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Summary of professional accomplishments

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1. Education and professional work

In the years 1998-2003 I studied at the College of Inter-faculty Individual Studies in Mathematics and Natural Sciences at the University of Warsaw, which allowed me to get a master's degree at the Faculty of Mathematics, Informatics and Mechanics in two fields, at the same time: the first master's degree in computer science (grade: 6, title: *Deterministic algorithm of recognizing prime numbers – logical approach*) and the second in mathematics (grade: 5, title: *Parallel algorithms with the use of backward differentiation formulas*). At the same faculty, I started doctoral studies, which I graduated in 2008, obtaining a Ph.D. in the discipline of mathematics with specialization in applied mathematics. My Ph.D. thesis entitled *Dirichlet-Neumann methods for solving in parallel discretization of elliptic problems* was prepared under the scientific supervision of prof. dr. hab. Maksymilian Dryja.

Since December 2009 I am working as an assistant professor at the Department of Probabilistic Methods in the Institute of Econometrics of the Collegium of Economic Analyses at the Warsaw School of Economics. In addition, since 2003, I have been teaching lectures mainly of the mathematics and informatic character, including the Faculty of Mathematics, Mechanics and Computer Science of the University of Warsaw in the years 2003-2012 and 2018-2019, and the Faculty of Management in Ciechanów of Wyższa Szkoła Menedżerska w Warszawie in 2006-2009.

I use my experience in the field of programming, algorithmic and mathematical-econometric modeling in commercial applications, among others in 2012-2014 as a specialist in econometric modeling in the Systematic Planning for Development of Wind Energy project in Lubelskie, in 2013-2014 in the Institute for Structural Research as a numerical expert in the Morfa project, as well as in 2014-2016 in BPO Poland as Big Data analyst and since 2016 at Cloud Technologies S.A. as an expert in mathematical modeling.

Since 2015, I'm also the Head of the Center of Physical Education and Sports at the Warsaw School of Economics, since 2010 I have been the President of the Academic Sports Association of the Warsaw School of Economics and since 2018 scientific supervisor of the Students' Scientific Association of Management in Sport.

2. Scientific accomplishment presented for assessment

The development of computer science, both in the field of constructing more powerful hardware and computationally efficient algorithms, has contributed to a significant expansion

of their use in various fields of science. However, advanced calculation methods requiring the use of computer programs and hardware commonly used in one area of science may be almost unknown in other areas.

The Markov chain theory has been known for decades and has fundamental meaning in the modeling of many natural, technical and economic phenomena (Podgórska et al., 2002). The generalization of Markov models, known as hidden Markov models (HMM) or switchable Markov models, appeared in literature in the 1960s (Cappé et al., 2005) and was used, among others, in recognizing speech, signals, handwriting, or in bioinformatics for DNA sequencing. Relatively little space has been devoted to this great method of automatic pattern recognition in economic sciences. Skills and knowledge acquired by me during the years of learning mathematics and computer science allowed for their perfect combination with econometrics, which resulted in the construction of algorithms that use hidden Markov models and their application in economic sciences. The description of these applications has been included in a cycle of ten thematically linked articles, which I present for assessment as a habilitation accomplishment, entitled: "**The use of hidden Markov models in economics and finance, with the emphasis of business cycles**".

[1] Bernardelli M., Dędys M., *Ukryte modele Markowa w analizie wyników testu koniunktury gospodarczej*, Badanie koniunktury – zwierciadło gospodarki. Część I, pr. zb. pod red. Konrada Walczyka, "Prace i Materiały Instytutu Rozwoju Gospodarczego", IRG SGH, Warszawa 2012, No. 90, pp. 159-181.

- MNiSW: list B, 7 p.

[2] Bernardelli M., *Non-classical Markov models in the analysis of business cycles in Poland*, "Roczniki" Kolegium Analiz Ekonomicznych SGH, No. 30, Oficyna Wydawnicza SGH, Warszawa 2013, pp. 59-74.

- MNiSW: list B, 6 p.

[3] Bernardelli M., *The procedure of business cycle turning points identification based on hidden Markov models*, Analyzing and forecasting economic fluctuations. pr. zb. pod red. Konrada Walczyka, "Prace i Materiały Instytutu Rozwoju Gospodarczego", IRG SGH, Warszawa 2015, No. 96, pp. 5-24.

- MNiSW: list B, 8 p.

[4] Bernardelli M., Dędys M., *The Viterbi path of hidden Markov models in an analysis of business tendency surveys*, Analyzing and forecasting economic fluctuations. pr. zb. pod

red. Konrada Walczyka, "Prace i Materiały Instytutu Rozwoju Gospodarczego", IRG SGH, Warszawa 2015, No. 96, pp. 25-47.

- MNiSW: list B, 8 p.

[5] Bernardelli M., Dędys M., *Przełącznikowe modele Markowa w analizie synchronizacji cykli koniunkturalnych*, "Roczniki" Kolegium Analiz Ekonomicznych SGH, No. 39, Oficyna Wydawnicza SGH, Warszawa 2015, pp. 213-227.

- MNiSW: list B, 9 p.

[6] Bernardelli M., Dędys M., *Mapping the respondents' assessments in the RIED manufacturing tendency survey using the Viterbi paths*, Niepewność a aktywność gospodarcza. pr. zb. pod red. Konrada Walczyka, "Prace i Materiały Instytutu Rozwoju Gospodarczego", IRG SGH, Warszawa 2017, No. 101, pp. 27-44.

- MNiSW: list B, 8 p.

[7] Bernardelli M., Próchniak M., Witkowski B., *The Application of Hidden Markov Models to the Analysis of Real Convergence*, Dynamic Econometric Models, Vol. 17 (2017) 59−80, http://dx.doi.org/10.12775/DEM.2017.004.

- MNiSW: list B, 13 p.

[8] Bernardelli M., Próchniak M., Witkowski B., *Przydatność ukrytych modeli Markowa do oceny podobieństwa krajów w zakresie synchronizacji wahań cyklicznych i wyrównywania się poziomów dochodu*, "Roczniki" Kolegium Analiz Ekonomicznych SGH, No. 53, Oficyna Wydawnicza SGH, Warszawa 2018, pp. 77-96

- MNiSW: list B, 9 p.

