is high, the same applies for the demand of balancing energy.

In Germany, the SB is also a key element for the calculation of the imbalance price. The general idea is to distribute the costs of balancing reserve activations for every quarter-hour to the BRPs, who caused the activations. The general calculation reads:

$$Imbalance\ Price_t = \frac{\sum Costs_t - \sum Revenues_t}{SB_t} \quad (2)$$

Regarding the settlement, the imbalance price calculated with equation (2) functions sufficiently to distribute the cost or revenues of activated balancing energy to the BRPs. But in case of a small average SB over a quarter-hour, the fraction in the formula can lead to extreme imbalance prices in a moderate system. To avoid this, the price is capped at the highest working price of all activated assets. Furthermore a linear function limits the price when the SB is between −500 MW and 500 MW. However, the imbalance price shall always incite the BRPs to balance predictable deviations on the market. This is addressed by the constraint that the imbalance price must be higher than the volume weighted average price of the corresponding hour.[1] Additionally, there is a surcharge, if TSOs must activate 80% of the procured aFRR and mFRR within one quarter-hour. It is the maximum of 100 €/MWh or half of the imbalance price (Bundesnetzagentur, 2012).

2.2. The Concept of Passive Balancing

According to § 4 (2) StromNZV and the balancing group contract, BRPs are obliged to keep imbalances to a minimum by taking reasonable measures. It is only allowed to use balancing energy for unpredictable deviations like power plant outages or short-term forecast errors for production or consumption (Bundesnetzagentur, 2013). Thus, it is prohibited to take intentional imbalance positions. However, the symmetric imbalance price in Germany gives a financial incentive to take an intentional imbalance position (Hirth and Ziegenhagen, 2015; Just and Weber, 2015; Zapata Riveros et al., 2015). Depending on the sign of their imbalance position, BRPs will either pay or receive the imbalance price for their imbalance. When the electricity system is short of energy, a BRP with a short portfolio must pay, but a BRP with a long portfolio gets payed the imbalance price. This system leads to incentives of taking imbalance positions to financially optimize the own portfolio. Table 1 shows the relation of imbalance prices

Table 1: Relation of SB and price deviation of imbalance and volume weighted average intraday price from January 01, 2016 to September 30, 2018. The numbers resemble a count of quarter-hours

	SB >0 MW	SB ≤0 MW
Imbalance price > Intraday price	54 372	1 670
Imbalance price ≤ Intraday price	6 300	34 034

SB: System balance

and volume weighted average intraday prices depending on the sign of the SB. If the system is short (positive SB), the imbalance price is higher than the intraday price in 90% of the cases. In this case, it would be better to buy additional volumes on the intraday market to be oversupplied and receive the imbalance price. It is the other way around for a power surplus (negative SB), when the imbalance price is lower than the intraday price in 95% of the cases. Most of the time, it is financially beneficial to take an intraday position that is opposed to the SB. This behavior is called passive balancing since it can reduce the SB (Lampropoulos, 2014; van der Veen and Hakvoort, 2016). The term is used in contrast to active balancing via balancing reserve activation by TSOs. To our understanding, every intentional reaction to the expected SB by intraday trading shall be called passive balancing as long as it reduces the SB. It is not relevant whether the intraday position reduces or increases the own imbalance as the overall effect on the system and the financial incentive is the same. The following analyses aim to show whether market participants apply this portfolio optimization on the intraday market and, if they do so, how it effects the system stability.

3. MATERIALS AND METHODS

If market participants use the information of the SB to optimize their portfolio, there must be a correlation between intraday price developments and the SB. This should apply especially to market activity close to gate closure as the SB is difficult to predict for a longer period. Therefore, we take the price deviation of the volume weighted average intraday price of quarter-hourly trades close to gate closure and the day-ahead price of the corresponding quarter-hour ($P^{ID\,GC} - P^{DA}$) as the independent variable of our analysis. The empirical study of Maskos (2017) shows that German TSOs regularly publish the past SB 10.65 min after the quarter-hour, which means that the latest information is available 4.35 min before gate closure of continuous trading.[2] In our calculation we consider all trades that are executed after this threshold.

The period of our analysis spans from January 1, 2016 to September 30, 2018. The end of the period must be set to that date as the German regulator changed the approach of accepting balancing reserve bids in October 2018 having a significant impact on the imbalance prices (Bundesnetzagentur, 2018). Therefore, data since October 01, 2018 are not part of the analysis to cover a period with a stable market design and comparable price incentives.

1 This constraint does not prevent that quarter-hourly intraday prices are higher than imbalance prices.

2 The gate closure of the "Same Delivery Area Trading" or "Trading until Delivery" is five minutes before delivery for the four German delivery areas. It is not considered here, since this market was only introduced on 13/06/2017 and its liquidity is lower than in continuous trading Niciejewska (2017).

Our study is divided into two steps, each testing one hypothesis. We start with a single correlation analysis between $P^{ID\,GC}$ and P^{DA} and the SB. A positive SB represents a short system. In this case it is economically beneficial to be oversupplied by buying additional volumes on the intraday market. This would lead to higher intraday prices. Therefore, we expect a positive correlation between the price deviation and the SB.

But which lagged SB has the highest impact on the intraday prices close to gate closure? We calculate the correlation for several time lags of the SBs from zero (the SB of the corresponding trading product) to 225 min. As market participants do not know the actual SB of the corresponding trading product, they can only use the latest published value to predict it. This is the SB of 60 min before delivery, because intraday trading is possible until 30 min before delivery and the TSOs publish the SB 10.65 min after the quarter-hour (Figure 2).

