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Monte Carlo method for pricing forecasting errors

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SUMMARY

Accurate day-ahead consumption and production forecasts are paramount for qualified electricity market participants. However, the cost of percentage-point improvement of the forecast accuracy may not be justified with the expenses of the imbalance settlement. We apply a Monte Carlo method to an electricity consumption time series to study the dependence of the imbalance settlement costs on MAPE of the forecast. Combined with regression, we compute the total value of a percentage-point improvement of MAPE.

KEYWORDS

Imbalance settlement, imbalance settlement expenses, forecasting error, forecasting error expenses, electricity market, short term electricity consumption forecasting.

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INTRODUCTION

Unbundling of electric power systems led to establishment of two separate layers of these systems, namely the technological layer governed by the laws of physics, and the market layer, governed by the laws of economy. Following their respective rules, these layers may come into conflict due to the disparity in their priorities. While the main goal of the technological layer is to provide the electricity to end-users and balance supply and demand at all times, the main goal of the market layer is to maximize profits to the stockholders of companies in electricity system. As the supply needs to be scheduled in advance, the crucial aspect of balancing the supply with the demand is its accurate short-term forecasting, allowing to plan the supply accordingly. However, no forecasting can be completely accurate, and some disparity is usually found between the forecasted and the actual demand, causing imbalances. In recent decades, introduction of renewable energy sources with variable generating power depending on weather conditions has complicated grid balancing even further.

Initial positions for the balancing markets are established before day-ahead markets, when the suppliers sell their generation capacities and the consuming market participants purchase them in auctions. Day-ahead market constitutes the most relevant aspect of balancing, as the market participants try to accurately predict their actual demand/production and sell the surplus or purchase deficient energy. When all profitable opportunities have been exploited, the trading may sometimes continue into intra-day market in an attempt to narrow the gap between contracted and physical position as much as possible. Once the so-called gate closure time passes, the trading for physical quantities stops and the control over balancing is passed to the central imbalance settlement administrator, who assures the stability of the electric grid in real time. Procuring reserve and energy balancing services follows the gate closure time, consisting of generators or loads able to adjust their supply or demand doing so at the instruction of the imbalance settlement administrator. The market participants, who deviated from their submitted schedule are charged for the costs of balancing their deviation induced, possibly increased by some accuracy incentive component (1). The revenues generated by the imbalance mechanism are handled differently in European countries, varying between daily, monthly, or yearly distribution between the balancing parties.

For Slovenian market, the behaviour of costs of imbalances was studied by Šavli in 2013 (2). The data in the paper demonstrates that the imbalancing expenses have been declining, showing that the market participants were investing into increasing forecasting accuracies. The paper also demonstrated that larger balancing groups tend to have better relative accuracies, which yields smaller relative imbalancing expenses.

IMBALANCE EXPENSES VERSUS ACCURACY COST

In most European countries, where the revenues of the imbalance mechanism are distributed between the market participants, the participants are faced with periodical financial transactions that can be either negative (i.e. additional bills for covering the expenses of the imbalance) or positive (i.e. payments received for imbalance volume helping to balance the market).

Both situations can occur in the presence of either positive imbalance volume, when the actual demand exceeds the forecasted one, or negative imbalance volume, when the forecasted demand exceeds the actual one. The latter corresponds to a long position in electricity market, and the former to a short one. Caution is advised when studying the bibliography on electricity imbalances, as the sign of the imbalance volume is not consistently defined. We use the definition form Slovenian Rules on the operation of the electricity market (3).

Even with positive transactions, the market participant may still be losing money in the balancing process, as these positive transactions may be the results of forced selling of excessive purchased energy at a low price. This example demonstrates the need of distinguishing the imbalance expenses, the payments or bills received from the imbalance settlement administrator, and the costs of accuracy, which is the amount of money lost (or earned) by (in)accurate forecasting of market participant's own demand. As the imbalance expenses are not necessarily negative, we prefer to call them the imbalancing transaction. Its value (Z) is computed from the imbalancing volume ($W_o = W_a - W_f$), the difference between actual (W_a) and forecasted (W_f) energy) and the imbalancing price for positive (C_+) or negative (C_-) imbalance. The costs of accuracy (S) are computed using the same quantities as the imbalancing transaction value, but in addition, we must take into account the price at which the forecasted energy was purchased in the electricity market (C_0). The formulae can be compared in Table 1. They are followed by interpretations of positive or negative imbalancing expenses and accuracy costs in the presence of either positive or negative imbalance volumes.

