• *László Paizs* •

INCENTIVE PROBLEMS IN THE HUNGARIAN ENERGY-BALANCING MECHANISM

This paper examines the functioning of the balancing market of the electricity sector in Hungary. Balancing energy is an ancillary service, which is used by the transmission system operator (TSO) to guarantee the continuous supply of electricity. The TSO resolves unforeseen imbalances by calling on power plants in real time to increase or decrease their production (called upward and downward regulation). In order to comply with the balancing mechanism and settlement process, market participants organize into so-called balancing groups led by the balancing responsible party (usually a trader or supplier). Based on the forecast of the balancing group's day-ahead production and consumption, the balancing responsible party (BRP) prepares the schedule of the balancing group, forwards it to the TSO, and then settles the imbalances with the TSO resulting from any deviation from the announced schedule. In our study we examine the question of how current balancing energy and imbalance prices affect the incentives on suppliers to keep their portfolio balanced. Taking only the price difference between negative and positive imbalance prices into consideration, we can say that the incentive on suppliers to avoid imbalances is very strong in the Hungarian market. However, we also show that because of the asymmetrical penalties for being long versus short, suppliers are inclined to under-contract energy on the wholesale market. Finally, our analyses also reveal that the current structure of the purchase and settlement price of balancing energy motivates the public utility wholesaler (the BRP for the public utility balancing group) to nominate more than its expected load.

INTRODUCTION

Since the liberalization of the Hungarian electricity market in 2003, it has been functioning as a dual market: there is an *open market* for authorized consumers, and a *public utility* market with prices set by the authorities. The market was liberalized gradually, in several phases. Beginning in January 2003 all consumers with electricity consumption higher than 6.5 GWh, and as of July 2004 all industrial consumers – together representing 70 percent of all consumers – have had the opportunity to choose their supplier freely.

The first phase of liberalization was characterized by great consumer activity. By the end of 2004 the consumption of consumers opting for an open market reached

20 percent of the total domestic consumption. The import competition resulting from the liberalization of external trade played the main role in the fast-paced expansion of this competitive market segment. The import share of open market consumers in the electricity supply was over 60 percent of the total in 2004. After the opportunities brought by import-based growth ran out, the competitive market slowed down significantly. While the share of open market consumption reached 25 percent by the end of 2005 and it was as high as 30 percent by the end of 2006, there was a sharp drop to 20 percent at the beginning of 2007, when open market consumers returned *en masse* to public utilities.

In spite of the strong activity on the demand side and the savings realized by large consumers – which were very significant at the beginning – the competition in Hungary is characterized by severely distorted market conditions. The long-term power purchase agreements between MVM (Hungarian Electricity Ltd.) and power generators present the biggest problem. Based on these agreements 65 percent of domestic power generation and 80 percent of domestic electricity sales are controlled by MVM. This means that although the ownership structure of the Hungarian power generation market is fragmented, the market itself is overwhelmingly dominated by MVM. We have to add that due to the restrictions on international competition, domestic conditions play a more important role in the development of power market competition than in other markets.

This paper examines the functioning of the balancing market of the electricity sector in Hungary. It is necessary to have a balancing energy market in order to control and financially settle unforeseen imbalances in the electricity market. The company responsible for the reliability of the electric power system called Hungarian Transmission System Operator, or MAVIR for short, is in charge of the purchase and settlement of balancing energy. MAVIR prepares the system schedule from the schedules that have been submitted by BRPs. This schedule contains the planned generation-consumption balance of the country for every 15 minute. If there is any deficiency in the system balance – for instance, because the actual generation by plants is less than the agreed amount – the TSO can restore the balance by drawing on reserves, and then charge the costs of balancing to those participants who failed to meet their schedule.

THE PROCUREMENT OF BALANCING ENERGY

In 2006, the Hungarian TSO purchased around 1300 MW reserve capacity from domestic power plants, which is approximately 20 percent of the annual peak consumption (approximately 6300 MW). The reserves have varying levels of response time, i.e. how fast they can be made available. Deficits are typically balanced out by calling upon the reserve that can be made available at the shortest notice, and if the deficit is very big and/or lasts for a longer period, cheaper and larger reserves with slower response times gradually replace the fast ones. The total cost of reserves utilized by MAVIR is approximately HUF 25bn, which increases the cost of every KWh supplied by about 0.7 Hungarian forints.