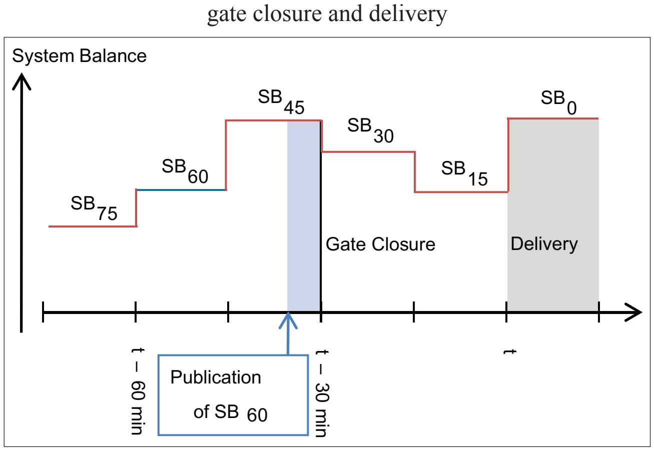
This leads to our first hypothesis

H_1: There is a positive relation between the SB and the deviation between intraday prices close to gate closure and day-ahead prices. The correlation is the highest for the latest published SB, which is 60 min before delivery.

Several studies confirm a non-linear relation between fundamental drivers and electricity prices due to the shape of the merit order (Misiorek et al., 2006; Chen and Bunn, 2010; Bunn et al., 2016). We expect such a non-linear influence also for the SB and study it with a scatter plot. Afterwards, we analyze the relation to the deviation between intraday prices close to gate closure and day-ahead prices by calculating the Spearman correlation coefficient. Its main use is to discover associations in nonlinear data sets (Borradaile, 2003).

The second step of our analysis is to fit a quantile regression model to estimate the price deviation $P^{ID\,GC} - P^{DA}$. Quantile regression was introduced by Koenker and Bassett (1978) and fully described by Koenker (2005) and Hao and Naiman (2007). Its idea is to fit individual models for estimating conditional quantiles of the distribution of a dependent variable using different coefficients for the independent variables at each quantile.

Figure 2: Diagram of the chronological sequence of system balance, gate closure and delivery



Let Y_i be the dependent variable and X_i a d-dimensional vector of explanatory variables including a constant. The regression model for the quantile level q is given by

$$Q_q\left(Y_t \mid X_t\right) = X_t b_t \tag{3}$$

in which, as implemented in software packages like R, Stata or Eviews, the parameters β_q are derived by solving the minimization problem:

$$\underset{\beta_q}{arg\,min} \sum_{t=1}^{T} \left(q - 1_{Y_t \le X_t \beta_q}\right)\left(Y_t - X_t \beta_q\right) \tag{4}$$

where

$$1_{Y_t \le X_t \beta_q} = \begin{cases} 1 & Y_t \le X_t \beta_q \\ 0 & otherwise \end{cases}$$

Quantile regression does not make any distributional assumptions other than assuming that the dependent variable is almost continuous (Koenker, 2005). So, there is no need to test for heteroskedasticity or autocorrelation of the residuals as it is necessary for an ordinary least squares regression (Wooldridge, 2013). The details on estimating standard errors for coefficients, inference and goodness of fit are explained in (Koenker and Machado, 1999).

If market participants use the information of the latest published SB, it should be a significant parameter of the model, even when fundamental variables associated with intraday prices are controlled for.

H_2: The latest published SB has a significant influence on all different quantile levels of the deviation between intraday prices close to gate closure and day-ahead prices.

Several studies show that fundamental variables can explain deviations between hourly intraday and day-ahead prices (Hagemann, 2015; Pape et al., 2016; Valitov and Maier, 2017). According to these papers, significant parameters are renewable and load forecast errors ($Delta^{Wind}$, $Delta^{Solar}$, $Delta^{Load}$), power plant outages (*outage*) and cross-border physical flows. This should also apply to quarter-hourly products, because their prices must match on average the price of the corresponding hourly product to avoid arbitrage opportunities. Therefore, we consider these parameters as control variables in our model.

The forecast errors are calculated as the day-ahead forecast minus the actual production or consumption. This is an approximation of the difference between the day-ahead position and the latest intraday forecast representing the volume the market participants try to close at the intraday market.

Cross-border flows can be nominated explicitly or implicitly. Market participants are able to explicitly allocate capacities on specific platforms to declare a cross-border flow from or to different neighboring countries. On these platforms the allocation of capacity is associated with a nomination and thus with a cross-border flow. We consider the net import of all flows from and to Germany's neighboring countries as a regressor for our model ($Net\ Import^{expl}$). Additionally, German market participants can directly match intraday bids and offers from other countries that are part of the cross-border intraday initiative (XBID) (EPEX SPOT SE, 2018) as long as there is enough net transport capacity available for the intraday market. The net position of all trades with buyer (seller) in Germany and seller (buyer) in another country is also considered in our model ($Net\ Import^{impl}$). Table 2 provides an overview of all variables and their data source.

