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ANALYSIS OF THE IMPACT OF IMBALANCE SETTLEMENT DESIGN ON MARKET BEHAVIOUR IN ELECTRICITY BALANCING MARKETS[*]

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Abstract
The imbalance settlement design is the part of an electricity balancing market design that stimulates so-called Balance Responsible Parties (BRPs) to balance their electricity production and consumption portfolio and to stick to their energy schedules by penalizing any deviations from these schedules with an imbalance price. There are numerous imbalance settlement design options, each of which gives different incentives to BRPs. The aim of this work is to analyze the impact of the imbalance settlement design on BRP behaviour, and thereby on balancing market performance. For this purpose an agent-based model has been built, in which the BRPs are the agents that decide autonomously in each round on their balancing strategy based on results in past rounds. Six alternative imbalance settlement designs are analyzed. We conclude from the analysis results that it is generally a better strategy for BRPs to opt for a long position rather than a short position, and to opt for a small imbalance rather than a large one. Furthermore, different imbalance settlement designs will lead to different but still similar results, because of the balancing market equilibrium that emerges as a result of the dynamic feedback loop between BRP behaviour and balancing market outcomes. An exception is formed by two-price settlement, which leads to much higher imbalance costs. Finally, it was found that the imbalance costs for large BRPs are relatively higher, and that the choice of imbalance settlement design has a greater impact on the behaviour of small BRPs.

I. Introduction

Balance management is the power system operation service that encompasses the continuous balancing of power supply and demand, or production and consumption. We define the ‘balancing market’ to be the institutional arrangement that establishes market-based balance management in a deregulated electricity market. A balancing market consists of three main pillars: balance responsibility, balancing service provision, and imbalance settlement. Balancing service provision concerns the provision of balancing services by market participants, and the activation of such services by the Transmission System Operator (TSO) for the real-time restoration of the system balance. Balance responsibility involves the submission of energy schedules by so-called Balance Responsible Parties (BRPs) to the TSO, and imbalance settlement involves the financial settlement of schedule deviations with an imbalance price between the BRPs and the TSO. The Balance Responsible Party is a market party that has taken up the responsibility for balancing a portfolio of generation and/or consumption connections.

[*] This work was supported by the Next Generation Infrastructures Foundation, and part of the research project ‘Balance Management in Multinational Power Markets.

In the imbalance settlement process, which takes place after real-time, both the schedule deviations of BRPs and the imbalance prices are determined. The schedule deviations are the differences between the net planned electrical energy exchange with the power grid as specified in the energy schedule and the actual electrical energy exchange, which is measured in real-time. The imbalance prices are determined according to a certain pricing mechanism. Usually, they are based on the prices for upward and downward regulation, i.e. real-time balancing services. The main time unit used within the balancing market is the Program Time Unit (PTU). For each PTU, BRPs specify planned energy exchange, for each PTU the schedule deviations are determined, and for each PTU one or multiple imbalance prices are determined, depending on the imbalance settlement design. In case of multiple imbalance prices, BRPs with a surplus receive the 'long imbalance price' and BRPs with a shortage pay the 'short imbalance price', which can be considered as the selling and buying of 'imbalance energy'. The financial settlement of the imbalance costs, which are the product of schedule deviations (in MWh) and the relevant imbalance price (in €/MWh), takes place for a larger period at once (e.g. for an entire month), between the BRPs and the TSO.

In the balancing market, there is a main feedback loop between the behaviour of BRPs and balancing market performance, which is basically formed by system imbalance volumes and imbalance prices and costs. The net sum of the imbalance volumes of all the BRPs in a power system (who represent all production and consumption in that power system), determines the system imbalance. The size of the system imbalance determines the amount of upward and downward regulation that is activated to restore the system balance. This activation determines the imbalance prices, which form the incentives for BRPs to submit accurate energy schedules, and to stick to those schedules. Although there is always some unforeseen imbalance, BRPs are able to influence their imbalance volume by means of over- and under-contracting of energy before final gate closure, and by means of internal balancing in real-time [1]. The goal of this 'portfolio balancing' is usually to hedge against the financial risks of imbalance settlement, i.e. to limit imbalance costs, but it also possible that BRPs earn some profit. In short, as a result of changing imbalance prices, BRPs may adapt their balancing strategies, which affects the future imbalance prices again. This incentive mechanism is a core part of the balancing market.