[9] Bernardelli M., *Hidden Markov Models as a Tool for the Assessment of Dependence of Phenomena of Economic Nature,* Acta Universitatis Lodziensis. Folia Oeconomica nr 338(5)/2018, pp. 7-20, http://dx.doi.org/10.18778/0208-6018.338.01.

- MNiSW: list B, 14 p.

[10] Bernardelli M., *Ocena korelacji wyników testów koniunktury z wykorzystaniem ukrytych modeli Markowa*, pr. zb. pod red. Konrada Walczyka, "Prace i Materiały Instytutu Rozwoju Gospodarczego", 2018, Warszawa, No. 100, str. 57-87.

- MNiSW: list B, 8 p.

Hidden Markov models have a number of advantages, which – especially in recent years – have been reflected in the number of applications in economics and finance. My work on the applicability of the HMM-based approach in broadly understood business surveys allowed for

a fresh look, which in combination with classical methods seems to be a big step forward in the process of automation of analysis and inference. My research has given the opportunity to develop alternative methods of analyzing issues in the field of business cycles – effective, easy to interpret, and above all characterized by weak assumptions of applicability. The results of these studies were published in the aforementioned articles, which for transparency were divided into four areas of economically important applications:

1. identification of turning points of the business cycle (articles 1-4),
2. synchronization of business cycles (articles 5-6),
3. convergence analysis (articles 7-8),
4. time series similarity measure (articles 9-10).

The listed applications are linked by one common proposed toolset, namely the combination of hidden Markov models and Viterbi paths. The procedure based on these tools, as shown by empirical analysis, is a sophisticated method from the borderline of computer science, mathematics, econometrics, and operational research, which gives opportunities for wide application in economic sciences. In the following subsections, the use of HMM in the four areas of application is described. It has been emphasized the added value of each of the articles and summarized the validity of the Baum-Welch and Viterbi algorithms.

2.1. Identification of turning points of the business cycle

My initial research with the use of hidden Markov models focused on the possibility of identifying turning points of business cycles. There are works (see, for example, Chauvet and Hamilton, 2005), in which this type of tool was used for that purpose. In general, however, Markov chains with an only two-element state space were considered. Additionally, in econometric studies (Hamilton, 1994), filtered or smoothed probabilities, which determines the state of the hidden Markov chain at any time of time independently, are usually used to find the unobservable variable.

The cycle of publication presented for assessment as a habilitation accomplishment is opened by the article [1], which contains an introduction to hidden Markov models described in the context of stochastic processes[1]. The research presented in the article included not only a two-element but also a three-element space of states. Above all, however, an alternative approach to assessing the states of the hidden Markov chain, namely the Viterbi algorithm, was

[1] HMM theory may be presented using probabilistic automaton terminology, see e.g. article [3].

used. It allows to find the so-called Viterbi path, that is, the sequence of states that is most probable, taking into account the observed values throughout the entire period, not just – as with filtered and smoothed probabilities – at a given moment. Such a global approach seems to be much more adequate from the point of view of studying the economic situation. In the article [1], the combination of HMM and Viterbi paths was used to analyze the balances of the respondents' questions to the business tendency survey conducted by the Research Institute for Economic Development of Warsaw School of Economics (RIED SGH). In the article respondents' answers to questions regarding the assessment of the current economic situation in Poland were considered. Data came from March 1997 to August 2011. The aim of the research was to determine the potential of the method by confronting the obtained results with the turning points of the business cycle dated by OECD (cycle of deviations) and (Drozdowicz-Bieć, 2012) (classic cycle). In addition, to the analysis of signals processed using the three-state HMM, the dating dates of the cycle deviations defined by Drozdowicz-Bieć (2008) were used. The results of the empirical analysis prove the high accuracy of the proposed approach and speak for using models with Markov chains with three states. Signals about the change of climate are very often delayed compared to the dating of turning points in the reference time series. This is due to the fact of the pre-emptive character of the reference indicators.

In the article [2], again the data from the business tendency survey in the manufacturing industry conducted by RIED SGH was used. However, the research has been extended to allow the use of the panel nature of the input data. Combinations of pairs of balances of respondents' responses have been taken into account, and the obtained results were compared with the results of calculations for input data consisting of single time series of balances, as well as with the available reference series (deviation cycle and classical cycle). The analyses were carried out for Markov chains with two, three and four states, and additionally, time series shifts were included to assess the leading or following character of the tested time series in relation to the reference time series. For the comprehensive analysis, the improved procedure of identification of turning points was used. This procedure was developed as a result of research and empirical analysis[2]. My approach proposition to combine HMM and Viterbi paths proved to be extremely flexible, making possible to use not only a different number of states but also multidimensional input data with different probability distributions (in the empirical analysis a normal distribution

[2] The results of the research were published, among others in Bernardelli M., *Kryteria optymalizacyjne w procedurze wykorzystującej ukryte modele Markowa do analiz danych ekonomicznych*, Rola informatyki w naukach ekonomicznych i społecznych. Innowacje i implikacje interdyscyplinarne. red. Z. Zieliński, Wydawnictwo Wyższej Szkoły Handlowej, Kielce 2013, Tom 2, str. 43-53; Bernardelli M., *Nieklasyczne modele Markowa – problemy numeryczne*, praca badawczo-rozwojowa, SGH 2012.

was used), at the expense of longer calculation time. Increasing the number of hidden Markov chain states improves the quality of fit to the reference time series and extends the interpretability of the issue under investigation. Additionally, the use of a combination of appropriate time series of balances of answers to the questions of the business tendency survey in the industry gives a clear improvement measured by the number of incorrect matches.

Article [3] contains the full version of the procedure of the identification of turning points based on HMM. It is an extension of the procedure used in previous articles, taking into account aspects that have proved to be important from the point of view of the economic applicability, numerical stability, and accuracy of the approximation. The proposed procedure provides a highly automatic way to find a hidden pattern in the analyzed data (if it exists). It includes initial data transformation (time series decomposition), Monte Carlo simulations increasing the probability of obtaining a global maximum and ensuring numerical stability, Baum-Welch algorithm for deterministic computation of model parameters, averaging parameters within the found groups of solutions, Viterbi algorithm to determine in the entire analyzed period the most probable representation of states of the hidden Markov chain, and above all, the choice of the best model based on multicriteria optimization. The procedure defined in this way allows for considerable flexibility in the selection of parameters and components. In particular, various decomposition or deseasonalization methods can be used with ease, e.g. instead of the STL algorithm, the X-13 ARIMA-SEATS method. You can also choose the right set of optimization criteria.