To address the expected non-linear effect of the SB, we include this variable with a third degree polynomial. This leads to the following model specification:

$$Q_q\left(P_t^{ID\,GC}-P_t^{DA}\right)=\beta_0^q+\beta_1^q SB_{t-60}+\beta_2^q\left(SB_{t-60}\right)^2 +\beta_3^q\left(SB_{t-60}\right)^3+\beta_4^q Delta_t^{Wind} +\beta_5^q Delta_t^{Solar}+\beta_6^q Delta_t^{Load} +\beta_7^q Outage_t+\beta_8^q Net\ Import_t^{expl} +\beta_9^q Net\ Import_t^{impl} \quad (5)$$

4. INFLUENCE OF SB ON INTRADAY PRICES

This section provides the results of the analyses described in Section 3. First, we carry out an exploratory data analysis showing a positive correlation between the SB and the price deviation between quarter-hourly intraday prices close to gate closure and quarter-hourly day-ahead prices. There is an indication that market participants use the information of the latest published SB to financially optimize their portfolio. This is confirmed by the quantile regression model presented in Section 4.2. The explanatory power of the models more than doubles by adding the polynomial of the latest published SB to a model that covers only other fundamental variables.

4.1. Correlation Analysis

Figure 3 shows the scatterplot of the volume weighted average intraday price of trades close to gate closure referred to the day-ahead price over the SB. It additionally depicts the regression lines that approximate the relation between the 0.05, 0.5 and 0.95 quantile level of the independent variable and the third degree polynomial of the SB. Even though in some cases the observations differ strongly from the regression lines there is a trend that higher SBs correlate with increasing prices and lower SBs with decreasing prices. This represents the effect that passive balancing should have on intraday price developments. Having a short system (positive SB), it is beneficial to buy additional volumes on the intraday market and to take a long imbalance position in the

Figure 3: Scatterplot of the volume weighted average intraday price of trades close to gate closure referred to the day-ahead price over the system balance. The blue lines represent a third degree polynomial regression of the 0.05, 0.5 and 0.95 quantile level

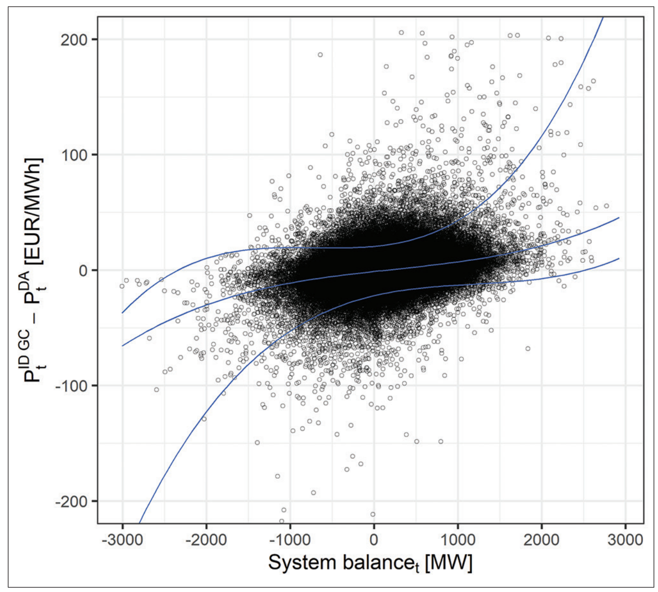


Table 2: Overview of explanatory variables and their data sources

Data	Description	Source
Day-ahead price	Market clearing price for a certain hour in the day-ahead auctions	Entelios GmbH
Intraday price	Volume weighted average price of all trades executed within 4.35 min to gate closure	Entelios GmbH
SB	The sum of imbalances from all German balancing groups	Common platform of German TSOs: https://www.regelleistung.net/ext/data/
Forecast error wind	Day-ahead prognosis minus extrapolation of the actual wind generation	Transmission system operators: http://www. 50Hertz.com, http://www.amprion.de, http://www.transnetbw.de, http://www.tennettso.de
Forecast error solar	Day-ahead prognosis minus extrapolation of the actual solar generation	Transmission system operators: http://www. 50Hertz.com, http://www.amprion.de, http://www.transnetbw.de, http://www.tennettso.de
Forecast error load	Day-ahead prognosis minus extrapolation of the actual electricity load	European network of transmission system operators: https://transparency.entsoe.eu/
Outage	Unplanned power plant outages occurring after day-ahead nomination	European energy exchange transparency platform: http://www.eex-transparency.com/de
Explicit net import	Net import via explicit intraday cross-border nominations	European network of transmission system operators: https://transparency.entsoe.eu/
Implicit net import	Net import from intraday trades with buyer (seller) in Germany and seller (buyer) in another country	Entelios GmbH

SB: System balance

balancing group (Section 2.2). This behavior should ceteris paribus lead to an increase of the intraday prices. The regression lines show a non-linear relation between the variables. High absolute SBs have a disproportionate impact on the price deviation between intraday and day ahead prices, which applies especially for the tails of the distribution. The reason might be the shape of the merit order. The supply function exhibits strong convexity and is sharply increasing at high and low price levels (Geman and Roncoroni, 2006; Karakatsani and Bunn, 2008; Kyritsis et al., 2017). At these prices, an additional demand for flexibility causes higher price jumps. This effect also applies for the merit order of balancing reserve activations. So, higher absolute SBs are associated with disproportionate imbalance prices and cause a higher incentive to use the intraday market for portfolio balancing.

During gate opening of the trading period for an associated product, market participants cannot know the actual SB for the period. Nonetheless, the latest published SB is a valuable information close to gate closure, because the SB has a strong autocorrelation (Kiesel and Paraschiv, 2017; Maskos, 2017). If market participants use the latest published information for own portfolio optimization, the correlation should be highest with this SB. Considering the observed non-linear relation, Figure 4 shows the Spearman correlation coefficients of different lagged SBs and the intraday prices of trades close to gate closure referred to the day-ahead price. We analyzed trades within the last 4.35 min to gate closure (left side) and also between 19.35 and 15 min (right side) to see whether market participants also react earlier to the published SB. For both intervals, the correlation coefficient is significantly highest on a 0.99 confidence level for the latest published SB. This is 60 and 75 min before delivery, respectively. Based on this analysis, H_1 is accepted.