Viewing the different existing options in imbalance settlement design, in particular the possible imbalance pricing mechanisms ([2], [3], [4]), the question arises what is the impact of different designs on balancing market performance. This question cannot easily be answered by comparison of balancing markets data of different countries, as there are usually too many other differences between countries [1]. Furthermore, simple assessments that do not take into account the dynamic feedback loop between BRP behaviour and balancing market performance are likely to be invalid. Therefore, we have built an agent-based model in MATLAB to analyze alternative imbalance settlement designs. In this model, BRPs are the agents that autonomously decide on their balancing strategies and learn from the impact that this has on balancing market results.

The goal of the work presented in this paper is not only to find the relative value of alternative imbalance settlement designs, but also to get more insight into BRP behaviour and into the functioning of the feedback loop between this behaviour and balancing market performance.

The structure of the paper is as follows. In Section II, a description of the agent-based model is given. Then, in Section III, the analysis itself is described, i.e. the model inputs and outputs. Next, the analysis results are presented and discussed in Section IV. Finally, the conclusions are listed in Section V.

II. Model description

In order to analyze the impact of imbalance settlement designs on balancing market performance, we have built a simplified agent-based model of the balancing market in MATLAB. In order to make the model as realistic as possible, we have dimensioned the input to the Dutch balancing market design and results. The main structure of the agent-based model is shown in Figure 1.

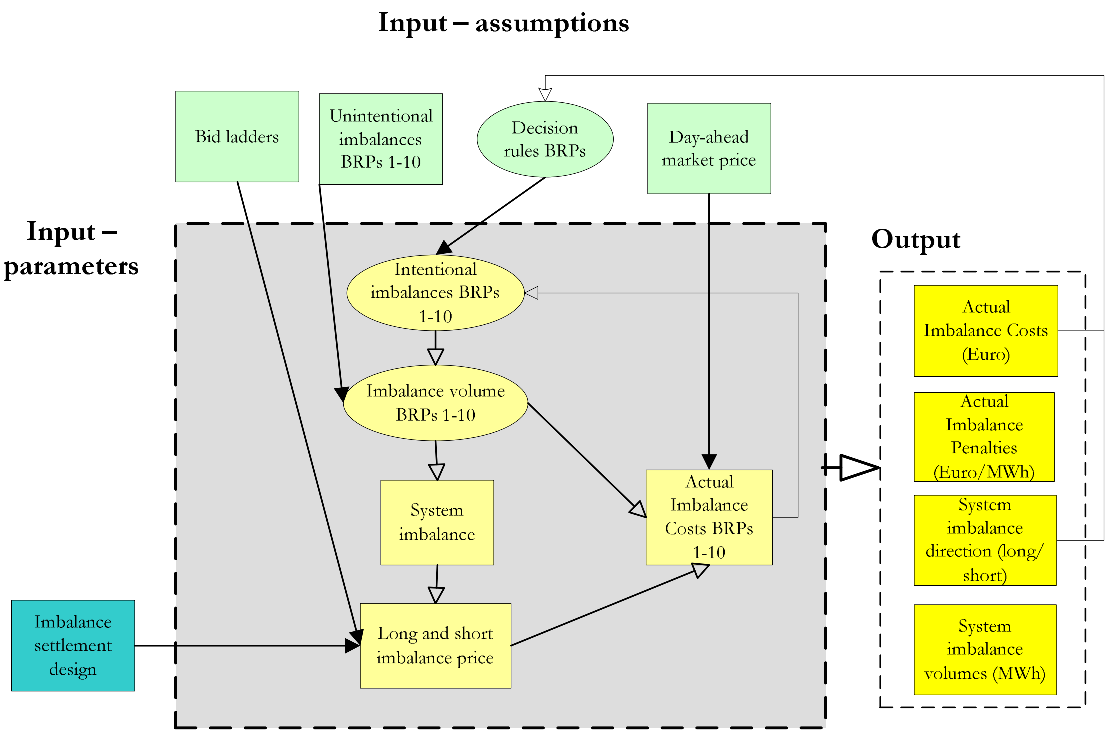


Fig. 1. Structure of the agent-based model of the balancing market

To start, we assume there are 10 BRPs with different portfolio sizes, namely 8000 MW, 6000 MW, 4000 MW, 3000 MW, 1000 MW, 900 MW, 800 MW, 600 MW, 500 MW, and 200 MW. Thus, the total portfolio size of the modelled balancing market is 25,000 MW, which is similar to the sum of generation and load in the Netherlands. Furthermore, the simulation run length is 1000 rounds, with each round equalling a PTU of 15 minutes, as is the case in the Netherlands. Thus, the run length equals ca. 10.4 days.