Table 1: Distinction in interpretations of imbalancing transactions vs. accuracy costs.

Sign of the imbalance volume W_o	**Net financial value to the company**	**Interpretation of imbalancing transaction (Z)**	**Interpretation of accuracy costs (S)**
Negative: long position	**Formulae**	$W_o < 0: \ Z = C_- \cdot W_o$	$W_o < 0: \ S = (C_- - C_0) \cdot W_o$
	Positive: revenue or profit?	The excessively contracted energy was sold on the market. The money received is the revenue from selling overstocked goods.	The long position of the company was different from the position of the market and contributed to the balance. The amount constitutes profit from selling at a price higher than purchasing price.
	Negative: expenses or loss?	Someone was paid to consume excessively contracted energy. The money paid is the payment for purchasing the demand on the market.	The excessively contracted energy was sold on the market at a price lower than the purchase price (possibly negative, i.e. the demand being purchased). The positive value is the loss generated in the process.
Positive: short position	**Formulae**	$W_o > 0: \ Z = C_+ \cdot W_o$	$W_o > 0: \ S = (C_+ - C_0) \cdot W_o$
	Positive: revenue or profit?	The insufficiently contracted energy generated demand that was sold on the market. The money received is the revenue from selling demand missing on the market.	The insufficiently contracted energy was purchased at a price lower than the original purchasing price. The amount presents opportunity profit for purchasing the energy at a lower price compared to the original purchase.
	Negative: expenses or loss?	The insufficiently contracted energy was purchased on the market. The money paid is the payment for purchasing this energy.	The insufficiently contracted energy was purchased later at a greater cost. The amount presents net loss for purchasing the energy at a greater price compared to the original purchase.

As the table details, the transaction to or from the market participant resulting from imbalance shows the nature of either expenses or revenue related to sales or purchase of required supply or demand, and the accuracy costs have the nature of (opportunity) profit or loss from the same sales or purchase. It is therefore mandatory for the market participant to consider not only the cash flow from these operations, but its actual contribution to the participant's financial result.

For each Balance Group, imbalance settlement administrator determines the imbalance volumes of the total realisation (of electricity consumption and delivery) by calculating the difference between the total realisation of a Balance Group and its market plan in an individual accounting interval.

CALCULATION OF LOSSES

The methodology for calculation of losses in Slovenian distribution grid is defined in the Rules on the operation of the electricity market (3). The Distribution System Operator estimates the electricity losses which occur during the operation of individual distribution network areas for the purpose of balance settlement on the basis of the past accounting data in the preceding three calendar years (3). The estimated losses in the distribution network area are calculated in each accounting interval by multiplying the quotient of losses by the total accepted energy of the distribution network area in the same interval.

FORECAST ACCURACY PRICING MODEL AND DATA

In the rest of the paper, we focus on the value of accuracy costs, *S*, and study their relation to the accuracy of the forecast. The accuracy of the forecast is measured as its Mean Absolute Percentage Error, and we want to derive *S* as the function of MAPE. We do this using a Monte Carlo simulation, whose inputs are:

- the exact, validated time series on energy usage (specifically, the time series of energy used to cover losses of a Slovenian Distribution System for the period 2011-2014),
- the price C_0, at which electricity for each period was purchased, and
- the time series of prices resulting from validated balancing expenses, i.e. C_+ and C_- for each hour of the same period.

Using this data, we simulate the accuracy costs using the current Slovenian balancing mechanism (3) for many different hypothetical forecasts. Each simulation is shown as a dot in Figure 1, with horizontal axis displaying the MAPE and the vertical axis displaying the accuracy costs. As can be seen, the scatter plot is linear up to small perturbations due to randomness of the simulation, and the regression on this data produces a linear function $S = p \times MAPE$, where *p* is the EUR amount expressing the cost of a single percentage point of MAPE for absolute costs and EUR/MWh amount for relative costs. The coefficient of determination is very high, $R^2 > 0{,}9985$, thus showing an almost completely linear relationship between MAPE and accuracy costs *S*.