Just like the energy market, the procurement of balancing power can also be organised as a competitive market. One of the most frequently used methods is when the TSO holds auctions at regular intervals (once a year, daily, or every hour) to procure reserves of the required quantity and composition for upward and downward regulation.

In the current model MAVIR procures control reserves at daily auctions. Within each reserve type participants submit two-part bids – containing capacity fee and energy price – for both upward and downward regulation. Settlement is based on the offer price: winning bidders get the capacity fee they bid for, and if activated they receive the energy fee contained in the bid submitted.

The main obstacle to competition on the balancing energy market (among others) is the long-term purchase agreement system. The dominance of MVM is made even more obvious on this market due to import competition being excluded (very restricted). MAVIR covers its regulation reserve needs almost exclusively from MVM: in 2005 MVM's share was as high as 95 percent. The regulatory authority currently addresses this problem by requiring MVM to submit bids to the balancing energy market that do not exceed the settlement prices of its contracts with generators.

THE SETTLEMENT OF BALANCING POWER

Market participants organize into so-called balancing groups, and the TSO settles the real-time imbalances financially with the balancing responsible parties (BRPs). The BRPs calculate what the members (power plants, traders, consumers) of their respective balancing group inject into the system as well as what they take out, and forward the balanced schedule to the system operator one day in advance. The settlement of balancing energy is based on the difference between the scheduled amount and the actual amount generated (loaded into the system) and consumed (withdrawn). The cost or revenue of balancing for the balancing group splits between the members of the balancing group.

The settlement price of balancing energy

The settlement of balancing energy, with those participants who require settlement, can be done in two ways. In the so called single-price system, the same price – though with the opposite sign – is applied for both the negative and positive imbalances. In the so called double price accounting system negative and positive imbalance prices are different; the former is higher than the latter. To settle balances in the United States they tend to use the single price system, while in European countries they prefer the double price system (*Glachant–Saguan* [2007]).

Double imbalance prices provide a strong incentive for market participants to keep their own position in balance. Since the energy price charged for negative imbalances is typically higher than the day-ahead price, and the energy price paid for positive imbalances is typically lower, the system penalizes both taking more or taking less. The measure of "penalty" for both negative and positive imbalances (B_{negative} and B_{positive}) can be expressed as the following:

$$B_{\text{negative}} = NIP - P$$
$$B_{\text{positive}} = P - PIP,$$

where P is the market price (for example the relevant power exchange price), NIP (negative imbalance price) is the settlement price of negative imbalances, and PIP (positive imbalance price) is the settlement price of positive imbalances. The cost of being short can therefore be measured as the difference in costs between buying energy on the balancing market and the wholesale market. The cost of any deviation from the submitted schedule can be reduced by keeping to the schedule more accurately, i.e. reducing the standard deviation of imbalances.

An additional feature of the double-pricing system is that often the price charged for imbalances does not only depend on the market player's own balance (be it positive or negative), but also on the direction of its balance relative to the overall status of the system (same direction/opposite direction). In countries that have their own electricity exchanges, the settlement of imbalances that are in the same direction as that of the system are based on the cost of balancing services, while the settlement of imbalances that are in the opposite direction are based on day-ahead power exchange prices. By using day-ahead prices the exposure of market parties to balancing risks is lower, as normally the price of the day-ahead market is lower (higher) than price of negative imbalance (positive imbalance) of the balancing market. Using less "penalizing" settlement prices in the case of imbalances in the opposite directions is justifiable, as participants with opposite direction balances actually decrease the real-time costs of the balancing of the whole system.

In the absence of an organized market in Hungary we have no reference price, which we could refer to when settling imbalances that are in the opposite direction

TABLE 1 • **The double imbalance price scheme In Hungary**

		MAVIR (system imbalance)	
		deficit (net upward regulation)	surplus (net downward regulation)
Balancing group	negative (short)	negative imbalance price	negative imbalance price, if there was upward regulation, otherwise 0
	positive (long)	positive imbalance price, if there was downward regulation, otherwise 0	positive imbalance price

as the system balance. Currently the way the settlement price is set does not depend on whether the direction of individual deviation is the same as that of the system deviation. A player with a negative balance will be charged the price of negative imbalance (NIP) even if the system has a net surplus, provided that in the settlement period the system operator performed both downward and upward regulation. If there was no regulation in the opposite direction to the net system balance, then the settlement price will be equal to zero.