Each BRP has for each round an unintentional imbalance (in MWh), which is calculated by multiplying the portfolio size with a forecast error. The forecast error is drawn from a normal distribution function with a mean of 0 and a standard deviation of 0.015. Furthermore, each BRP has to decide for each round on an intentional imbalance (in MWh), which is the only decision variable in the model. For each round, the BRPs have to decide between six 'options':

- Option 1: -0.02 * portfolio size
- Option 2: -0.01 * portfolio size
- Option 3: -0.005 * portfolio size
- Option 4: 0.005 * portfolio size
- Option 5: 0.01 * portfolio size
- Option 6: 0.02 * portfolio size

The combination of these possible intentional imbalances and the probability distribution function of the unintentional imbalance comes down to a 80% chance that options 1 & 6 are large enough to cover an unintentional imbalance in the opposite direction (given that this opposite direction occurred), a 50% chance that options 2 & 5 are large enough, and a 25% chance that options 3 & 4 are large enough. This combination has been arbitrarily chosen, but is considered to create a meaningful set of options for the BRPs.

The sum of the unintentional imbalance and the intentional imbalance of a BRP is his BRP imbalance. The net sum of all BRP imbalances determines the system imbalance (in MWh). Figure 2 shows what this looks like in the model (the black line represents the system imbalance). In addition, the sum of BRP surpluses (positive BRP imbalances) determines the 'market surplus' (in MWh), and the sum of BRP shortages (negative BRP imbalances) determines the 'market shortage'.

In the model, there are fixed bid ladders assumed for upward and downward regulation. These bid ladders consist of multiple regulation bids, with each bid containing a bid volume (in MW) and a bid price (in €/MWh). These bids are ranked in order of increasing bid price (upward regulation) or decreasing bid price (downward regulation). The bid ladders are based on bid data from the Netherlands in 2009. For each round, the activation of upward and downward regulation is derived from the market shortage and market surplus. In the model, it is assumed that resp. the required upward and downward regulation equals 25% of resp. the market shortage and market surplus (in MWh). As the bids are in MW, however, and bids are not fully activated at once, it is assumed that an equivalent of 2 MWh of bid volume needs to be activated to deliver 1 MWh of actual balancing energy. Finally, if the required regulation in one direction is smaller than 0.75 of the required regulation in the other direction, the first (regulation in the 'minor direction') is set to zero. This has led to an around 17% occurrence of both upward and downward regulation activation, which is half of the occurrence of two-sided regulation in the Netherlands in 2009.

Based on the activation of upward and/or downward regulation, and on the assumption that marginal pricing is used for the settlement of regulation bids (as is the case in the Netherlands), two imbalance prices are determined for each round, applying the specific imbalance pricing rules given by the imbalance settlement design. These are an imbalance price for BRP surpluses, the 'long imbalance price', and an imbalance price for BRP shortages, the 'short imbalance price'. The analyzed alternative imbalance settlement designs are introduced in Section III.

After the imbalance prices and the BRP imbalances for the specific round are known, the Actual Imbalance Costs (AIC) for each BRP can be calculated. Although the settlement involves, as said above, the payment of the imbalance price for each MWh of imbalance, the actual penalty can be estimated by the difference between the imbalance price and the day-ahead spot price, as we can assume that the imbalance could have been prevented by trading on the day-ahead market. Thus, the AIC reflect the opportunity costs of leaving an imbalance. The AIC is calculated for each round, and for each BRP, according to Equation (1).

$$AIC_{n,m} = \begin{cases} (P_{si,m} - P_{da,m}) * IV_{n,m} & \text{if } IV_{n,m} < 0 \\ (P_{da,m} - P_{li,m}) * IV_{n,m} & \text{if } IV_{n,m} > 0 \\ 0 & \text{if } IV_{n,m} = 0 \end{cases} \qquad (1)$$

In this equation, $AIC_{n,m}$ are the actual imbalance costs for BRP n in round m, P_{si} is the 'short imbalance price' applied to BRP shortages, P_{li} is the 'long imbalance price' applied to BRP surpluses, P_{da} is the day-ahead spot price, and $IV_{n,m}$ is the imbalance volume of BRP n in round m.

