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Review of doctoral dissertation of Bartosz Uniejewski MSc

"Forecasting wholesale electricity prices to support decision-making in power companies: Use of regularization and forecast combinations"

This document was prepared in response to information number 9/3/D12/2023 issued on March 29, 2023 referring to resolution of Scientific Council of Management and Quality Studies of Wrocław University of Science and Technology asking for a review of doctoral dissertation "Forecasting wholesale electricity prices to support decision-making in power companies: Use of regularization and forecast combinations" prepared by Bartosz Uniejewski MSc.

The review is prepared in reference to the requirements specified in act "Prawo o szkolnictwie wyższym i nauce" Dz. U. z 2021 r. poz. 478 with later changes (Act).

In the first part of the review I evaluate meeting of the formal requirements by the dissertation, and next I present an assessment if, following art. 187 pkt. 1 and 2 of the Act, it meets the following requirements:

1. Doctorial dissertation presents general theoretical knowledge of the candidate in the area of management and quality studies.
2. The candidate exhibits the ability to perform the scientific research in an independent way.
3. The dissertation presents an original solution to the research problem.

The review is finished by the conclusion and recommendation.

Evaluation of formal requirements

The dissertation has a form of cycle of articles having the same subject and is prepared in the English language. It is accompanied by an abstract in Polish and English language. Therefore it meets the requirements specified in art. 187 pkt. 3 and 4 of the Act.

The dissertation consists of 5 papers. Every paper is prepared in co-authorship. The co-authors are mostly with the supervisors. In 4 papers the candidate is the first author and his contribution is assessed as at least 50%. In the fifth paper, where the candidate is not the first author the contribution is assessed as 1/3. The reported values meet the requirements to formally accept them as a basis for evaluation in doctoral degree process.

The subject of the dissertation is support of decision-making processes in power companies by application of models allowing for forecasting of wholesale electricity prices. In particular, the candidate evaluates in the dissertation energy trading strategies supported by such forecasting models. Therefore the subject of the research is within the management and quality studies research discipline.

Detailed review of scientific merit of the dissertation

Dissertation of Bartosz Uniejewski MSc has 128 pages and is written in the English language.

The dissertation consists of the overview of the research that constitutes 40 pages and five research papers:

1. Uniejewski, B., Marcjasz, G., Weron, R., 2019b. Understanding intraday electricity markets: Variable selection and very short-term price forecasting using lasso. International Journal of Forecasting 35, 1533–1547.
2. Uniejewski, B., K.Maciejowska, 2022. Lasso Principal Component Averaging – A fully automated approach for point forecast pooling. International Journal of Forecasting, 2022, DOI: 10.1016/j.ijforecast.2022.09.004.
3. Uniejewski, B., Marcjasz, G., Weron, R., 2019a. On the importance of the long-term seasonal component in day-ahead electricity price forecasting: Part II – Probabilistic forecasting. Energy Economics 79, 171–182.
4. Uniejewski, B., Weron, R., 2021. Regularized quantile regression averaging for probabilistic electricity price forecasting. Energy Economics 95, 105121.
5. Maciejowska K., Uniejewski B., Weron R., 2023. Forecasting Electricity Prices. In: The Oxford Research Encyclopedia of Economics and Finance, DOI (arXiv): 10.48550/arXiv.2204.11735.

In the dissertation the candidate states that its objective is to develop robust electricity price forecasting techniques and this term is used in the thesis multiple times. Therefore it would be valuable if the dissertation defined how the candidate understands the *robust* term and how it is possible to test if some proposed method has this property.

The research objective 1 is to use LASSO method for feature selection to build well-structured forecasting models without the need for expert knowledge. Since the thesis is defended in management sciences I would welcome a more detailed elaboration in the text why this is indeed valuable, i.e. a review in what aspects relying on expert knowledge (possibly in combination with analytical techniques) might lead to challenges in building predictive models. Especially that later it is said that "Regressors are selected from a set of explanatory variables assumed to be correlated with electricity prices, based on in-sample analysis." and simple functional form is advocated for because they are interpretable and easier to explain (which implicitly assumes involvement of an expert and expert judgement in the process). I agree with the later statement of the candidate that "they allow designing sparse models that are much easier to interpret and faster to estimate than dense multi-parameter models without a significant loss in forecast accuracy", but I would expect a detailed managerial analysis of why these two factors are important. For example a justification that estimation time of more complex models is indeed a prohibitive factor for their application in practice.

The candidate focuses on LASSO regularization. I would welcome more justification why this form of penalty was chosen, as other options (e.g. non-convex penalties) are considered in the literature. Also the text refers to the works of Tikhonov (1963). I think it is also useful to mention the pioneering work of W. James, and C. Stein, Estimation with quadratic loss, Proc. Fourth Berkeley Symposium, 1, 361–380, Univ. California Press (1961) in this area (and later extensions including shrinking to other values than the origin and a positive-part James-Stein estimator). *I recommend that during the thesis defense the candidate discusses the main findings of this stream of research*.