The rules of setting imbalance prices recently changed in Hungary. Earlier the unit price of balancing energy was fixed, the settlement prices of positive and negative deviations were determined by multiplying the public utility wholesale prices with fixed factors.[1] In order for balancing energy to correspond more to the costs of regulation performed by the TSO, as of July 1, 2006 the fixed price system was replaced by cost-based pricing. Under the new scheme the settlement price of imbalances is based on the average procurement cost of balancing services.

TABLE 2 • **The settlement price of imbalances in Hungary in 2006** (HUF/KWh)

Period	The settlement price of negative imbalances	The settlement price of positive imbalances
January 2006–June 2006		
Peak period*	22.65	0.88
Off-peak period*	11.23	0.00
Average**	13.47	0.26
July 2006		
Average***	15.28	0.00

* Unit price imposed by the authorities.
** Fifteen-minute settlement price average, assuming that in 90 percent of the settlement periods there was some downward or upward regulation.
*** Fifteen-minute settlement price average.

An assessment of the Hungarian imbalance price system

The Hungarian balancing mechanism will be assessed against the requirements considered necessary to achieve healthy operation of the balancing energy market. We examine how much the current system of imbalance prices encourage suppliers to avoid imbalances, how big is the risk it poses to market participants, whether it helps minimise overall balancing costs, and how much room it leaves for arbitrage or other undesirable gaming.

[1] The peak and off-peak period unit prices of negative imbalances were respectively 1.3 times the peak and off-peak period public utility wholesale prices set out in the regulation. The price of positive imbalances in peak and off-peak periods were equal to the pro-rata average of peak and off-peak period public utility wholesale prices, while in peak periods they were equal to 0 (*Network Code* [2006]).

As the costs of system-level balancing are usually considerable (see below in the study), market participants need to be encouraged to cover their generation and consumption as accurately as possible. For example, the more accurate forecast of generation and load and better incentive mechanisms within the balancing group can help to meet individual schedules more accurately.

However, it is important to see that the measures taken by BRPs to avoid imbalances are costly, even if these costs are borne not at the level of centralised system control, but by the market participants themselves. Therefore, the minimisation of system balancing costs cannot be considered the ultimate goal. If this happened, it would lead to a very high degree of individual balancing, which in turn would increase the cost of individual balancing too much. Theoretically, the pricing system of the balancing energy market can be considered optimal if it provides incentives for individual balancing of market participants to such an extent that its marginal cost is exactly the same as the marginal cost of system level balancing.

IMBALANCE PRICE SPREAD

The economic cost of being short or long depends very much on the difference between the negative and positive imbalance prices. To demonstrate the potential impact of the spread between negative and positive imbalance prices, let us consider a BRP owning only load (i.e. a supplier). Assuming that the supplier's real-time deviation from its schedule is a random variable following normal distribution, and that the opportunity cost of buying or selling balancing energy are identical (*NIP* – *P* = *P* – *PIP* = *B*). The average value of the imbalance costs of the supplier can be expressed as the following:

$$2B\frac{\sigma}{\sqrt{2\pi}}, \tag{1}$$

where σ is the standard deviation of imbalances, and *2B* is the difference between the negative and positive imbalance prices (see *Appendix 1* for a detailed description of the calculation). So if a supplier can predict the consumption of its clients with a five percent margin of error, and the difference between imbalance prices is EUR 50/MWh, then the average cost of balancing for the supplier will be approximately EUR 1/MWh. If this price difference increases, then the projected balancing cost will increase, and so will the incentive to keep their portfolio balanced.

The difference between imbalance prices in Hungary has been EUR 50–60/MWh in the past 18 months, which is very high, compared to price differences abroad (*see Table 3* and *Figure 1*). The price system of Hungarian balancing energy can therefore be considered very penalizing. We have to add that expensive balancing energy may act to stunt the development of competition especially in the early phases of liberalization.