To be able to calculate the AIC, the day-ahead market price must thus be known. This price has been set at 36 €/MWh, which was about the average day-ahead spot price for the Netherlands in 2009. This price lies on purpose below the upward regulation bid prices and above the downward regulation bid prices, as this is usually the case in reality.

A crucial model assumption relates to the decision rules the BRPs apply to choose a specific option (intentional imbalance) in each round, i.e. the decision-making algorithm. We have assumed the following. For each option, each BRP calculates an 'expected AIC'. This expected AIC is calculated following equation (2).

$$E(AIC)_{n,X} = p_{n,X,short} * avAIC_{n,X,short} + p_{n,X,long} * avAIC_{n,X,long} \qquad (2)$$

In this equation, $E(AIC)_{n,X}$ is the expected AIC for BRP n for option X, $p_{n,x,short}$ is the probability that the system is short given that BRP n chooses for option X, $p_{n,x,long}$ is the probability that the system is long given that BRP n chooses for option X, $avAIC_{n,x,short}$ is the average AIC of BRP n of past rounds in which he chose for option X and the system was short, and $avAIC_{n,x,long}$ is the average AIC of BRP n of past rounds in which he chose for option X and the system was long.
Thus, the expected AIC for each option is calculated taking into account the likelihood of occurrence of both system imbalance directions. This is because the system imbalance has a large influence on the imbalance prices, as becomes clear from the description of the different imbalance settlement designs that are analysed (see Section III). Moreover, with this equation the BRPs take into account that their choice for an intentional imbalance has an impact on the system imbalance.

For the calculation of the average AIC values, a recency parameter has been included (see e.g. [5]), so that the results of more recent rounds weigh heavier in the decision-making of the BRPs. The recency parameter has been set to the value of 0.9.

The final choice of a BRP for a specific option occurs through a draw from a probability distribution function, with probabilities based on the relative size of expected AIC for the six different options. We have opted for this, because choosing the option with the minimum expected AIC leads to the same BRPs selecting the same options time and time again, which creates biased actual imbalance costs for individual BRPs. We could say that the BRPs keep on experimenting (and being partly irrational), while they also keep on learning from the results of past rounds and make decisions based on those results.

III. Analysis

Six different imbalance settlement (IS) designs have been analyzed in this model. These are represented by six cases. Case 1 is the reference case, from which the five other cases have been adapted. The cases are described below.

- Case 1: *Single pricing.*
  The ‘long imbalance price’ (imbalance price applied to BRP surpluses) and the ‘short imbalance price’ (imbalance price applied to BRP shortages) are identical, namely the marginal regulation price in the main regulation direction[1]. BRPs with a surplus receive this price, and BRPs with a shortage pay this price.
- Case 2: *Two-price settlement*
  The imbalance price for BRP imbalances in the direction opposite to the system imbalance is still based on the marginal regulation price of the main regulation direction, but the other imbalance price is equal to the day-ahead market price. This means that the day-ahead market price is applied to the BRPs who passively contribute to reducing the system imbalance (are helping the system).
- Case 3: *Dual pricing*
  If both upward and downward regulation are activated, the ‘short imbalance price’ is the upward regulation price and the ‘long imbalance price’ is the downward regulation price. If regulation occurs in only one direction, single pricing is applied.
- Case 4: *Alternative payment direction*
  The ‘long imbalance price’ is still applied to BRP surpluses and the ‘short imbalance price’ to BRP shortages, but the direction of payment changes. Normally, BRPs pay the when they are short and receive when they are long; in this case they receive when the BRP imbalance is opposite to the system imbalance (i.e. when the BRPs help to balance the system) and they pay when the BRP imbalance is in the same direction (i.e. when the BRPs partially cause the system imbalance).
- Case 5: *Imbalance pricing based on total costs*
  In this case, the imbalance price is not based on the marginal regulation price, but on the total balancing costs, i.e. the total costs for the TSO of all the activated balancing bids in both regulation directions. It is assumed that marginal pricing is used for settlement of the balancing bids. The imbalance price, which is the same for both imbalance directions, is calculated by dividing the total balancing costs (in Euro) by the net activated balancing energy (in MWh). Finally, imbalance price limits are set, which are equal to the marginal upward and downward regulation price.
- Case 6: *Incentive component*
  For the PTUs in which the system imbalance is larger than 50 MWh, an incentive component of 5 €/MWh is added to the long imbalance price and subtracted from the short imbalance price, turning the single pricing regime into a dual pricing regime.