It is worth stressing, that the procedure has its limitations of applicability. First of all, it is affected by the limitations of the Baum-Welch algorithm itself. It may happen that the applied iterative algorithm will not reach convergence. In the case of economic phenomena, however, we usually deal with smooth enough functions so that it does not constitute a significant limitation. Secondly, too short time series affect the insufficient number of degrees of freedom to obtain a meaningful approximation. Thirdly, due to the specifics of the input data, the obtained results may be uninterpreted. Such a situation may be caused, for example, by the lack of (unknown) regularity in the data, or too high variability implying the occurrence of a too chaotic pattern, to be considered acceptable for economic data. Depending on the data: their variability and the length of the considered time series, as well as depending on the number of hidden Markov chain states, the probability of finding the local optimum instead of the global maximum, changes. In order to decrease this probability, the number of Monte Carlo simulations should be increased, which translates into greater computational complexity.

Due to the theoretical limitations mentioned above, it is important to verify its suitability of the proposed procedure for data encountered in economic practice. This assessment, based on empirical analyzes, turns out to be highly positive. The effectiveness of the procedure has been demonstrated, among others, in articles in the cycle of publication presented for assessment as a habilitation accomplishment. First of all, comparative analyzes of turning points of business cycles identified on the basis of data from surveys with points dated by recognized institutions such as OECD (articles [1] - [4]), were carried out. These comparisons proved to confirm the effectiveness of the proposed approach. What's more, it turned out that HMM gave a more accurate indication, which was confirmed after the revision of turning points by the OECD. In the article [4] a comparison with "hard" macroeconomic data is made. The comparison of the turning points determined on the basis of the respondents' answers to the question about production volume and on the basis of the sold manufacturing production (in constant prices) shows that turning points have been identified in both time series, but downshifts of the reference time series were, in general, is signalled with a lead.

In the article [11][3], the HMM procedure was used to analyze data from the business tendency survey in road transport, namely the business activity indicator in internal transport (WKT), business activity indicator in international transport (WKTM) and the indicator of economic condition of transport (KE). Thanks to the turning points identification, periods assessed by the respondents as a better or worse economic situation in road transport were distinguished, and these assessments were compared with the phases of the business cycle of Poland and its largest neighbors. In addition, information provided by business climate indicators has been compiled with appropriately deseasonalized time series of real values, such as GDP, the value added of an industry, construction, transport, storage and communication, exports and imports. The changes in respondents' moods in the assessment of business activity segments mapped by the KE and the WKT indicators, turned out to be parallel to the OECD Composing Leading Index (CLI) and to fit relatively well into the business cycle of Europe. The most probable paths of three- and four-state Markov chains slightly better than two-state paths correlate with the changes in the economics in Poland, at least as regards signaling all phases of the business cycle.

[3] Bernardelli M., Dędys M., Ukryte modele Markowa w analizie wskaźników koniunktury w transporcie. [w:] Koniunktura w transporcie. Metodyka badań, wyniki, modele, red. S. Dorosiewicz, Instytut Transportu Samochodowego, Warszawa, 2013, s. 62–73/126 s.

Performed analyzes related to the identification of turning points of the business cycle prove the effectiveness of the proposed procedure using HMM. They also provide the basis for using this approach to construct an early warning indicator (compare Abberger and Nierhaus, 2010). However, this is a difficult task, because the change in the length of the given time series may result in a different realization of the states of the hidden Markov chain, which is the result of the Viterbi algorithm. Meanwhile, changes in historical indications are an undesirable phenomenon. Theoretically, such an event means a structural change of the model parameters, which, however, hinders the automation of calculations of the indicator and possible prediction rules. The combination of knowledge and experience in the areas of econometrics, computer science, and mathematics, however, allows us to believe that this task will be successfully accomplished and that it will be another milestone in business tendency surveys.

2.2. Synchronization of business cycles

The synchronization of business cycles, apart from the turning points identification, is another area of HMM applications (Krolzig, 1997; Smith and Summers, 2005; Dufrénot and Keddad, 2014). The procedure described and applied in articles [1] - [4] for the turning points identification was adopted in the articles [5] and [6] for the research of business cycles synchronization. The article [5] analyzes the time series of indices of industrial production in Poland, Italy, and Germany. The proposal to analyze the synchronization of business cycles of a pair of economies consisted of considering a two-dimensional observable component and a hidden Markov chain with four states that would reflect the business climate for both economies. Following (Philips, 1991) it was assumed that the state (0, 0) corresponds to periods in which both economies are in the slowdown phase and the state (1, 1) periods in which both economies are in the upward phase. Conclusions regarding possible interactions between economies are drawn, however, on the basis of Viterbi's paths, not on the basis of the HMM matrix of probabilities of transitions, which significantly distinguishes this work from previously published articles. The most probable path of the hidden Markov chain for a pair of economies was compared with analogous paths obtained for one-dimensional time series and models with two-state hidden Markov chains.

The results support the fact that the four-state Viterbi paths provide much richer information on the synchronization of the business cycles of the two economies compared to the conclusions that can be drawn from the two-state paths, especially when it comes to

identification of the turning points of business cycles of weaker economies. Signals about the end of the growth phase appear earlier than analogous signals in two-state paths.

The article [5] proposes also a method of local smoothing of the time series, which allows becoming independent of the HMM susceptibility to the relative size of the crisis or economic growth. In many applications, we are interested in detecting the change of the business climate, not the size of the change. Without the application of this solution, the effects of the financial crisis in 2008 were so deep that previous and subsequent crises would not be detected in the time series decomposition, due to their disproportionate size to the size of the 2008 crisis. The local smoothing method is another novel element, which allows for better calibration of the procedure parameters to improve its accuracy.

The procedure of testing the synchronization of business cycles based on HMM was used in the article [6], in which the advantages of Viterbi paths were presented. In particular, the focus was on answering the question about the relationship between responses of respondents to different questions of the business cycle test conducted by RIED SGH. The analysis included questions about the volume of production, volume of total orders, finished goods inventories, selling prices of products, level of employment, and financial standing. This issue was considered in the category of synchronization of business cycles constructed on the basis of various (one- and two-dimensional) input data, where, in addition, determining possible shifts between the examined time series was included.