4.2. Quantile Regression Model

The analysis in Section 4.1 has shown a significant positive Spearman correlation coefficient between the SB and the difference between intraday prices close to gate closure and the day ahead price. The maximum for trades between 4.35 and 0 min to gate closure was for the SB 60 min before delivery. We further analyze this relation with the quantile regression model described in equation (5). Besides the lagged SB, we consider wind, solar and load forecast deviations, power plant outages and explicit and implicit net import as control variables in our model. Table 3 presents the estimation results at different quantile levels. The explanatory power measured by the pseudo R-squared (Koenker and Machado, 1999) is in the range of 0.16-0.23. So, the model fit is too low to make predictions on the deviation between intraday prices closes to gate closure and day-ahead prices, but there are still regressors with coefficients significantly different from zero.

The forecast errors for wind and solar are significant on a 1% level all coefficients show the expected sign. The price impact for both variables is higher on the tails of the distribution, which can be explained with the shape of the merit order as described in Section 4.1. In accordance with the findings of Hagemann (2015), the price impact is lower for solar than for wind. A forecast error of 1 GW for wind leads to a price change between 1.7 and 2.5 €/MWh, whereas the same forecast error for solar influences the prices only

Figure 4: Spearman correlation of the intraday prices of trades close to gate closure referred to the day-ahead price and lagged system balances

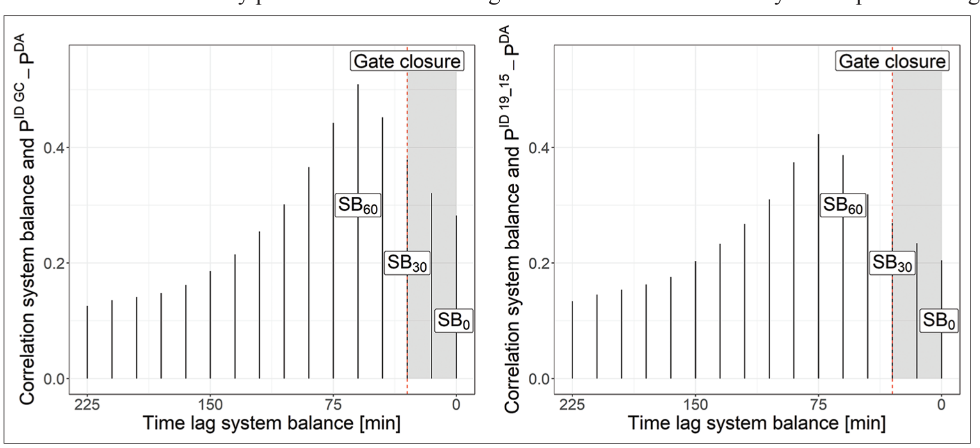


Table 3: Estimation results of the quantile regression model shown in Equation (5)

Quantile	0.05	0.1	0.25	0.5	0.75	0.9	0.95
Intercept	**−19.16**	**−14.61**	**−8.37**	**−2.23**	**3.96**	**10.96**	**16.03**
Wind	**$2.27\cdot10^{-03}$**	**$1.98\cdot10^{-03}$**	**$1.73\cdot10^{-03}$**	**$1.70\cdot10^{-03}$**	**$1.86\cdot10^{-03}$**	**$2.19\cdot10^{-03}$**	**$2.50\cdot10^{-03}$**
Solar	**$5.50\cdot10^{-04}$**	**$4.78\cdot10^{-04}$**	**$5.03\cdot10^{-04}$**	**$4.73\cdot10^{-04}$**	**$6.43\cdot10^{-04}$**	**$8.24\cdot10^{-04}$**	**$9.98\cdot10^{-04}$**
Demand	**$3.88\cdot10^{-04}$**	**$2.31\cdot10^{-04}$**	**$1.13\cdot10^{-04}$**	$-3.92\cdot10^{-05}$	**$-2.45\cdot10^{-04}$**	**$-6.01\cdot10^{-04}$**	**$-8.97\cdot10^{-04}$**
Outages	$-1.28\cdot10^{-04}$	$2.98\cdot10^{-05}$	$1.89\cdot10^{-05}$	**$-2.16\cdot10^{-04}$**	**$-3.13\cdot10^{-04}$**	**$-4.98\cdot10^{-04}$**	$-4.41\cdot10^{-04}$
Net $Import_{expl}$	**$6.93\cdot10^{-04}$**	**$3.53\cdot10^{-04}$**	$-6.91\cdot10^{-05}$	**$-4.63\cdot10^{-04}$**	**$-9.04\cdot10^{-04}$**	**$-1.52\cdot10^{-03}$**	**$-1.83\cdot10^{-03}$**
Net $Import_{impl}$	**$1.48\cdot10^{-03}$**	**$1.52\cdot10^{-03}$**	**$1.78\cdot10^{-03}$**	**$2.10\cdot10^{-03}$**	**$2.56\cdot10^{-03}$**	**$3.09\cdot10^{-03}$**	**$3.60\cdot10^{-03}$**
SB60	**$2.16\cdot10^{-02}$**	**$1.86\cdot10^{-02}$**	**$1.54\cdot10^{-02}$**	**$1.36\cdot10^{-02}$**	**$1.22\cdot10^{-02}$**	**$1.20\cdot10^{-02}$**	**$1.12\cdot10^{-02}$**
$(SB60)^2$	**$-1.27\cdot10^{-05}$**	**$-8.53\cdot10^{-06}$**	**$-4.13\cdot10^{-06}$**	**$-1.49\cdot10^{-06}$**	**$1.33\cdot10^{-06}$**	**$4.83\cdot10^{-06}$**	**$9.07\cdot10^{-06}$**
$(SB60)^3$	**$3.57\cdot10^{-09}$**	**$2.23\cdot10^{-09}$**	**$9.60\cdot10^{-10}$**	**$5.60\cdot10^{-10}$**	**$1.18\cdot10^{-09}$**	**$2.53\cdot10^{-09}$**	**$4.97\cdot10^{-09}$**
R^2 adjusted	0.232	0.209	0.187	0.173	0.159	0.161	0.173