Regarding the general specification of estimator used, as given in equation (4.2), the candidate penalizes all parameters of the model. I think it would be worth to comment on the reason for this choice of penalty, as a frequent alternative is to allow in the model for a constant term which is not penalized. Additionally the candidate writes "The value λ in Eq. 4.2 indicates how significant the variables have to be to remain in the final model.". However, the precise meaning of this statement depends on how the X matrix is prepared. In particular if e.g. transformation of the features in the model is performed or not. This aspect is not mentioned in the description. It is later explained in the Paper 1, where the candidate specifies that VST transformation is used for the target variable and explanatory variables (except the weekly dummies). Indeed in this case penalizing all parameters can be justified but it is not discussed.

I assess the results presented in Paper 1 related to this objective as valuable scientifically. I would like to make one remark here. In the description of the results the candidate stresses that LASSO is used to select variables. However, in practice it performs both variable selection and parameter shrinking for variables kept in the model. This is a different approach to using LASSO only to select variables (a preprocessing step) and then use a separate estimation step to build a final model. Indeed the candidate tests it by building the $ARX_{x\%}$ models. However, the results of this comparison were not fully comprehensive to me. *I recommend that during the thesis defense the candidate gives a more detailed discussion of quality of the models obtained using LASSO only for variable selection vs also for shrinkage of estimated parameters.*

The idea of combining forecasts, covering objective 2 of the paper, is interesting and valuable scientifically. The performance of the developed LPCA method in comparison to other methods is convincing, and the study was conducted diligently. What would be interesting is checking how Bayesian Model Averaging (both applied to raw predictions and on PCA components) would perform in comparison to the approach proposed in the text. This time the candidate uses the N-PIT transformation of the values. There is one technical issue with it. One cannot use ECDF directly in this model as it would lead to inability to apply quantile of normal distribution for extreme values (but it is easily fixed by transforming ECDF so that it never produces 0 and 1 values). *What I found interesting, and not discussed in the text, that in Paper 1 the VST transform is used, while in Paper 2 N-PIT is used. I would like the candidate to discuss why different transforms were used in these works and what are their relative strengths and weaknesses.*

Objective 3 is related to probabilistic forecasting of energy prices. Again, in my opinion this is a well-chosen and justified research topic.

The finding that taking into account long-term component is useful for short-term predictions is an important contribution. *During the defense I recommend that the candidate discusses possible economic explanations behind this finding (i.e. what extra information that is not captured in other features does long-term component have and what are the underlying reasons for this).*

Apart from this finding I also consider the discussion of various approaches to averaging of probabilistic forecasts and introduction of LQRA method as valuable results.

Objective 4 is the most valuable contribution from the perspective of management sciences. It directly links the predictive methods studied in the dissertation with managerial decision processes. The analysis of effectiveness of different trading strategies is directly applicable in business practice. In the description of the strategies there is one imprecise element. I was not sure if there is an assumption that exactly one buy and sell bid must be made on each day. In general a usual practice is that a full specification of the optimization model using mathematical notation should be presented in the paper. *As an*

element that I would find valuable to be discussed by the candidate during the defense is how much additional gains would be possible if we did not assume that exactly one trade per day should be made (for example that we allow to keep the battery loaded and decide not to sell). Especially with consideration of amortized cost of one charge-discharge cycle.

Objective 5 to "conduct a critical review of forecasting in the electricity markets and provide an outlook for future research in this area" and related paper should be treated as a supplementary information from the perspective of dissertation evaluation. The reason is that they do not solve a research problem directly. However, it contributes to showing general theoretical knowledge of Bartosz Uniejewski in the scope of the dissertation, which is part of the evaluation criteria.

Conclusion

The research result of the dissertation is development of several methods for prediction of wholesale electricity prices and showing that these methods can be applied to support managerial decision-making. In my opinion the quality of the obtained results is significantly above the typical expectations for dissertations in the management and quality studies discipline.

In relation to the requirements of the Act my opinion is:

1. The dissertation presents the general knowledge of the candidate in the discipline of management and quality studies. In particular Paper 5 presents an overview and outlook of research directions in the domain of forecasting of electricity prices.
2. The candidate has shown the ability to perform research, which is proven by already published Papers 1, 2, 3, and 4. The results presented in these papers are original and valuable scientifically and the preparation of the papers shows that the candidate has the required practical skills in scientific writing.

The comments presented in the review have minor weight and do not influence the overall positive evaluation of the dissertation as excellent.

In summary, the dissertation meets the requirements of the Act in the discipline of management and quality studies and I recommend to allow for its public defense.

Additionally, because of the quality of the obtained results I recommend distinction of the dissertation. The main arguments for giving an award are:

1. The number and quality of the published results are exceptional. As of the day of this writing the total number of citations of works of Bartosz Uniejewski as reported by Google Scholar is 724, and h-Index of 11. Such values would be evaluated as very good even for applicants for habilitation degree in Polish educational system.

2. Apart from the aggregate assessment of the results, analyzing them individually exhibits that they have high theoretical and applicational value. In my opinion the most important results in this scope are:
    a. Results in applications of model regularization and model averaging both for point and probabilistic predictions of electricity prices.
    b. Results in evaluation of trading strategies that take advantage of the probabilistic predictions of electricity prices.
    c. Assessment of importance of long-term seasonal component in day-ahead electricity price forecasting.

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Bogumił Kamiński