Firstly, individual time series were studied. While this approach is an effective and convenient way of identifying the leader among the analyzed time series and with an easy interpretation of the results, in the case of the analyzed data from RIED SGH, none of the questions turned out to bring knowledge in advance greater than the others. Certainly, however, an increase in the number of states gives additional information about the phenomenon under investigation.

The study was also conducted for a two-dimensional case, in which the time series of respondents' answers to selected pairs of questions were taken into account. Despite the potential of this approach, attention should be paid to the difficulty in interpreting the results, due to the lack of an imposing order of states – unlike in the one-dimensional case. What's more, there is even no guarantee of the existence of model parameters that would correspond to the input data. In particular, for many combinations of the business cycle survey questions, the corresponding models could not be constructed due to the inability to achieve convergence of the iterative process. Hence, while a larger number of dimensions can give more information

about the studied phenomenon, the one-dimensional approach gives a greater chance of obtaining meaningful results from an economic point of view.

The article [6] also proposed an alternative way to visualize the states on the Viterbi path, which seems to be more accessible to present information on synchronization, including possible cycles shifts. This method allows for convenient comparison of the results of the procedure based on HMM for different sizes of the state space.

Synchronization of business cycles is not – at this stage of research – fully automated, but the proposed HMM-based approaches seem to contribute greatly to the development of this issue, while the potential seems to be still unused, leaving room for further improvement and research.

2.3. Convergence analysis

The idea of the next possible application of HMM in economics, i.e. the analysis of cyclical and income convergence, was born from the inspiration of the Head of the Department of Probabilistic Methods, dr. hab. Bartosz Witkowski, prof. SGH. His many years of experience and research in this area contributed to obtaining the grant[4] of the National Science Center "*On the use of hidden Markov models in the analysis of income-level and cyclical convergence with emphasis on the turning points"* with dr. hab. Mariusz Próchniak, prof. SGH, being the head of the project. Part of the results of these studies is described in articles [7] and [8], and more specifically, an analysis of the similarity of countries in the synchronization of cyclical fluctuations and equalization of income levels for 28 European Union countries, focusing on determining the similarity of Poland in relation to the other 27 countries the EU. The 12 macroeconomic variables from 1995-2016 were taken into account, above all, the level of GDP per capita according to PPS and the real GDP growth rate. The results of both analyzes have confirmed, among others, the occurrence of economic divergence during the global crisis and the strong nominal convergence of inflation rates between Poland and the EU-27 group. These results are consistent with the analyses of other researchers (e.g. Mucha, 2012; Monfort et al., 2013).

The key to these analyzes is the application of a new approach that uses the identification of turning points with an algorithm described and used in all the works included in thematically

[4] Detailed information on participation in research projects is presented in Section 3.3 and Attachment No. 4, point II G).

linked articles presented for assessment as a habilitation accomplishment. Turning points were determined[5] for 324 time series being differences of the respective 12 variables from 27 pairs of countries: Poland and subsequent countries from the EU-27 group. Due to the shortness of the series, numerical stability of the results and ease of interpretation two-state HMM were used: state 0 means the year in which the countries in terms of the analyzed variable were similar, while state 1 indicates a discrepancy between countries. The difference in the conducted research described in articles [7] and [8] occurs at the final stage of the proposed convergence analysis procedure, namely in the first of these studies, for each year the obtained states of Viterbi paths are averaged. After such aggregation, the value 0 means perfect convergence (similarity), while the year in which the arithmetic mean equals 1 means the period of indisputable lack of similarity (divergence) between Poland and other EU countries. Calculations using an arithmetic mean, however, imply that each of the EU-27 countries has the same meaning to determine the occurrence of convergence or divergence. Meanwhile, the size of the economies of countries in the EU differs significantly. Therefore, the more economically significant results seem to be given by the approach presented in the article [8], in which the modification of the average was added in the last step of the convergence analysis procedure. Instead of the arithmetic average, to use weighted averages was proposed, where the weights should correspond to the size of the economies of individual countries. In this study, the analysis was carried out for weights proportional to the number of inhabitants of individual countries. The results show, in some aspects, high robustness to the data aggregation method, but in some cases the obtained conclusions are different. It has been confirmed, among others, the real similarity of Poland to other EU countries in terms of GDP per capita levels according to PPS and GDP growth rates, with a short period of divergence during the global crisis. On the other hand, differences, partially significant, were observed at the rate of convergence in relation to the research with equal weights.

In addition to turning points identification and business cycles synchronization, the real convergence research is an example of successful application of the new HMM-based method. This method may be subject to further modifications and generalizations. For example, instead of weights related to the population, you can use e.g. the GDP of a given country. Analyzes can also be carried out for specific subgroups of countries. The presented method of assessing the similarity of countries can also be replaced by a procedure using a new measure of the similarity of time series, described in the next section.

[5] Due to missing data, it was not possible to obtain stable results for some variables.

2.4. Time series similarity measure

Assessment of the relationship between time series is an issue that is often erroneously from a methodological point of view, solved by the Pearson correlation coefficient. The methods of determining similarity, dedicated to time series, are predominantly those based on cointegration and using the idea of a copula (Lhermitte et al., 2011; Serra and Arcos, 2014). There are also distance measures that can be used for time series, such as Euclidean, Manhattan or Mahalanobis. The article [9] presents an alternative measure of the similarity of time series based on two-state hidden Markov models and Viterbi paths. In the proposed innovative method, states of the hidden Markov chain are determined for appropriately normalized time series being differences or sums of corresponding points of the examined time series (depending on the sign of the Pearson's correlation coefficient). On the basis of the Viterbi path, the r_{HMM} coefficient is calculated as an analog of the Pearson linear correlation coefficient r corresponding to the percentage of periods in which the analyzed time series behave similarly. For perfect similarity $r_{HMM} = 1$.

The proposed method is not universal, but it allows a fairly accurate reflection of the similarity between the time series. What's more, this approach makes it possible to distinguish periods in which the time series show a greater similarity to those in which they clearly differ from each other. The advantages of this method, besides the ease of interpretation of results, are also weak assumptions of applicability and the possibility of generalization. However, the key is the high effectiveness in assessing the dependence of various time series of an economic nature, confirmed on real macroeconomic data in the article [9], as well as on the survey data (article [10]).

