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Review report on Bartosz Uniejewski's doctoral dissertation titled: *Forecasting wholesale electricity prices to support decision-making in power companies: Use of regularization and forecast combinations*, prepared under the supervision of prof. dr hab. Rafał Weron (supervisor) and dr Katarzyna Maciejowska (assistant supervisor).

The doctoral thesis of Bartosz Uniejewski is dedicated to the development of robust techniques for forecasting electricity prices and demonstrating potential areas of application for these forecasts in the decision-making process of energy market participants. The dissertation consists of two parts. In the first part, which is 40 pages long, the thesis covered the most important scientific achievements, showing a broader perspective and commenting on those elements that are crucial in the decision-making process under risk conditions. In the following part, the original articles that are the basis of the scientific achievement are presented. In total, the doctoral thesis consists of 128 pages.

All of the papers that constitute the doctoral dissertation were written in co-authorship, with one of the co-authors being the main or assistant supervisor each time. This demonstrates an exemplary model of cooperation between experienced researchers and young adepts and proves the continuous development of extremely resilient human capital, thanks to the efforts of Professor Rafał Weron and his team, the world's leading energy market research center for years.

In the case of three papers (article 1, 3, 4), the role of Bartosz Uniejewski is leading, while in the remaining two, his contribution is equal to that of the other co-authors. This shows that the candidate demonstrates the ability to work in a team in various roles, including as a leader.

Four out of five articles that make up the doctorate were published in reputable journals (International Journal of Forecasting, Energy Economics), the last in a scientific encyclopaedia (The Oxford Research Encyclopedia of Economics and Finance). In total, Bartosz Uniejewski

is a co-author of 13 papers in which problems related to price forecasting on the electricity market are addressed. All these studies are published in recognised journals and contribute to an impressive number of citations and bibliographic indicators for this stage of his career.

The doctoral thesis includes five independent objectives. The first two refer to the construction of forecasting models that offer the best predictive properties. The third objective extends the first two in the sense that it offers interval (probabilistic) forecasts in addition to point forecasts. The fourth objective is specific because it emphasizes that in the case of price forecasting on the electricity market, market participants have an asymmetric loss function, and the forecasting process should take this condition into account. All these goals have a common factor, namely they use LASSO regularization. Finally, the last goal is to try to conjecture what research areas related to forecasting on the electricity market will become crucial in the near future.

It is obvious that Bartosz Uniejewski made a careful selection of the goals of this doctoral dissertation based on the conducted research, choosing only a part of his rich scientific achievements, but I must admit that all goals are logical, coherent, and treated separately they are ambitious, interesting and important from the point of view of the application. In addition to the undoubtedly important methodological context, the PhD candidate shows that he understands the conditions and specificity of the electricity market very well.

The first article has two achievements, empirical and theoretical. The first is the exploration of the intraday electricity market (the German EPEX), and the second is the demonstration that using LASSO regularization for variable selection leads to competitive energy price forecasts. The study also showed that the intraday market operates under different principles than the day-ahead market. Additionally, the paper presented the relationship between the level of regularization or the number of variables in the ARX model and the overall forecast accuracy. Finally, it suggested that LASSO parameters require optimization for different states of the electricity market.

The second paper proposes using Principal Component Analysis (PCA) to aggregate information from forecasts obtained from models estimated for different estimation windows, and then using LASSO to select the best principal components from the point of view of forecast accuracy. The results obtained indicate that the combination of PCA and LASSO outperforms approaches in which each component was separately applied, and is a good solution for automating forecasting tasks. It was also noted that more accurate forecasts are obtained when algorithms for individual energy markets are calibrated.

The third article applies and examines a proposal to combine separately modeled trend and seasonality components with a stochastic component (Seasonal Component AutoRegressive, SCAR for short) to build probabilistic forecasts. The main achievement of the study is to show that SCAR almost always "outperforms" typical benchmarks when considered in the context of probabilistic forecasts, but is also more accurate than the bootstrapping and historical simulation methods.