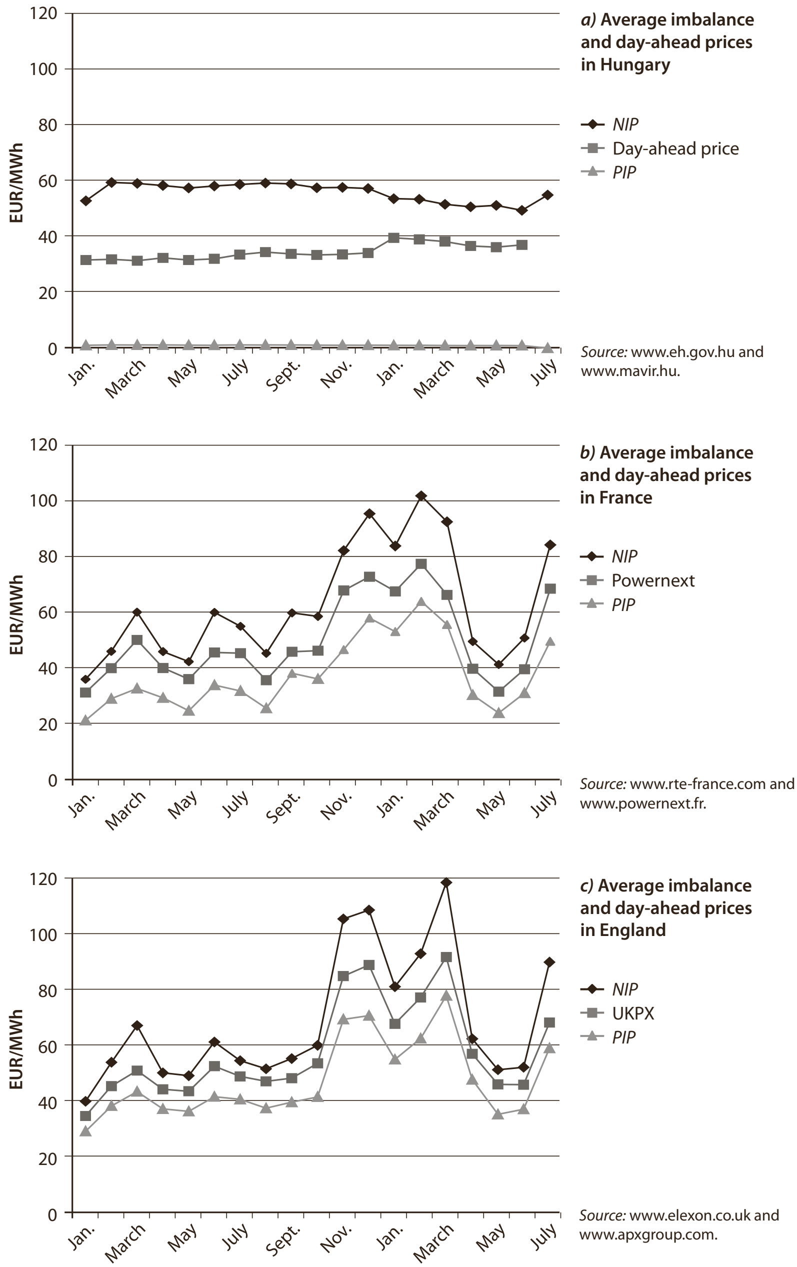

FIGURE 1 • **Average imbalance and day-ahead prices on the Hungarian, French and English electricity markets** (January 2005 – July 2006)

TABLE 3 • **Imbalance prices in European countries, 2005 (EUR/MWh)**

Country	The average price of negative imbalances	The average price of positive imbalances	Price difference
Austria	51	24	27
Belgium	56	12	44
Czech Republic	21	0	21
Denmark	36	27	9
United Kingdom	55	39	16
Finland	32	27	5
France	50	45	5
Greece	44	44	0
Netherlands	69	28	41
Ireland	69	60	9
Poland	37	24	13
Hungary	40	0	40
Germany	70	2	68
Norway	29	29	0
Italy	102	23	79
Portugal	58	23	35
Sweden	32	28	4

Source: EC [2005]: Report on progress in creating the internal gas and electricity market, COM(2005) 568 final, Commission of the European Communities p. 67.

Suppliers that have recently entered the market naturally have a smaller clientele than their more established competitors. Due to the fact that it is much harder to plan the schedule, service to smaller consumer portfolios can only be provided if we make greater use of balancing energy. Balancing is consequently a greater burden to smaller suppliers than to big ones. Hence, the high exposure to balancing risk may act to prevent new players from entering the market.