The questionnaire data came from the business tendency survey in the manufacturing industry conducted by RIED SGH. The aim of the study was to determine the value of the r_{HMM} measure for pairs of balances of respondents' answers. The results of the study, in addition to verification of the suitability of the new measure, allow to assess the possible redundancy of questions. A high value of the r_{HMM} coefficient would mean that two questions carry the same volatility information in the respondents' assessments. The obtained results were compared with the values of Pearson's correlation coefficients. Considering the r_{HMM} coefficient, the ranks of respondents' answers to the questions of the business tendency survey in the manufacturing industry can be described as significantly different. Meanwhile, the values of Pearson's

correlation coefficients for some pairs of series show a degree of similarity, which would question the reasonableness of asking the questions in the survey.

Therefore, it seems that the scope of applicability of the proposed method of testing the similarity of time series is greater than the scope of applicability of Pearson's linear correlation, and the indications in the cases under consideration better reflect the actual degree of similarity of the time series. Not to be overestimated from the economic point of view, is the possibility of easy interpretation of the r_{HMM} coefficient. This approach can also be used as a method of studying the phenomenon of convergence as an alternative to that presented in articles [7] and [8]. Research in this area is ongoing and should be completed in 2019.

2.5. Main results and conclusions

The considered cycle of publication is combined by tools used in the analysis – hidden Markov models and Viterbi paths. The most important applications and results contained in ten articles include:

- The possibility of practically automatically identification of turning points of the business cycle. The quality of fitting to the reference time series, as well as the potential enrichment of the amount of information about the studied phenomenon, can be achieved by increasing the number of states from two (most commonly found in the literature) to three or four. By adding intermediate states, the HMM model processes the signals hidden in respondents' answers differently and thus gives hope for faster capture of information about climate change. Identification of turning points can be also improved by the use of panel data.
- Convenient methods for testing the synchronization of business cycles. The easiest to interpret is the combination of Viterbi paths for one-dimensional input data. The presentation of the results can be performed both in the form of a graph of a path of states (with the possible marking of periods in the same HMM state) or a set of states in the table. This allows us to track possible shifts in the examined cycles, and in the case of two economies, the dominant one.

  A more sophisticated approach is to study synchronization using two-dimensional input data. Despite the potential difficulties in the interpretation of results, due to the lack of ordering of states, such a method gives, if there is a clear pattern in the synchronization of two business cycles, greater opportunities.

- An innovative method of convergence analysis, allowing any sets of variables and countries. This computationally costly, but effective approach allows not only to say that convergence occurred but also to estimate its rate. In the aggregation phase of the results obtained for individual variables, it is possible to use both the usual arithmetic mean and the weighted averages of the economies of individual countries. The analysis carried out on the example of Poland and the EU-27 countries confirmed, among others the occurrence of nominal convergence of inflation rates and economic divergence during the global crisis.
- A similarity measure for the time series is expressed in the form of the coefficient $r_{HMM} \in \langle 0; 1 \rangle$, and additionally allows to distinguish periods in which the behavior of both time series is more similar than those in which they behave differently. Adequacy of the measure has been confirmed on selected, real macroeconomic data and on survey data.

A wide range of applications in finance and economics allows to draw the following conclusions regarding methods based on hidden Markov models and Viterbi paths:

- HMM is an effective approach to the analysis of time series and research of convergence and business cycles.
- The tool, treated as automatic pattern recognition, has low assumptions of applicability compared to econometric models.
- For macroeconomic and survey data, we get a high quality of fitting, provided that there is enough simulation (numerical stability), submitting the appropriate transformations (e.g. deseasonalization, local smoothing), as well as the existence of a pattern in the data.
- The results of procedures based on HMM and Viterbi paths are easily interpretable.
- The proposed procedure gives the possibility of easy generalization and modification.
- Increasing the number of states and the dimension of the input data allows you to improve the quality of fitting and enrich the returned information.

The previous experience and the knowledge gained in the research related to the described tool, which is HMM, also allow us to hope to use it for the construction of an early warning indicator. Forecasting seems to be a more difficult task to automate in comparison to the identification of turning points or historical analysis of time series, but in many cases, it was

possible to obtain signals about changes in the business climate in advance, which gives grounds for further research in this area.

Another, worth checking idea is the verification of the hypothesis about the usefulness of r_{HMM} coefficient in convergence studies, as an alternative to the HMM-based approach, but operating on the averages of the Viterbi path states.

Both directions of further research are in progress, and preliminary results will be presented at conferences in 2019.

3. Further scientific achievements

3.1. Further publications after obtaining the Ph.D. degree

My research after obtaining a doctoral degree was carried out in many ways. They were combined by the use of modern econometrics, mathematical, IT or statistical methods for analysis and economic inference. Below, selected publications have been described, which were not listed as thematically linked articles presented for assessment as a habilitation accomplishment. Publications have been divided due to the subject matter.

3.1.1. Other publications with analyzes based on hidden Markov models

[11] Bernardelli M., Dędys M., *Ukryte modele Markowa w analizie wskaźników koniunktury w transporcie.* [w:] Koniunktura w transporcie. Metodyka badań, wyniki, modele, red. S. Dorosiewicz, Instytut Transportu Samochodowego, Warszawa, 2013, s. 62–73/126 s.

Description of the results of the application of the procedure for the identification of turning points in research on the economic situation in transport. The periods assessed by the respondents as a better or worse economic situation in the car transport were compiled with the phases of the business cycle of Poland and its largest neighbors.

[12] Bernardelli M., *Kryteria optymalizacyjne w procedurze wykorzystującej ukryte modele Markowa do analiz danych ekonomicznych*, Rola informatyki w naukach ekonomicznych i społecznych. Innowacje i implikacje interdyscyplinarne. red. Z. Zieliński, Wydawnictwo Wyższej Szkoły Handlowej, Kielce, 2013, Tom 2, str. 43-53.

The article describes the results of analyses related to the selection of the optimization criterion in the procedure of computing parameters of hidden Markov models used to identify turning points of the business cycle in Poland. The information

criteria (AIC, BIC), the maximum likelihood function and the frequency of obtaining a given set of parameters in Monte Carlo simulations were taken into account. The study was conducted on the basis of data from the business tendency survey in the manufacturing industry conducted by RIED SGH.