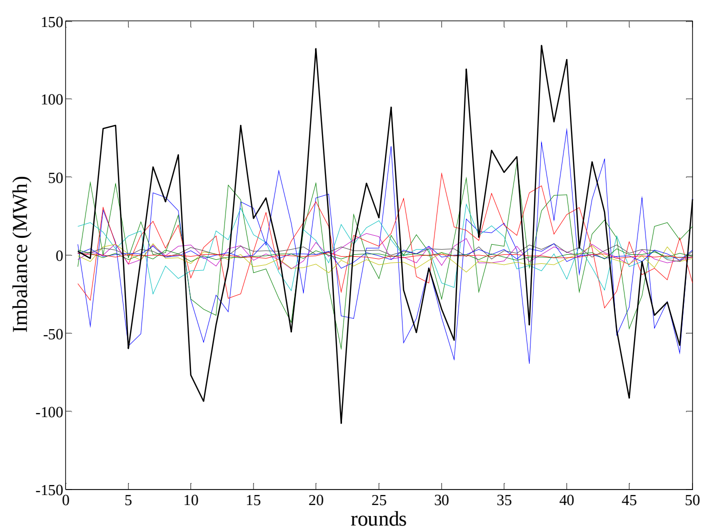
[1] The main regulation direction is upward when there is a negative system imbalance (system shortage), in which case the imbalance price under the single pricing regime is equal to the upward regulation price of the marginally activated upward regulation bid. When there is a system surplus, the imbalance price is the marginal downward regulation price.

The above IS designs are based on existing designs in European balancing market. Single pricing is applied in e.g. Spain and Greece [2]. Two-price settlement is applied in the Nordic region. Dual pricing and an incentive component are applied in the Netherlands [3]. Dual pricing is there only active when a specific ‘regulation state’ has occurred, however, which was only about 10% of the time in 2009. Imbalance pricing based on total costs is applied in Germany. However, Germany applies pay-as-bid pricing to the pricing of regulation bids, which results in lower imbalance prices, compared to case 5 in our analysis. An alternative payment direction is to our knowledge not applied anywhere, but is an interesting hypothetical design.

The most important indicators for balancing market performance in relation to imbalance settlement are the total Actual Imbalance Costs (Euro) aggregated for all BRPs and all rounds, and the average AIC for different intentional imbalance options, in order to compare their relative value. Furthermore, the Actual Imbalance Penalty (AIP) (Euro/MWh) is also of interest. The AIP for BRP surplus indicates the average costs of having a 1 MWh surplus as a BRP, and is calculated as the average of the day-ahead market price minus the long imbalance price over all rounds. The AIP for BRP shortage is calculated as the average of the short imbalance price minus the day-ahead market price over all rounds. This is similar to the calculation of the AIC, see equation (1). The AIC and AIPs are of importance for the economic evaluation of the different cases. In order to evaluate security of supply, the average system surplus (MWh), the average system shortage (MWh), and the occurrence of system surplus (%) and occurrence of system shortage (%) are useful indicators. In Section IV, we will compare the outcomes of the different cases on the basis of these indicators. Imbalance prices will not be given, as these prices do not reflect the actual costs of imbalance. However, the average imbalance prices can easily be derived by adding/subtracting the day-ahead market price to/from the AIP.

To obtain the results as presented in section IV, five runs of the agent-based model have been executed per case, and the averages of the results of those runs have been taken. This way, the results are more likely to be representative. Furthermore, we have noted the similarity in the results of different runs, which forms a verification check of the model, and proves that the results are consistent.

Fig. 2. Build-up of the system imbalance from the BRP imbalances



IV. Results

The results of the analysis of the six different imbalance settlement (IS) designs, represented by the different cases, are summarized in Table 1. We will start the discussion with a first brief comparison of the results. Next, we will discuss the results of case 1, which is the reference case, and then continue to discuss the other cases by comparing the results with those of case 1. After that, we will look into the BRP-specific results, which can provide insight into the importance of the portfolio size for the impact of IS design on performance from a BRP perspective. Last, we describe the gained insight in the 'balancing market equilibrium' that we have observed in the simulation.