Asymmetrical penalties

Figure 1 illustrates yet another peculiar aspect of balancing energy pricing in Hungary. While in England and France the position of negative and positive imbalance prices with respect to the wholesale price can be said to be symmetrical, in Hungary the position of imbalance prices compared to wholesale price are asymmetric. The tendency that the difference between the wholesale price and the positive imbalance price significantly exceed the difference between negative imbalance price and wholesale price can be observed since January 2006.

In the price structure of Hungary, the cost of settling a long position is significantly higher than that of a short positions ($P - PIP > NIP - P$). It is easy to see how this encourages suppliers to under contract energy on the wholesale market and thus avoiding long positions.

Let us look at the behaviour of a supplier when $P - PIP > NIP - P$. When making decision on the wholesale purchase of energy, the supplier is faced with the following problem. If he cuts the wholesale purchase of energy by one unit, he gains the saving of the power exchange price, lessens his exposure to the *PIP* (i.e. the likelihood that he ultimately goes long and needs to sell the surplus at PIP), while raising its exposure to the NIP (i.e. the risk that it subsequently goes short and needs to make up the shortfall at the PIP). Defining p^s = the probability that the position of the supplier is ultimately short, this can be expressed as

$$\text{Gain} = P - p^s NIP - (1 - p^s)PIP. \quad (2$$

To minimize the cost of his wholesale energy purchase *plus* the expected costs of balancing, the supplier will reduce his purchasing of energy down to the point where there is no further gain from cutting down on trading, i.e.

$$P - p^s NIP - (1 - p^s)PIP = 0, \quad (3)$$

that is

$$p^s = \frac{1 - (PIP/P)}{(NIP/P) - (PIP/P)}. \quad (4)$$

If we put the averages of wholesale and balancing energy prices for the first six months of 2006 into the equation (P = 9.85 HUF/KWh, NIP = 13.47 HUF/KWh, PIP = 0.28 HUF/KWh), we get the following: the optimal probability of a supplier going short in the given period was approximately 0.73. Therefore, a supplier can minimize his expected costs in the period studied by purchasing only so much energy as to result in a short position for 73 percent of the settlement periods.

In *Appendix 1* we provide a detailed assessment of the optimal *degree* of suppliers under-contracting. Our calculations show that in the first six months of 2006 the optimum degree of under-contracting for a supplier was on average equal to 0.6 times the standard deviation of the consumption forecast error σ.[2] So assuming for example that the supplier has a demand forecast error standard deviation of 5 percent, then according to our estimation he must have contracted only 97 percent of its projected consumption. If all participants are inclined to under contract, then of course the whole system will also tend to be "under-contracted". On the basis of this example, and assuming that there are altogether four suppliers on the market, all having equal shares, the system imbalance has a mean of –3 percent, and a standard deviation of 2.5 percent (= 5% $/\sqrt{4}$) (see *Figure 2*).

[2] In addition to trying to minimize the costs there are of course other factors (for example arbitrage) that can drive the behaviour of market participants. Naturally, when calculating the optimal degree of under-contracting we did not take these factors into consideration.

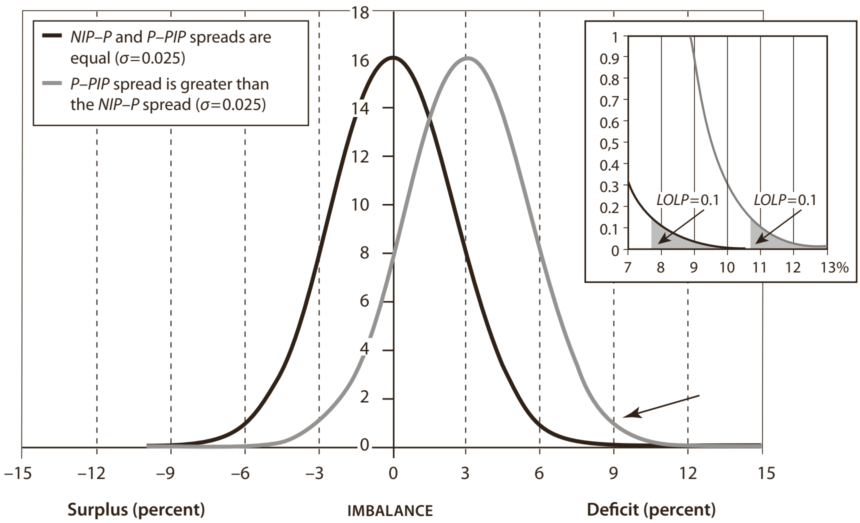

FIGURE 2 • **Density function of system imbalance when the *NIP–P* and *P–PIP* spreads are equal and when they are not**