[13] Bernardelli M., *Parallel deterministic procedure based on hidden Markov models for the analysis of economic cycles in Poland*, "Roczniki" Kolegium Analiz Ekonomicznych SGH, 2014, No. 34, Oficyna Wydawnicza SGH, Warszawa, str. 75-87.

The calculations related to the determination of HMM model parameters are quite time-consuming, and the computation time increases drastically with the increase in the number of states, length or the dimension of the input data. Acceleration can be achieved by performing parallel calculations. The article presents a way to parallelize some of the calculations related to Monte Carlo simulations, and the idea was successfully verified in numerical experiments, in which tests were carried out comparing the calculation time depending on the number of available processor cores.

[14] Bernardelli M., *The economic situation in Poland through the prism of the situation in the enterprises on the basis of the business tendency survey*. [w:] Enterprises in unstable economy, red. B. Prusak, Gdańsk University of Technology, Gdańsk, 2015, s. 109–136/248 s.

The survey respondents of the business tendency survey in the manufacturing industry conducted by RIED SGH answer questions about the current and predicted (according to respondents) state of enterprises. The use of HMM and Viterbi paths made it possible to question the usefulness of opinions asked about the future. While the answers to most questions related to the current situation seem to correlate with reference data from, among others, from OECD databases, the predictions are rather inaccurate.

3.1.2. Construction and application of algorithms

[15] Bernardelli M., *Method of QR decomposition's fast updates for linear regression models*, "Roczniki" Kolegium Analiz Ekonomicznych SGH, 2012, No. 27, Oficyna Wydawnicza SGH, Warszawa, str. 55-68.

The proposition of the QR decomposition's fast updates algorithm, which for large volumes of data changing in real time, gives the adjustment of linear regression parameters allowing the prediction. The algorithm can be used, among others on financial markets such as Forex or cryptocurrency exchanges.

[16] Bernardelli M., *Overlapping Multigrid Methods as an Efficient Approach for Solving the Black-Scholes Equation*, Quantitative Methods in Economics, 2015, Vol. XVI, No. 1, Warsaw University of Life Sciences Press, str. 25-36.

The article describes the proposal of the two-level multigrid method modification by allowing subdomains to overlap. This method was used to solve the one-dimensional Black-Scholes equation, based on the implicit Euler scheme. Numerical experiments confirmed the superiority of the proposed method in relation to the classical multigrid method through the shorter time of computation, savings in memory and ease of parallelization, and above all, greater accuracy of the solution approximation.

[17] Bernardelli M., *Correction of deviations from the probability distribution of exam results*, Edukacja w Dyskursie, 2015, No. 3, Akademia Pomorska w Słupsku, Słupsk, str. 171-186.

The threshold for passing the basic matura exam in the Polish language is set at 30%. According to statistics published by the Central Examination Board, in the vicinity of this value, significant deviations from the theoretical probability distribution are visible, caused by the lack of objectivity of people responsible for checking the matura exams. The article proposes a method for determining the deviation correction using local polynomial interpolation. The analyses carried out for the results of the results from the years 2012-2014 show that the number of people who shouldn't have passed the exam is higher by 6-12 thousand than actually registered.

[18] Bernardelli M., Kowalczyk B., *Optimal Allocation of the Sample in the Poisson Item Count Techniques*, Acta Universitatis Lodziensis. Folia Oeconomica, 2018, nr 335(3)/2018, str. 35-47. DOI: 10.18778/0208-6018.335.03.

Indirect surveys are the basic tool used for sensitive questions. The article refers to one of these methods and concerns the optimal allocation of the sample between the test and control groups. The problem is relatively easy when the allocation is based on estimators using the method of moments, but it is not trivial for the maximum likelihood estimation (ML) when the study sensitive variable is a latent one and is not directly observable. Meanwhile, the ML estimation has better properties and therefore more practical significance. To determine the optimal allocation of the sample, Monte Carlo simulations and the iterative EM algorithm were used based on the ML estimation.

[19] Bernardelli M., *Metoda ustalania norm klasyfikacyjnych na klasy sportowe w konkurencjach lekkoatletycznych*, "Roczniki" Kolegium Analiz Ekonomicznych SGH, 2018, No. 53, Oficyna Wydawnicza SGH, Warszawa, str. 11-28.

In this article, the proposition of the method of determining classification standards for sports classes in athletics competitions are given. The method reflects the specificity of each competition, the quality of results in recent years, the overall international competitiveness, and above all adjusts the assessment of sports level to Polish realities. The procedure is based on quantiles of probability distribution matched to historical data from Europe, the world, and Poland. The full parametrisability of the procedure allows maintaining the balance between the quality of the achieved sports results and capturing the current sports level of athletes in a particular competition. From the new Olympic cycle the method will be implemented by the Polish Athletics Association.

3.1.3. Bonus-malus systems

[20] Topolewski M., Bernardelli M., *Optymalizacja reguł przejścia systemu bonus-malus o składkach Q-optymalnych*, "Roczniki" Kolegium Analiz Ekonomicznych SGH, 2015, No. 37, Oficyna Wydawnicza SGH, Warszawa, str. 229-252.

Bonus-malus systems are used to differentiate a'posteriori premiums in the risk assessment process in automobile insurance. In the literature on the subject, systems analysis tools and premium calculation criteria are well described. Relatively little space is devoted to the optimization of transition rules between classes of bonus-malus system. The article proposes a greedy algorithm for optimization the transition rules of bonus-malus systems of different sizes for insured portfolios characterized by the function of the risk structure of various parameters.

[21] Topolewski M., Bernardelli M., *Improving global elasticity of bonus-malus system*, Quantitative Methods in Economics, 2017, Vol. XVIII, No. 1, Warsaw University of Life Sciences Press, str. 120-133.

Another article using the optimization algorithm for bonus-malus system transition rules to achieve possibly best premium elasticity as defined by Loimaranta and global elasticity introduced by De Pril. In numerical experiments systems of different size for portfolios characterized by inverse Gaussian risk structure function with various parameters were analyzed.

[22] Bernardelli M., *Implementacja metody badania własności reguł przejścia systemów bonus-malus w Apache Spark*, "Roczniki" Kolegium Analiz Ekonomicznych SGH, 2018, No. 50, Oficyna Wydawnicza SGH, Warszawa, str. 95-17.