A. First overview of results

Looking first at the average system surplus and shortage in MWh and occurrence of system surplus and shortage for the different cases, we find that these are quite similar for the different cases, which could signify that BRPs behave similarly in the different cases due to similar incentives provided by the imbalance price. However, the average Actual Imbalance Penalties (AIPs; see above) do indicate that there are large differences in incentives, which is confirmed by the differences in average Actual Imbalance Costs (AIC; see above). Still, the total AIC, i.e. the total actual imbalance costs aggregated for all BRPs and all rounds, are not that different for different cases. Case 2 is the exception.

Table 1. Results of the analysis of alternative imbalance settlement designs (cases)

Results	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**
Average system surplus (MWh)	48.8	47.1	47.8	44.7	46.6	46.6
Average system shortage (MWh)	-39.7	-39.1	-38.2	-41.5	-41.2	-38.5
Occurrence system surplus (%)	58.6	57.4	58.9	52.3	55.4	58.7
Occurrence system shortage (%)	41.4	42.6	41.1	47.7	44.6	41.3
Average AIC 1 (Euro)	472	680	533	494	470	490
Average AIC 2 (Euro)	267	314	257	233	238	237
Average AIC 3 (Euro)	154	222	173	167	175	170
Average AIC 4 (Euro)	122	185	137	154	136	123
Average AIC 5 (Euro)	129	205	157	181	155	148
Average AIC 6 (Euro)	241	339	278	320	296	302
Total AIC (Euro)	1,917,526	2,703,960	2,138,123	2,197,403	2,120,355	2,012,835
Average AIP for BRP surplus (€/MWh)	-2.26	14.58	1.93	4.19	-0.08	-0.20
Average AIP for BRP surplus and system surplus (€/MWh)	25.83	25.40	25.40	46.70	34.15	27.51
Average AIP for BRP surplus and system shortage (€/MWh)	-42.05	0.00	-31.73	-42.41	-42.72	-39.56
Average AIP for BRP shortage (€/MWh)	2.26	17.71	5.11	-4.19	0.08	3.82
Average AIP for BRP shortage and system surplus (€/MWh)	-25.83	0.00	-19.84	-46.70	-34.15	-23.45
Average AIP for BRP shortage and system shortage (€/MWh)	42.05	41.60	40.88	42.41	42.72	42.53
Difference AIP 'shortage – surplus' (incentive to be long)	*4.52*	*3.13*	*3.18*	*-8.38*	*0.16*	*4.02*

It is noted that a system surplus always occurs more often than a system shortage. The proportion is generally 60%-40%. In then Netherlands in 2009, a system surplus occurred in 55.7 % of the PTUs which is also a clearly higher occurrence. Also, the system imbalance volume is relatively small, thanks to the BRPs who limit their imbalance and due to the fact that these imbalances even out partially (see Figure 2). Furthermore, we observe that the total AIC is mostly in the order of 2,000,000 Euro, which comes down to 2,000 Euro per round, and to 200 Euro per BRP per round on average. This is ca. 20,000 Euro per BRP per day. Assuming that the total included generation/load of 25,000 MW represents 600,000 MWh of energy per day, and that its economic value is equal to 36 €/MWh (the day-ahead market price), the total financial value is 21.6 M€. The total AIC is about 0.9% of that total value, which is the right order of magnitude, considering the BRP imbalance volumes (see Section II). Finally, we observe that the average AIPs for BRP shortage and BRP surplus lie often as close to zero as has been the case for the Netherlands in 2009 (average AIPs were 3.8 €/MWh for BRP shortage and 0.8 €/MWh for BRP surplus [1]). All this forms important proof of the validity of the model.

B. Case-specific results

Case 1: Single pricing

The single pricing mechanism has led to a total Actual Imbalance Costs of 1,917,526 Euro over 1,000 rounds, which means an average AIC for the average BRP of 192 Euro per round. However, the average AIC for the different options (intentional imbalance choices) deviate a lot from this. It can be clearly observed that over the entire range of options, an intentional surplus is less expensive then an intentional shortage: Option 6 is twice less expensive than option 1, option 5 is more than twice less expensive than option 2, and option 4 is still clearly less expensive then option 3. This finds its origin in the relatively higher costs of upward regulation compared to downward regulation as reflected in the bid ladders, which is usually the case in real balancing service markets. Furthermore, a small intentional imbalance is clearly less expensive than a large intentional imbalance in either direction. The analysis results show that the BRPs generally go for the cheapest option, as was the expectation given the included decision-making algorithm[2]. This can also explain the larger occurrence and size of system surpluses.