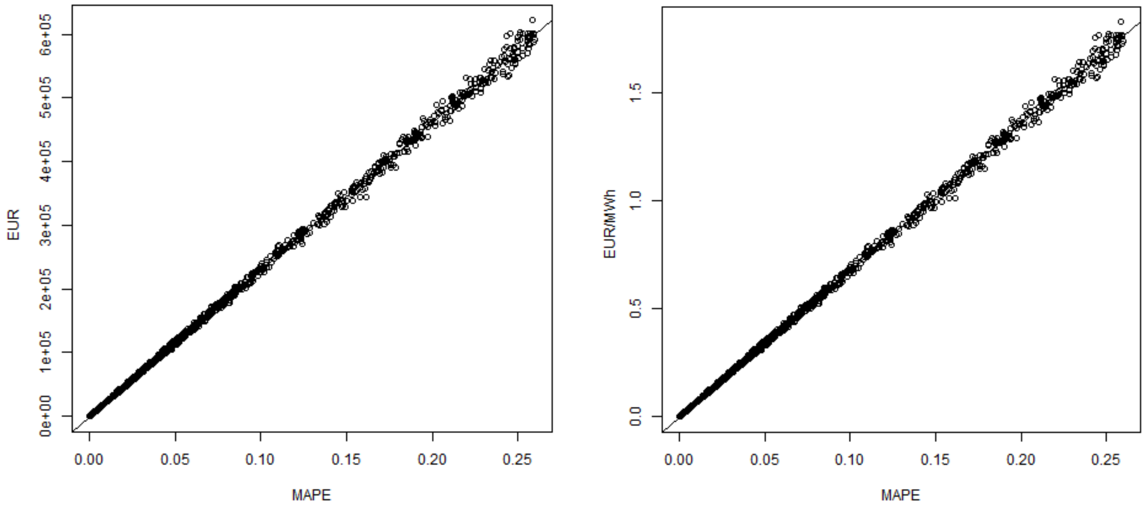

Figure 1: Dependence of the accuracy costs on MAPE for a particular energy usage time series: absolute costs in EUR (left) and relative costs in EUR/MWh (right).

Similarly as the absolute expenses in EUR, the relative expenses in EUR/MWh can be estimated as a function of MAPE. They show the same linear behaviour.

EVALUATION RESULTS

Table 2 shows the value of coefficient *p* in the case of linear dependence of absolute accuracy costs on MAPE (row two), and the value of the coefficient *p* in the case of linear dependence of relative accuracy costs on MAPE (row three), together with the standard error of the corresponding linear models. The results show that for the specific time series, i.e. for covering the losses in the Slovenian distribution grid, a percentage-point increase in MAPE results in just over 39.000 EUR annual savings. On the other hand, each MWh of energy purchased to cover these losses yields an average price of 6,76 cEUR per percentage point of the forecasted accuracy.

Table 2: Regression coefficients of the linear dependency of accuracy costs on MAPE

Coefficient *p*	Unit	Value	Std. error
Absolute	EUR/year	39.054	47,65
Relative	cEUR/MWh	6,76	0,00828

DISCUSSION AND CONCLUSIONS

The results show that in the case of purchasing energy to cover losses in Slovenian distribution system, the cost of accuracy depends linearly on the MAPE of the forecasted usage. This linearity is based on the special regime under the balance settlement mechanisms, as the errors are not progressively penalized when exceeding the tolerance interval in the case of covering losses (3). For a general market participant, the behaviour demonstrated is valid when MAPE is well within the tolerance interval (i.e. below 5% MAPE value), or when exceeding the transitional zone of growing penalty, i.e. after 20% MAPE value. Between these two regimes, cubic dependency of *S* on MAPE is expected due to a quadratic term in the definition of the penalty price (3). However, the results presented here establish a lower estimate of the cost of accuracy of electricity balancing. As electricity losses are frequently estimated to be a fixed percentage of total energy usage (3), the overall usage profile of electricity usage in Slovenian distribution systems follows the same shape of hourly diagram as energy losses. Hence we can quite safely estimate that the benefit of a percentage point of improvement in forecasting accuracy in total Slovenian energy consumption is at least 6,5 cEUR per MWh consumed, rising to twice this value as MAPE grows. Given that the total consumption of Slovenian distribution in 2014 was 10.323 GWh (4), the overall annual benefit of improvement of all Slovenian electricity forecasts by one percentage point is estimated to be at least 670.000 EUR. A calculation of these figures for specific consumption time series allows each market participant to estimate their own benefits from improving the accuracy of their own forecasts, thus enabling each of them to find a financial balance between accuracy benefits and expenses of obtaining it. Furthermore, such an investigation would help the electricity market operator to fine-tune the parameters of balancing mechanism and incentivize the accuracy of market forecasts enabling desired stability and quality levels of power supply.

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