Bold numbers indicate significance on a 1% level. All other parameters are not significant on a 5% level. SB: System balance between 0.47 and 1 €/MWh. Considering the fact that electricity is a homogenous good, a one MW trade in the intraday market caused by any driver can be expected to have a similar effect on the price. One reason for the difference might be that forecast errors are traded only partly on the market and by different portfolio owners. Market participants can match opposing positions within their portfolio or use own flexible assets to balance deviations and trade only net imbalances. Moreover, solar generation is mostly during peak hours. The higher liquidity during these hours may cause a lower price effect of forecast deviations (Hagemann and Weber, 2013).

The coefficients for demand are only partly significant and do not show the expected signs at every quantile level. Looking at the forecast error for demand, there are two possible reasons. First, system operators do not get temporal measurements of all loads. The electricity demand of small customers is estimated based on standard load profiles, which makes it more difficult to predict the forecast deviations. Therefore, a part of the deviation can be part of the SB, which causes a price impact in itself. Second, there are different calculation methods for forecasted and actual demand. The forecast is the TSO's prognosis of the total load. The actuals are an extrapolation based on power plant schedules. The different approaches might lead to an imprecise calculation of the forecast deviation.

Power plant outages are the only variable that is predominantly insignificant even though previous studies found a significant effect on hourly intraday prices (Hagemann, 2015; Valitov and Maier, 2017). The reason might be a problem with the data. According to the Regulation on Wholesale Energy Market Integrity and Transparency, power plant operators must report (unplanned) outages even if the power plant was not running before (European Parliament, 2011). This might reduce the validity of the data.

There is also a significant relation between implicit net imports and the price development on the intraday market. This is in contrast to Hagemann (2015), who found no significant influence of German-French intraday trades for his market analysis of 2010 and 2011. During the period of our analysis, the coefficients are between 1.48 and 3.6 €/MWh per GW. It is more attractive for foreign assets to sell volumes to German market participants when the price level is high and to buy volumes from Germany when the price level is low. This indicates that the implicit net imports are an endogenous result of the price movements on the intraday market.

The signs of the coefficients for explicit imports are positive for low quantiles and negative for high quantiles. The interpretation of the coefficients is difficult. We assume a complex interaction of endogenous and exogenous effects, defined by the differing generation mix in Germany versus its neighboring countries. For example, in high quantiles peak power plants in neighboring countries could make use of the high price level and sell their physical flexibility. The imports dampen the price move. On lower quantiles and thus prices the effect seems endogenous, so that rising price levels increase the amount of imports.

Looking at the significance of the coefficients, a consideration of the aforementioned control variables is necessary to determine the impact of the lagged SB on intraday trades. The model results show a significant relation with the independent variable for the three polynomial variables on all quantile levels. Therefore, H_2 is accepted. It can be assumed that market participants react to the publication of the lagged SB by adapting their imbalance positions. If the SB is assumed to be short, market participants buy energy on the intraday market leading to higher prices and vice versa. This behavior can either reduce their own imbalance (if the portfolio is unbalanced congruent to the system) or even increase it (if the portfolio was in balance or unbalanced opposed to the system). The financial benefit of the intraday position itself and the effect on the SB is the same for both situations and only depends on the actual SB.

The price effect of the lagged SB is not linear as the quadratic and cube parameter are significant for all quantile levels. Higher absolute SBs have a stronger impact on intraday price movements. Reasons might be the convex merit order of flexible assets on the intraday market and the higher price incentives that are associated with high absolute SBs (compare Section 4.1).

To illustrate the meaning of the lagged SB, we also run a model only considering all other parameters. Its pseudo R-squared was between 0.07 and 0.09. Adding just the lagged SB as a third degree polynomial improves the model accuracy by up to 195%. This indicates that the SB is the most important predictor to estimate intraday price movements close to gate closure. It provides more explanatory power than just the forecast deviations the BRPs must compensate.

5. IMPACT OF PASSIVE BALANCING ON SB

Section 4 has shown the statistical evidence that market participants use the information of the latest published SB to optimize their portfolio by adapting their imbalance position. This section analyses the effect of this behavior on the system stability.

5.1. Approximation of Passive Balancing Volumes

To estimate the impact of passive balancing, we compare the actual SB with a hypothetical SB that would have prevailed without passive balancing ($SB^{\text{No PB}}$).

$$SB_t^{No\ PB} = SB_t - Vol_t^{PB} \tag{6}$$

A calculation method is required to estimate the passive balancing volumes. Intraday trades are published anonymously. There is an information about the TSO area of buy and sell party, but not about the specific balancing group. Therefore, it is not possible to analyze the behavior of single market participants looking for the potential intention of the position.