The average AIP for BRP surplus is -2.26 €/MWh and the average AIP for BRP shortage is 2.26 €/MWh. Thus, being long by 1 MWh generates an average actual profit of 2.26 Euro per round, whereas being short by 1 MWh costs 2.26 Euro. This symmetry is the result of the single pricing mechanism; after all, the short and long imbalance prices are always identical. When we specify these AIPs for PTUs with either a system surplus or a system shortage, we find values that are much further from zero, which is caused by the dependency of the imbalance price on the system imbalance direction. When the system is short and the BRP has a surplus, he has an actual *profit* of 42.05 €/MWh. This is because he is helping the system. This actual profit is clearly higher than the one BRPs receive from being short while the system is long – here they only gain 25.83 €/MWh. Also, the costs of being in the wrong direction (i.e. contributing to the system imbalance) are lower when BRPs have a surplus. Thus, the AIPs clearly show that creating a long position is generally the best BRP strategy. It should be noted, however, that this is only valid as long as the combined BRP strategies still create similar balancing market results.

[2] The frequency of selection of different options was found to be clearly (negatively) correlated with average AIC as expected, which is why the inclusion of those figures into this paper was deemed superfluous.

Case 2: Two-price settlement

Two-price settlement leads to a total AIC sum of 2,703,960 Euro, which is ca. 40% higher than that of single pricing (case 1). This makes case 2 by far the most expensive case. The IS design can easily explain this: With two-price settlement, BRPs receive no profit for being in the right direction. This is reflected in the AIPs. The average AIC are also much higher for the different options. However, the relative height of average AIC of different options remains about the same, which explains the similar occurrence and size of system surpluses and shortages compared to case 1. Finally, it is interesting to note that the average AIP for BRP shortage minus the average AIP for BRP surplus of 3.13 €/MWh (which is an indicator of the strength of the incentive to be long rather than short), is in the same range as the 4.52 €/MWh of case 1. Apparently, the different incentives provided by this IS design still lead to a general incentive to be long that is similar to case 1.

Case 3: Dual pricing

Dual pricing also leads to a very similar occurrence and size of system surpluses and shortages, but the total AIC are ca. 10% higher than in case 1, as is also reflected by the somewhat higher average AIC values for the different intentional imbalance options. This is clearly caused by the IS design; dual pricing makes imbalances more expensive for the PTUs for which it is active. In the simulation runs, dual pricing was active in 17% of the rounds, which shows that the potential impact of this IS design is large. Although the strength of the incentive is similar to case 1, the average AIP for BRP surplus is positive here, meaning that BRPs do on average have actual costs of having a positive imbalance. The specific AIPs for being in the wrong direction are clearly less favourable (less negative) than in case 1, which is the expected effect of dual pricing.

Case 4: Alternative payment direction

The results of this case are clearly different from case 1; especially the occurrence of system surpluses is significantly lower (52.3% compared to 58.6%) and the general incentive to be long too, which is -8.38 instead of 4.52. This means there is a general incentive to create a short position rather than a long position. However, a system surplus still occurs more than a system shortage, suggesting that this is still the least-costs result for the system as a whole. Apparently, this IS design makes a short position relatively less costly, which has resulted in a larger occurrence of system shortages compared to case 1. This can be explained by the peculiarity of this specific IS design. Because the short and long imbalance prices are still determined in the same way as in the single pricing regime (case 1), case 4 makes BRPs with a surplus pay the downward regulation price in PTUs with a system surplus, whereas they would receive this price in case 1. Furthermore, BRPs with a shortage receive the downward regulation price in PTUs with a system surplus, whereas they would pay this price in case 1. Thus, the difference in AIP between case 1 and 4 for PTUs with system surpluses is twice the downward regulation price. This IS design still gives incentives to balance the BRP portfolio, but increases both costs and profits for resp. BRP surpluses and BRP shortages during system surpluses, which apparently brings BRPs to reduce the long positions significantly.

Case 5: Imbalance pricing based on total costs

The results for case 5 show a somewhat lower occurrence of system surpluses compared to case 1 (55.4% instead of 58.6%), which is, like in case 4, accompanied by a clearly lower incentive to be long: only 0.16 €/MWh, instead of 4.52 €/MWh. This means that new BRPs will not be stimulated to balance their portfolio (or balance passively), unless they change the system imbalances and thereby affect the imbalance prices and incentives. Looking at the results of this simulation, however, AIC and AIPs are nevertheless quite high: the total AIC are higher than for case 1, and so are the average AIC of most options, and the average AIPs in case of system surpluses are much higher. The latter observation is similar to case 4. In case 5, the higher actual costs and profits for respectively causing and resolving a positive system imbalance are hard to explain. Most likely, they are caused by the relatively high added costs of activated upward regulation bids in PTUs with a system surplus and both upward and downward regulation.