The aim of the article was to present an accurate algorithm for testing bonus-malus systems from the transition rules point of view. There was a suspicion of the suboptimality of the obtained solutions in case of approximation algorithms. Thanks to the use of Apache Spark and the MapReduce paradigm, it has been possible to construct a parallel, effective approach with full scalability. The implementation includes the option of setting parameters such as the number of bonus-malus system classes and the number of claims.

3.1.4. Big data

[23] Bernardelli M., Dędys M., *Cheater detection in Real Time Bidding system - panel approach*, "Roczniki" Kolegium Analiz Ekonomicznych SGH, 2015, No. 39, Oficyna Wydawnicza SGH, Warszawa, str. 11-23.

A proposition of an effective method of detecting fraud attempts in Real Time Bidding (RTB) system. The method consists of two different econometric models, one for user classification, and the other for distinguishing real websites from those specially crafted by fraudsters. The presented models are closely related and are used where the rapid filtering of traffic generated by Internet bots is crucial.

[24] Bernardelli M., *Econometric modeling of panel data using parallel computing with Apache Spark*, "Roczniki" Kolegium Analiz Ekonomicznych SGH, 2016, No. 41, Oficyna Wydawnicza SGH, Warszawa, str. 189-202.

Apache Spark contains many algorithms for econometric modeling. However, the library lacks methods dedicated to large data sets of panel character. The article presents the implementation of estimating the fixed effects using the MapReduce programming model. Two popular approaches have been presented: within transformation and least squares dummy variables method (LSDV).

[25] Bernardelli M., *Predicting hourly Internet traffic in the RTB system – panel approach*, "Roczniki" Kolegium Analiz Ekonomicznych SGH, 2017, No. 47, Oficyna Wydawnicza SGH, Warszawa, str. 5-17.

The article describes a panel econometric model allowing for the control in the RTB system of costs related to the online bid request traffic. This approach allows to spread the costs throughout the day instead of spending them at the beginning of the day at once. Unusual in the model panels are hours, and spending limits are determined based on historical data. On the basis of computer simulations, the model with fixed effects works better than the classical linear regression model.

[26] Bernardelli M., *Big data recommendation problems in e-commerce solutions for small business*, Research on Enterprise in Modern Economy – Theory and Practice, 2017, No. 3/2017 (22), Warsaw University of Life Sciences Press, str. 65-76.

Intelligent recommendation systems significantly contribute to the growth of sales, but generally, require extensive computer infrastructure and specialist knowledge. The article describes the implementation of a recommendation algorithm that is not as effective as more advanced methods, but thanks to its simplicity and low hardware requirements, it meets the needs of small businesses operating in the e-commerce market.

[27] Bernardelli M., Lipiński Ł., *Anonimowość w Internecie – identyfikacja płci użytkowników na podstawie historii odwiedzanych stron internetowych*, "Roczniki" Kolegium Analiz Ekonomicznych SGH, 2018, No. 53, Oficyna Wydawnicza SGH, Warszawa, str. 147-162.

The article presents the method of identifying the gender of Internet users, using data from user profiles containing website addresses and frequency of visits. The proposed approach combines lexical analysis of words from Internet domains, artificial neural networks, mathematically sophisticated vector representation of user profiles and logistic regression as the main classifier. The effectiveness of the method was confirmed on the basis of computer simulations made using 10 million profiles of Polish users, reaching 82% correct classifications. The method can be used in personalized marketing as a source of savings in the form of reducing unnecessary expenses for ill-targeted advertising.

3.1.5. Convergence analysis

[28] Bernardelli M., Próchniak M., Witkowski B., *Cycle and Income-Level Convergence in the EU Countries: An Identification of Turning Points Based on the*

Hidden Markov Models, "Roczniki" Kolegium Analiz Ekonomicznych SGH, 2017, No. 47, Oficyna Wydawnicza SGH, Warszawa, str. 18-31.

In the study described in the article, the β-convergence hypothesis was positively verified, however, it turned out that the β-convergence process had a different pace between the turning points in the paths of economic growth of the European Union countries identified on the basis of HMM. Turning points (in 2008 and 2013) were considered as structural breaks for the β-convergence model. According to calculations, the slowest β-convergence was in the 2008-2012 subperiod, i.e. during the global crisis.

[29] Bernardelli M., Próchniak M., Witkowski B., *Konwergencja dochodowa: mocne i słabe strony istniejących podejść*, Kwartalnik Kolegium Ekonomiczno-Społecznego "Studia i Prace", 2017, No. 3 (31)/2017, Oficyna Wydawnicza SGH, Warszawa, str. 71-86.

A review description of the current state of knowledge on the subject of convergence along with an attempt to identify issues whose solution seems to be crucial for the further development of analyzes on convergence processes, including the identification of the relationship between many existing types of convergence, including β, ρ or γ, as well as explanation of discrepancies in the analysis of conditional convergence, resulting from difficulties with arbitrary selection of growth factors to the model used, or ambiguously confirmed in the literature inadequacy of Bayesian averaging procedures. The last key problem identified was the consideration of the instability of economic growth processes over time. As a solution, it was proposed to use methods based on hidden Markov chains.

[30] Bernardelli M., Próchniak M., Witkowski B., Konwergencja dochodowa w krajach UE: ujęcie miesięczne, pr. zb. pod red. Konrada Walczyka, "Prace i Materiały Instytutu Rozwoju Gospodarczego", 2018, Warszawa, No. 100, str. 89-116.

The article describes the results of research on the β-convergence hypothesis for the whole EU-28 group on the estimates of individual variables on a monthly basis. Estimations of the convergence rate were obtained on the basis of extrapolated data using the monthly values of the economic sentiment indicator coming from the survey. The β-convergence hypothesis on the basis of monthly data has been positively verified, but it turned out that the convergence occurred at different rates between the turning points identified with the use of HMM. In addition, large deviations of estimates for

extrapolated monthly data were observed in relation to results based on annual values of time series, which allows to state that the monthly approach gives a more complete picture of economic growth paths in EU countries.