The current balancing mechanism with unequal *NIP – P* and *P – PIP* spreads imposes high system balancing costs compared to the costs that would be incurred by a symmetrical spread around the day-ahead price (assuming that the difference between *NIP* and *PIP* is the same under the two pricing regimes). Since the frequency and the maximum value of negative imbalances increases, the system operator has to keep larger generation capacities in reserve for upward regulation.

In order to quantify this latter effect, let us compare the amount of upward regulation capacity needed to achieve a *LOLP*[3] of 0.1 percent under the existing pricing scheme as well as under a pricing scheme with equal *NIP – P* and *P – PIP* spreads (NIP_s = 16.445 HUF/KWh and PIP_s = 3.255 HUF/KWh, that is $NIP_s - P = P - PIP_s$ = 6.595 HUF/KWh and $NIP_s - PIP_s = 2 \times 6.595$ HUF/KWh). As shown in the close-up view in *Figure 2*, under the current pricing scheme the need of the system for upward regulation reserve reaches 10.5 percent of load, while with symmetrical spread around P it would only reach 7.5 percent.

Market dominance and "gaming"

Table 4 shows the developments in regulating and balancing energy prices in the past 18 months.

[3] *LOLP* = Loss of Load Probability

TABLE 4 • **Regulating and balancing energy prices in Hungary** (HUF/KWh)

	Regulating market		Balancing market	
Period	incremental energy price	decremental energy price	negative imbalance price	positive imbalance price
January 2005–January 2005	8.2	0	13.90	0.23
February 2005–December 2005	8.8	0	15.50	0.25
January 2006–June 2006	12.9	0	14.40	0.24
July 2006–August 2006	14.3	0	14.30	0.00 ??
September 2006			20.48	0.90 ??

Note: the figures indicate the weighted average of the peak and off-peak prices values. Following the terminology of the Network Code we refer to the procurement side of the balancing energy market as "regulating market", and the settlement side of it as "balancing market".

One of the most striking features of the Hungarian balancing energy market is the extremely low price of positive imbalances. Even considering that the key feature of the double pricing system is to incentivise more accurate planning, the size of penalty imposed on long positions seems to be unwarranted. The main reason for the low positive imbalance price is the fact that the Hungarian TSO receives a very low price for the surplus energy from the providers of downward regulation. In other words, the price of decremantal energy is very low (0 HUF/KWh) in the regulating market. This is due to the monopolistic structure of the regulating market, i.e. the fact that only MVM offers bids for decremental energy to the TSO.[4] Besides having the ability to influence the prices of regulating services, MVM are also capable of manipulating the overall system balance. This is due to the large size of the public utility balancing group managed by MVM. The latter's consumption accounts for 65-70 percent of the total domestic consumption. This enables MVM to shift the system balance in a direction that is favourable to the company's own interest.

Next we show that in the present pricing system MVM is encouraged to nominate more than its expected load (i.e. declare a larger than-anticipated load). Let us assume that MVM nominates more than its expected load and this brings the market into surplus. What happens in such situations? First, MVM as the single provider of regulating services will be called upon by the TSO to decrease output from its generators. The zero price of decremantal energy means that MVM pays nothing to the TSO for reducing its output. Second, MVM as the balance responsible party of the public utility balancing group will have a positive imbalance volume, which will be settled at the positive imbalance price of 0.24 HUF/kWh. Hence the net profit for MVM from pushing the system into a surplus is 0.24 HUF/kWh times the positive imbalance volume of the public utility balancing group. This arbitrage between the two markets could only be prevented if the positive imbalance prices were lower than the prices for decremental energy.

[4] Under sufficiently competitive conditions, the price for decremantal energy would come close to the variable cost of the least efficient operating plant (i.e. the plant with highest marginal cost).