Case 6: Incentive component

For this case, the results are general increase of Actual Imbalance Penalties for all possible combinations of BRP position vis-à-vis system imbalance direction. This is the consequence of the incentive component, which has been active in ca. 36% of the rounds. This explains the increase of total AIC from 1,918 Euro per round to 2,013 Euro per round. Because the system surpluses reach above the 50 MWh limit more often than the system shortages, the average AIC of option 6, the largest intentional BRP surplus, have increased the most.

C. BRP-specific results

The above results are from a systems perspective. However, it is also interesting to look at the analysis results from a BRP perspective, and look at the importance of portfolio size. Comparing the relative height of the average Actual Imbalance Costs of different intentional imbalance options for different BRPs, we find that large BRPs have a more stable preference order of options. This preference order is equal to observations mentioned under the discussion of the results of case 1: small and positive imbalances are less costly than large and negative imbalances. However, for small BRPs often very different preference orders emerge. It is hard to explain these, because they vary a lot between different small BRPs. Still, we do observe specific changes in preference order in different cases, which makes the impact of IS design different for large and small BRPs. The balancing strategies of small BRP differ much more per IS design. Looking at the total AIC for different BRPs in different cases, it is found that case 2 is the most expensive option for all but the largest BRP. For the largest BRP, case 1 and case 6 are clearly the cheapest IS designs. For small BRPs, case 2 is by far the most expensive options. These findings can be explained by the fact that large BRPs have a larger influence on the system imbalance size and direction, as a result of which they have a larger chance of being in the wrong direction. As case 2 is the only case that prevents BRPs from actually earning money for being the right direction, this case is relatively expensive for small BRPs. Finally, the AIC per MW of portfolio is several times higher for large BRPs, again due to their larger influence on the system (although in reality the netting of unintentional imbalances within the portfolio will offset this).

D. Balancing market equilibrium

Although the different imbalance settlement designs do give different incentives to the Balance Responsible Parties, as is indicated by the Actual Imbalance Penalties, overall performance is still strikingly similar. We observe a relationship between the system imbalance state (size and occurrence of system surplus and system shortage) and the relative strength of the incentives that are shown by the specific AIP values. As BRPs try to minimize their Actual Imbalance Costs, a combination of system imbalance states and imbalance prices develops that is economically optimal for the market. This optimal ‘balancing market state’, or ‘balancing market equilibrium’, is apparently not very different for the six analyzed imbalance settlement designs.

V. Conclusions

The six different imbalance settlement (IS) designs have a significantly different impact on balancing market performance in terms of system imbalances, Actual Imbalance Penalties, and Actual Imbalance Costs, but still the results are quite similar. The largest differences can be found in the Actual Imbalance Penalties for specific combinations of BRP and system imbalance direction.

Generally, the best strategy for Balance Responsible Parties to minimize their actual imbalance costs is to create a long position (intentional surplus) rather than a short position (intentional shortage), and to opt for a small intentional imbalance rather than a large one.

The imbalance costs-minimizing behaviour of the BRPs creates a balancing market equilibrium which is similar for different IS designs, even though specific incentives deviate quite a bit. The consistently higher occurrence of positive system imbalances (system surpluses) finds its origin in the shape of the bid ladders – the upward regulation bids being generally more expensive – in combination with the general feature of IS designs that the ‘short imbalance price’ is based on the marginal bid price for upward regulation and vice versa.

What can still be said about the differences in IS design is that two-price settlement is the least performing design, both from a systems perspective and from an individual BRP perspective. The imbalance costs resulting from this design are much higher than for the other designs. Furthermore, the specific IS designs of the alternative payment direction and imbalance pricing based on total costs create such incentives that the occurrence of system surpluses drops significantly, which can be regarded as a negative point from a security of supply perspective.

The impact of IS design is different for BRPs of different portfolio size. Small BRPs attune their balancing strategies more to the IS design. In addition, small BRPs have lower imbalance costs due to their smaller influence on the system imbalance, but the level of these imbalance costs are also more uncertain for the same reason.

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