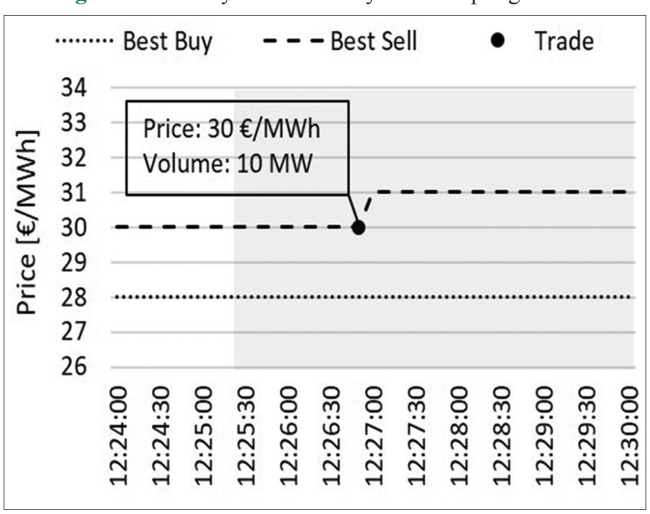
Instead, we estimate the effect by considering all quarter-hourly intraday trades close to gate closure, when market activity is highly affected by the reaction to the latest published SB (Section 4). The underlying assumption is that a trade close to gate closure is associated with a physical influence on the system. This might not always be the case, as some trades might be of speculative nature aiming to capture price moves.

Asset owners have well specified costs which are defined by their short-term marginal generation costs and ramping constraints. They are reflected in the prices of their limit orders. So, the order book represents the flexibility offer given a certain price level (plus noise due to speculative orders, which could increase traded volumes). However, portfolio managers are price takers on the intraday market if they are not able to compensate the imbalance of their portfolios by adapting the operation of a physical asset. Their opportunity costs are defined by the imbalance price, which justifies to pay the bid-ask-spread as long as the price(s) of the best limit order(s) are better than the expected imbalance price. The same applies for market participants who want to use the financial incentive of the system by taking an intentional imbalance. So, the aggressor of a limit order changes the position only financially via trading, whereas the opposite part adapt the operation of a flexible asset, which changes the SB. If the sell side is the aggressor of a trade (Vol^{Sell}), the counterpart is assumed to be a generation unit ramping down or a consumption unit ramping up. The system gets shorter. If the buy side is the aggressor (Vol^{Buy}), the system gets more oversupplied. The passive balancing volume is the net position of both volumes.

$$Vol_t^{PB1} = Vol_t^{Sell} - Vol_t^{Buy} \tag{7}$$

Comparing the price of a trade with the best sell and buy order at this time shows whether the sell or buy side is the aggressor of the trade. Figure 5 illustrates the approach with an example of one trade of 10 MW within the last 4.35 min to gate closure. The buy side forced the trade. So, Vol^{Buy} is 10 MW and Vol^{Sell} is 0 MW. The passive balancing volume is −10 MW. The whole calculation approach is illustrated in Table 4 for the quarter-hour from 12:45 am to 1:00 pm of April 24, 2016. On average, the net trading volume per quarter hour is 35 MW for the analyzed period (January 1, 2016 to September 30, 2018) considering the last 4.35 min and 70 MW considering the last 19.35 min before gate closure.

Figure 5: Intraday trade with buy side accepting sell bid



5.2. Comparison of System Stability Indicators

The result of the approach described in Section 5.1 is a time series of a hypothetical SB that would have prevailed without trading close to gate closure, which we use as an approximation to estimate the effect of passive balancing (Equation 6). We compare it with the actual SB to assess the impact on system stability by analyzing two indicators. The total absolute SB reflects the activation of balancing reserves. It is possible that TSOs must activate positive and negative balancing reserve within one quarter-hour. In this case, the SB is the net position of both. Therefore, it does not equal the amount of the total balancing reserve activation. But a lower total absolute SB is an indication for a reduced balancing demand. High absolute SBs are another important indicator as they determine the level of procured balancing reserve. We consider the effect on the 95th percentile of the SB.

Table 5 shows for both indicators the difference of the calculation for the actual SB and the SB without intraday trading close to gate closure. Thus, negative numbers mean that intraday trading has a positive impact on the system stability. Our analysis indicates that trading within the last 4.35 min to gate closure causes a reduction of the total absolute SB of 1.78% and of the 95th percentile of 1.66%. These numbers are an upper limit for the effect of this trading period, as not every trade close to delivery has a physical influence on the SB and is done because of passive balancing. However, market participants already react earlier to the SB as the analyses presented in Figure 4 suggests. A second calculation shows the effect of trading of the last 19.35 min, which is directly after publishing the SB of 75 min before delivery. The positive influence enlarges to a reduction of 5.3% for both indicators. So, our analyses indicate that intraday trading close to gate closure is strongly influenced by the information of the SB and it reduces balancing needs.

5.3. Overshooting of SB

Critics of passive balancing argue it can lead to an overshoot of the SB. If the market participants react too strong by trying to be on the opposed side of the SB, the SB swings to the other direction. To our understanding, this is only critical, if an overreaction leads to high positive or negative SBs.