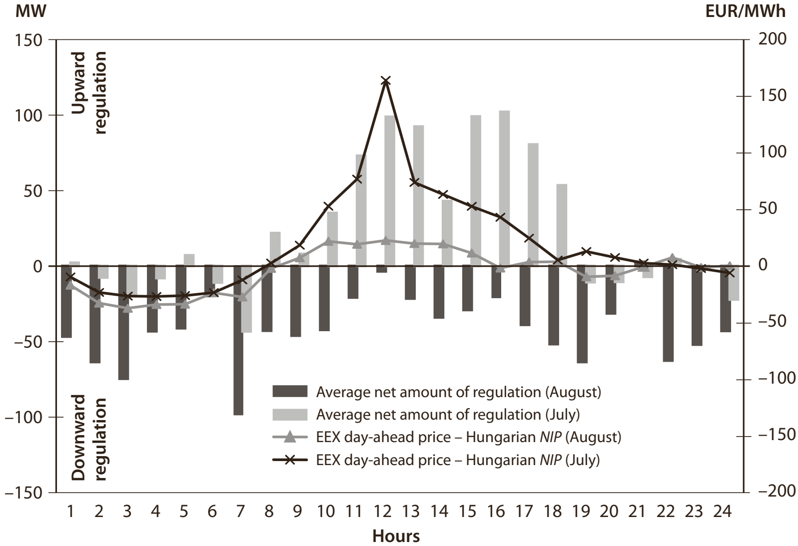

FIGURE 3 • **Direction of regulation versus the *NIP – P* spread in the Hungarian electricity market in July and August 2006**

Although we have no data about the development of the position of the public utility balancing group, the available aggregate data on the system imbalance are in line with the prediction that MVM continuously nominates more than its expected load. In 2005, the total volume of upward regulation was 384 GWh, while that of downward regulation was 545 GWh, meaning that in the course of the past year the system balance was more often in surplus than in deficit. This, in combination with the predicted under-contracting behaviour of suppliers other than MVM (i.e. ones serving the free segment of the market), suggests that MVM indeed keeps nominating more than the expected load of the public utility balancing group.

The 15 minute increment data on system balance pertaining to July and August of 2006 that were on the Hungarian TSO's webpage also suggest over-nomination by the MVM. As seen in *Figure 3,* in each hour of the day in August the TSO purchased on average more downward regulation than upward regulation. In contrast, in July the direction of regulation was predominantly upward. In *Figure 3* we also show for each hour of the day the estimated average spread between negative imbalance price and day-ahead price[5]. We can observe that in July the market price in the peak hours significantly exceeded the settlement price for negative imbalances, creating a huge incentive for arbitrage between the two markets. We suspect that in this period suppliers serving the free segment of the market generated large deficits in their scheduled portfolio, thereby making it impossible for MVM to push the system balance into surplus.

[5] This latter was calculated on the basis of the EEX day-ahead prices.

CONCLUSIONS

The balancing mechanism plays a central role in the wholesale electricity market. On the one hand, it is crucial in maintaining network stability and, on the other, it allows for a market-based settlement of imbalances between network users and the TSO. However, designing a balancing mechanism is a very complex task. The price system needs to incentivise the BRP to stay in balance, needs to minimize the social costs of balancing and at the same time needs to be robust against activities that threaten the functioning of the market.

In our study we examined the incentive properties of the current Hungarian energy balancing mechanism. We showed that the large spread between the NIP and the PIP creates a strong incentive for BRPs to reduce their imbalances resulting from inaccurate forecasts. On the other hand, we also show that, due to the existence of asymmetric penalties in the price system, BRPs have an incentive to under contract in the wholesale market as a hedge against real-time long positions and the associated higher imbalance costs. Finally, we demonstrated that MVM, who is responsible for the balancing of the public utility balancing group, has a strong incentive to nominate more that its expected load. This is due to the inconsistency in the pricing of decremantal energy versus positive imbalances, which is allowing for a positive spread between the negative imbalance price and the decremantal energy price. As a monopoly provider of downward regulation and the leader of the largest balancing group, MVM can push the system balance into surplus and then earn a positive profit from selling energy in real time to the TSO.