In the fourth article, a combination of LASSO regularization and Quantile Regression Analysis (LASSO QRA) was proposed to construct interval forecasts and a comprehensive comparison with benchmarks. The study conducted for two electricity markets showed the advantage of the proposed approach, especially when the "tuning" of the model is automatic.

In such cases, the resulting forecasts were more accurate and precise. Importantly, the study presented a strategy that, using hourly forecasts, can offer additional profits to a market participant with energy storage.

The fifth article identifies the most promising directions for research related to forecasting prices in electricity markets. Given that Bartosz Uniejewski, as well as his supervisor and assistant supervisor, themselves represent a leading stream in this area of research worldwide, the proposals belong to the category of self-fulfilling predictions.

Bartosz Uniejewski places the achievements presented in the doctoral dissertation in the discipline of Management and Quality Studies, and more precisely in the decision-making process of electricity market participants. He rightly notes, referring to the relevant literature, that in the case of the electricity market, decisions are accompanied by risk. Operational decisions related to offering energy or ordering it by market participants require forecasts of energy prices, regardless of whether the market participant operates on the regular market or over the counter. Accurate forecasts directly affect the improvement of financial results. In the context of risk, it is important to provide accurate and reliable forecast intervals, which is particularly important in the event of extreme phenomena and high price volatility. The context of the research presented in the dissertation is accurate and deep, which proves that the knowledge of Bartosz Uniejewski goes beyond the area of statistics and forecasting, covering issues related to the functioning of energy market.

Summing up, the presented results are extremely valuable from the point of view of developing forecasting methods and have great application values. The common feature of the presented articles is ingenuity, combining knowledge from various areas of statistics, and all this has been supported by a very meticulous analysis that makes the results credible. This does not mean, however, that the presented doctoral dissertation does not provoke some questions or comments.

When building forecasting models, attention is focused on assessing the accuracy or precision of forecasts, but usually economic interpretation is omitted. As a result, the user knows what algorithms lead to "good" predictions, but does not understand why this happens. Is it then possible, and is it justified, to propose such interpretations? Is it reasonable to identify variables or categories of variables that are crucial for a given type of market? In the fifth article (page 7), it was mentioned that even the data preparation process, which previously required a series of human decisions, is now increasingly automated. So, are we getting closer to a situation where we don't need to understand the market to make good forecasts, and is there a real threat that soon the role and presence of human "supervision" over algorithms will be completely reduced?

Is there space to include meteorological data in the models, or is these information proxied by the variables previously used in the models? Is there a difference between day-ahead and intraday markets in the use of this data?

When proposing an investment strategy (article 4), it was assumed that the market participant already has an energy storage and might use it for arbitrage. Is it possible to estimate the maximum cost of having such an energy storage facility in a reasonable period that would allow maintaining a positive financial result?

The doctoral dissertation of Bartosz Uniejewski, is of undeniable value, which results from several factors. Firstly, it raises current issues in the field of forecasting theory, and at the same time stems from the mechanisms of functioning of electricity markets. The results obtained are unique and highly valuable, both from the perspective of theory and practice, i.e. management of a company operating in the energy sector. Moreover, the scientific achievements, including the five publications constituting the basis of the dissertation, belong to the international scientific achievements and constitute the essence of the research trend in the field of electricity price forecasting. All PhD students should strive to achieve such a degree of internationalization of their research and scientific activity. I am very happy that doctorates of such a high scientific level are prepared at Polish universities, that there are centres in Poland where world-class research is conducted, and where students can learn from the best.

To sum up, I would like to emphasize that the reviewed dissertation meets all the requirements of a doctoral dissertation with a large margin, and therefore I request Bartosz Uniejewski, to be admitted to the further stages of his doctoral procedure, leading to the award of a doctoral degree in the field of Social Sciences and the discipline of Management and Quality Studies. Due to the exceptional qualities of the doctoral thesis, I am applying for awarding Bartosz Uniejewski, an appropriate award.

Yours sincerely,

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Associate professor