We analyze empirical data to study whether overshooting is a problem in Germany or not. For the period from 2012 to the end of September 2018, we identify situations, when the SB exceeds a threshold in positive and negative direction within 2 h (Figure 6). Our threshold for a strong overshoot is an absolute value 1000 MW, which is approximately the 95th percentile of all SBs between 2016 and the end of September 2018. The threshold for

Table 4: Example calculation of SB without passive balancing as described in equations (7)

Date time	April 24, 2016 12:45 am – April 24, 2016 1:00 pm		
Actual SB	Sell volume	Buy volume	SB without passive balancing
−1580.67 MW	327.8 MW	20.1 MW	−1888.37 MW

SB: System balance

a critical overshoot follows a definition of the German regulator. If the TSOs must activate 80% of the procured aFRR and mFRR within one quarter-hour, the imbalance price gets an additional surcharge (Bundesnetzagentur, 2012). The minimum amount of procured aFRR and mFRR is 2518 MW for the considered period. So, 2000 MW represent an 80% share.

The empirical analysis shows that the number of strong overshoots declines from 2012 to 2014 (Table 6). One important reason for the reduction is the increased use of the quarter-hourly intraday market. Previously, portfolio management was done mostly in hourly resolution leading to systematic activations of positive and negative balancing reserves within 1 h (Remppis et al., 2015; Koch and Hirth, 2019). This was most critical in the morning and in the evening when load and solar energy generation change strongly within 1 h (Kiesel and Paraschiv, 2017; Märkle-Huß et al., 2018). Therefore, strong overshoots did not happen because market participants actively took a position on the market, but because of a lack of active intraday trading. The number of situations with strong overshoots remains on a constantly low level after 2014. A critical overshoot never happened between 2012 and September 2018.

Figure 6: Example of system balance on April 15, 2017 from 08:30 to 10:30 am. The system balance swings from – 1600 MW to +1900 MW within 2 h. This is considered as a strong, but not a critical overshoot

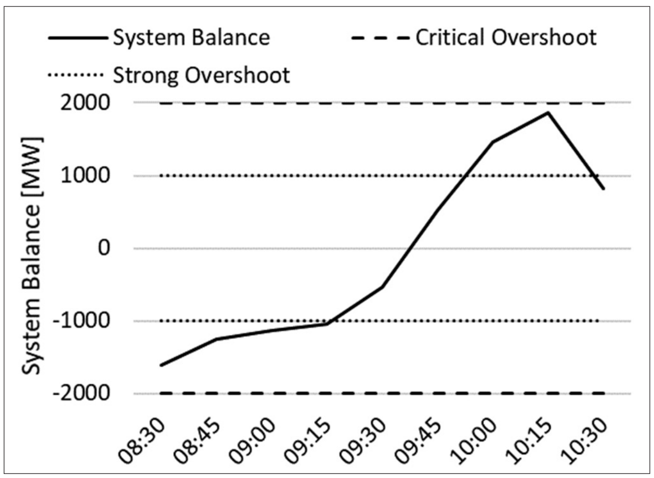


Table 5: Impact of intraday trading close to gate closure on system stability. It reduces the sum of absolute SBs and its 95th percentile leading to a reduction of balancing reserve activation and procurement

Time period	Last 4.35 min	Last 19.35 min
Total absolute SB	−56.7 GWh/a	−172 GWh/a
	−1.78%	−5.39%
Absolute $SB_{0.95}$	−16.0 MW	−50.8 MW
	−1.66%	−5.28%

SB: System balance

To identify the impact of passive balancing on overshooting, we use the same approach as described in Section 5.1. We approximate the hypothetical SB without the net position of intraday trading close to delivery. We did the calculation both for the period of the last 4.35 min and for the last 19.35 min to gate closure. The analyzed time series show no critical overshoot, but a slightly higher number of situations with a strong overshoot.[3] So, the results suggest that intraday trading close to gate closure has a positive impact on overshooting even though the market participants react to the SB. The concerns of overshooting are currently unfounded.

5.4. Effect of Stronger Reactions to the SB

The analyses in Section 4 indicate that at least a part of market participants reacts to the information of the latest published SB. Assuming that some of them are doing so by taking intentional imbalances, we analyze what would happen, if more market participants would follow the underlying price incentive. This is done by assessing the impact of a doubling of the net intraday trading volumes on the previously introduced system stability indicators. We apply again the calculation method explained in equation (7) on the two time periods of the last 4.35 and 19.35 min to gate closure. The results show a positive impact on the total absolute SB and a reduction of high absolute SB for both cases (Table 7). There is a minor influence on situations with a strong overshoot (threshold 1000 MW) and still no situation with a critical overshoot of the system (threshold 2000 MW).

These numbers are a conservative estimate of the actual effect, because a pure doubling of the net volumes does not consider the potential reaction of the market participants on the new SB. However, the analysis indicates that additional reactions to the price incentive has the potential to further reduce the activation and procurement of balancing reserves without leading to a critical overshoot of the system.

3 The calculation is only done for the same period as for the other analyses of the intraday market (01/01/2016 to 30/09/2018).

Table 6: Overview of strong and critical overshoot (threshold 1000 MW and 2000 MW) between 2012 and September 2018. Overshoot means that the SB exceeds the threshold in positive and negative direction within 2 h

Year	Actual SB		SB without intraday trading close to gate closure			
	Strong overshoot	Critical overshoot	Strong overshoot		Critical overshoot	
			4.35 min	19.35 min	4.35 min	19.35 min
2012	166	0				
2013	67	0				
2014	22	0				
2015	14	0				
2016	6	0	8	9	0	0
2017	15	0	18	23	0	0
Q1-Q3 2018	14	0	13	17	0	0

SB: System balance

Table 7: Impact of a doubling of the net trading volume on system stability indicators