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APPENDIX

1. The imbalance cost of a free market supplier

The aim of this appendix is to provide an estimate of the imbalance cost of a free market supplier under the assumption that $NIP - P = P - PIP$; i.e. its cost exposure to negative and positive imbalances are the same. (Note that under such prices a supplier has no incentive to nominate differently from its expected load.) Let $B = NIP - P$ $(= P - PIP)$ and x a random variable denoting the supplier's imbalance position. Then the expected cost of imbalances can be expressed as follows:

$$K = -B \int_{-\infty}^{0} xf(x)dx + B \int_{0}^{\infty} xf(x)dx,$$

where $f(x)$ is the probability density function of x. If x follows a normal distribution with mean 0 and standard deviation σ, then

$$K = -B \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{0} xe^{\frac{x^2}{2\sigma^2}}dx + B \frac{1}{\sigma\sqrt{2\pi}} \int_{0}^{\infty} xe^{\frac{x^2}{2\sigma^2}}dx,$$

that is

$$K = -B \frac{1}{\sigma\sqrt{2\pi}} \left[-\sigma^2 e^{\frac{x^2}{2\sigma^2}}\right]_{-\infty}^{0} + B \frac{1}{\sigma\sqrt{2\pi}} \left[-\sigma^2 e^{\frac{x^2}{2\sigma^2}}\right]_{0}^{\infty}$$

of which

$$K = 2B \frac{\sigma}{\sqrt{2\pi}}.$$

So if for example a supplier has a demand forecast error standard deviation of 5 percent and the difference between the negative and positive imbalance prices *2B* is EUR 50/MWh, then the imbalance cost of the supplier will be approximately EUR 1/MWh.

2. The optimal degree of under-contracting for a free market supplier

The aim of this appendix is to provide an estimate of the degree of under-contracting by a supplier in the Hungarian electricity market. Q denotes the supplier's customers' consumption. Real-time consumption then equals the expected amount of consumption plus the forecast error, θ, which is distributed according to $F(\theta)$. To meet its customers' demands, the supplier purchases $(1 + u)Q$ amount of energy on the wholesale market, where u stands for the degree of under-contracting.

If the real-time consumption is less than the contracted energy, i.e. $\theta < u$, then the surplus energy is sold at the *PIP* (positive imbalance price). The supplier's loss can be expressed as the following:

$$K = (u - \theta)(P - PIP)$$

If the real-time consumption is greater than the contracted energy, i.e. $\theta > u$, then the missing energy has to be covered in the balancing market at the NIP (negative imbalance price). The loss made by the supplier will be

$$K = (u - \theta)(NIP - P).$$

The expected cost of imbalances is then *K*, where

$$K = (P - PIP)\int_{-\infty}^{u}(u-\theta)f(\theta)d\theta + (NIP - P)\int_{u}^{\infty}(\theta - u)f(\theta)d\theta,$$

where *f* is the probability density function of the forecast error. The optimal degree of under-contracting is then *u* that minimizes *K*:

$$\frac{\partial K}{\partial u} = F(u)(NIP - PIP) - (PIP - P),$$

So the value of *u* solves

$$F(u) = \frac{NIP - P}{NIP - PIP} = \frac{1 - (PIP/P)}{(PIP/P) - (NIP/P)},$$

where *F* is the probability distribution of the forecast error *θ*. Given *F*, the optimal degree of under-contracting *u* can be solved. Assume that *F* is normal with mean 0 and standard variation *σ*. In the first six months of 2006, the average day-ahead price *P* was 9.85 HUF/KWh, the average *NIP* 13.47 HUF/KWh and the average *PIP* 0.28 HUF/KWh. Using these values we get

$$F(u) = 0.2737.$$

If *F* is normal, this can be expressed as

$$F(u) = 1 - \Phi\left(-\frac{u}{\sigma}\right) = 0.2737,$$

from which

$$\Phi\left(-\frac{u}{\sigma}\right) = 0.7263,$$

i.e.

$$-\frac{u}{\sigma} = 0.6,$$

i.e.

$$u = -0.6\sigma.$$

Our calculation shows that a supplier should on average be 0.6*σ* under-contracted in the first half of 2006. Assuming that the supplier had a consumption forecast error standard deviation of 5 percent, he should optimally cover only 97 percent of its expected consumption on the wholesale market.