Time period	Last 4.35 min	Last 19.35 min
Total absolute SB	−16.3 GWh/a −0.52%	−30.8 GWh/a −0.97%
Absolute $SB_{0.95}$	−2.26 MW −0.23%	−8.31 MW −0.86%
Number of additional strong overshoot 2016-2018	+6	-2
Number of additional critical overshoot 2016-2018	0	0

SB: System balance

6. DISCUSSION

The analyses presented in Section 4 show a significant correlation between the intraday price level close to gate closure compared to the day ahead price and the latest published SB. This indicates that portfolio managers react to that information due to the incentive of the imbalance price. This inducement does not depend on the actual imbalance of the portfolio. It is solely a comparison of the current intraday price and the expected imbalance price. Therefore, it is likely that a part of the intraday positions is coming from market participants taking intentional imbalances that are opposed to their expectation of the SB. However, further research is required to show whether this assumption holds as it needs an analysis of single balancing groups including their initial position and the forecast of their portfolio. Essl (2018) was able to study such data for Austria and concludes that BRPs, who take intentional imbalance positions, stabilize the system. If this is confirmed by further research, the regulator should consider to allow intentional imbalance positions. The analysis of Section 5.4 shows that additional reactions to the imbalance price incentive can further stabilize the system.

Several European countries already follow this approach. The Netherlands early trusted in the mechanics of passive balancing. The local TSO TenneT stated already in 2011 that passive balancing enables a reduction of SBs (TenneT, 2011). Another example is the Belgian market, where passive balancing is expected to reduce the required activation of balancing reserve (Zapata Riveros et al., 2015). According to Belgium's TSO Elia, this is crucial to incentivize investments in system flexibility by market participants and to minimize residual imbalances (Elia, 2013). In the United Kingdom, traders without physical generation are allowed to trade in the intraday market for profit and furthermore to have imbalance positions (Elexon, 2016).

An efficient reaction to imbalance price incentives requires a timely publication of the relevant data (Hirth and Ziegenhagen, 2015; Joos and Staffell, 2018). In the Netherlands, TenneT provides the information about the activated energy for upward and downward regulation for every minute with a delay of 2 min (TenneT, 2019). Similarly in Belgium, ELIA publishes a live value of the current system imbalance and activated reserves as well as estimated activation costs per minute (Elia, 2019a). System imbalances and prices per settlement period are then published a few minutes after the end of the settlement period (Elia, 2019b). In the United Kingdom, ELEXON goes as far to publish activations whenever it accepts a bid or offer in its balancing mechanism, thus giving the market participants information even for upcoming settlement periods (Elexon, 2018).

In contrast to the aforementioned examples, German TSOs publish only the SB of a whole quarter-hour with a delay of almost 11 min. We recommend to reduce the delay for publishing the SB also in Germany in order to give the market participants the best information for portfolio optimization. The TSOs must evaluate upfront an appropriate publication time to keep the necessary quality of the data. A timely publication would also help with regards to market transparency. Currently, providers of FRR have an advance in information, because they have an accurate indication of the current SB through their balancing reserve activations. Thus, they can use this advantage for a better forecast of the SB and a faster reaction to the intraday market to get better prices. This would diminish with a faster publication as provided by the above mentioned foreign TSOs and lead to an increase of transparency among market participants.

7. CONCLUSION

The analyses presented in this paper indicate that BRPs react to imbalance price incentives to financially optimize their own portfolio. In a first step, we applied a correlation analysis between the price deviation from quarter-hourly intraday prices close to gate closure to the corresponding quarter-hourly day-ahead prices and different lagged SBs. There is a positive correlation between those parameters which means that intraday prices rise with a shortage in the system. The highest correlation coefficient was found for the latest published SB being an indication that market participants use this information to adapt their imbalance position by intraday trading. In a second step, we run a regression models to estimate different quantiles of the price deviation between quarter-hourly intraday and day-ahead prices. The model accuracy increases by up to 195% when adding the latest published SB to a model considering only fundamental parameters as regressors. This indicates that the SB is the most important predictor to estimate intraday price movements close to gate closure. It provides more explanatory power than just the forecast deviations the BRPs must compensate. The price effect of the lagged SB is not linear. Higher absolute SBs have a stronger impact on intraday price movements. Reasons might be the convex merit order of flexible assets on the intraday market and the higher price incentives that are associated with high absolute SBs.

So, the intraday trading close to gate closure is highly affected by reactions to the SB. If the SB is assumed to be short, market participants buy energy on the intraday market and vice versa. This behavior is called passive balancing and can either reduce their own imbalance or even increase it. The financial benefit of the intraday position itself and the effect on the SB is the same for both situations. Nonetheless or precisely for that reason, intraday trading close to gate closure has a positive impact on balancing demand and supply. It reduces both the required balancing energy and high SBs up to 5%. Our analyses also show that this behavior did not cause situations with a critical overshoot of the SB. In fact, it could even diminish strong overshoots of the SB. Under the current status, there is still room for more reactions to the SB. According to our calculation, doubling the observed net intraday volumes within the last minutes of trading leads – without consideration of any feedback effects – to a small reduction of balancing demand and high SBs without causing critical overshoots.

Reacting to the latest published SB could be even more efficient with an earlier publication of that information. The German TSOs normally publish the SB of a whole quarter-hour approximately after 11 min, whereas the Dutch and Belgian TSO provide the information about the activated balancing reserve energy within every minute with a delay of 2 min. The German TSOs should consider to adapt such an approach for increased efficiency in balancing activities. It can help market participants to better estimate the SB in order to prevent overshooting and reduce balancing reserve activations. Moreover, it would help to reduce the advance in information for balancing reserve providers and increase transparency among market participants.

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