In addition to the authorship or co-authorship of these publications, I am also a scientific co-editor of numbers 30 (2013), 34 (2014), 39 (2015), 41 (2016), 47 (2017) and 53 (2018) of the "Annals" of the Collegium of Economic Analysis of the Warsaw School of Economics. The issues contain peer-reviewed publications of selected speeches from the annual conference *Modeling of panel data: theory and practice*. From 2015 (numbers 3-5) I also hold the position of statistical editor of the journal Edukacja w Dyskursie, published by the Pomeranian Academy in Słupsk.

I also took part in the translation into Polish of the handbook Aczel AD, Sounderpandian J., "Statystyka w zarządzaniu", Wydawnictwo Naukowe PWN, 2017. My authorship is translations of three chapters: Sampling and sampling distributions (Chapter 5), Quality control and improvement (Chapter 13) and Multivariate analysis (Chapter 17).

3.2. Statistics of research

1. My publications after Ph.D. include the following (prepared independently or in co-authorship):
   - 31 articles in journals (national or international), including 16 in English,
   - participation in a scientific edition of 6 monographic editions of "Annals" of the Collegium of Economic Analysis SGH.

   Furthermore, under review are the following:

   - 2 articles, including one in English.

2. The parametric description of my publications can be summarized by[6]:
   - Hirsch index: 4 (according to Google Scholar), 3 (according to BazEkon).
   - Total number of MNiSW publication points: 309, including:
     - for journal publications: 248,
     - for chapters in monographs and editions: 53.

[6] See Attachment 3a prepared by the SGH Library.

3. Total number of conference presentations (at least the national stage): 48, including[7]:
    - at international conferences: 23,
    - at national conferences: 25.

4. The number of prepared journal reviews: 18, including:
    - 1 for journals ranked by JCR (MNiSW – list A):
        - Post-communist Economies (1 review),
    - 8 for the journals included in the list B by MNiSW:
        - Przegląd statystyczny (1 review),
        - Studia Ekonomiczne PAN (1 review),
        - International Journal of Management and Economics (1 review),
        - Metody Ilościowe w Badaniach Ekonomicznych (1 review),
        - „Roczniki" Kolegium Analiz Ekonomicznych SGH (3 reviews),
        - e-mentor (1 review).
    - other reviews:
        - Narodowe Centrum Nauki, Konkurs Opus, Nr 237381, Panel HS4 (1 review),
        - Journal of Banking and Financial Economics (7 reviews),
        - Econometric Research in Finance (1 review).

3.3. Participation in research projects

In 2012, I was at two-month research internship at the Institut für Energietechnik in the Laboratory for Energy Conversion at ETH Zurich under the supervision of dean prof. dr. Reza S. Abhari. My work in Switzerland, referred to collectively as *Economic Analysis of RES Growth Potential in Poland*, concerned the risk management related to the construction of wind farms and the optimization of the location of wind farms in Poland. The analyses took into account legal regulations and the financial and economic situation and were conducted using dedicated WindSeeker software and one of the fastest computer clusters in the world owned by the Zurich University of Technology. I presented the results of my scenario analyzes for our country, among others at the coordinated by the Embassy of Switzerland talks at the National Fund for Environmental Protection and Water Management and the Marshal's Office of the

[7] The detailed list included in Attachment 4, point II I).

Mazowieckie Voivodship in Warsaw. These presentations contributed to the launch of a pilot project *Systematic Planning for Development of Wind Energy in Lubelskie*. The project was aimed at identification of places suitable for economic reasons for the construction of wind farms in the region of the Lublin province. In the project, I was responsible, among others, for calibrating model parameters and performing calculations, which were a key element in determining potential investment areas and long-term planning at the level of decision-makers. As part of the project, on September 10, 2014 in Lublin, a conference *NEO – Nowa Energia dla Lubelskiego* was organized, and then on 17-18 February 2015 in Zurich a workshop *NEO Implementation & Execution Workshop*, of which I was a co-organizer, as well as a chairman of the *Regulations linked with economy* session.

In the years 2011-2014, I took part in another project. The goal of the *National Foresight Program* funded by the Minister of Science and Higher Education was to develop tools and implement a system of cyclical assessment of the scientific and technological potential allowing shaping the science and technology policy of Poland. Together with dr. hab. Bartosz Witkowski, prof. SGH, we were the main investigators preparing the concept of econometric model and the development of mechanisms for collecting and verifying data indicating the potential of specific directions of research, technology and the area of pioneer technologies. The functional form of the model proposed by us is a classic Cobb-Douglas production function, in which each of the production factors is determined by a separate partial equation being an expanded macroeconomic function that directly or indirectly (for example through capital or employment factors) depends on the level of development technology in a given sector of the economy in a given region. The practical application of the model has been verified on the basis of data from the pilotage expert panel, and the implementation of the results described in the report *NPF – wdrożenie wyników. Metoda określania endogenicznego potencjału regionu i kraju w oparciu o model matematyczno-statystyczno-ekonometryczny. Tom 2: Model dynamiki rozwoju ekonomicznego kraju i regionów w sytuacji wdrażania poszczególnych kierunków badań/technologii i rozwijania obszarów inteligentnej specjalizacji. Raport finalny, uwzględniający rezultaty oceny eksperckiej oraz weryfikacji i interpretacji modelu.* I was presenting the results, among others, at the Ministry of Science and Higher Education and at the Economic Challenges in Enlarged Europe conference in Tallinn (16-18 June 2013) in the presentation entitled *The impact of innovative R & D expenditures on regional development: Polish foresight program perspective*.

In the 7th Competition for the Best Scientific Projects organized by the National Bank of Poland, the most-rated application turned out to be the project entitled *Antycykliczny bufor kapitałowy polskiego sektora bankowego – propozycja optymalnej jego wielkości i analiza zmian w czasie z wykorzystaniem złożonego wskaźnika wczesnego ostrzegania*, in which my participation was estimated at 40%. The new method proposed by me, based on cyclical comparison of specific values from the area of economics and finance with a benchmark based on known data observed before banking crises, allows for an alternative to the existing methods of monitoring the situation of the economy and the banking sector, with a sufficiently early advance, signals warning of its deterioration. The method is characterized by high flexibility in the use of data, as well as the ability to calibrate parameters. The description of the method together with the empirical analysis was published in the NBP Materials and Studies (no 331/2018), and presented, among others, at the 6th National Conference Modeling of panel data: theory and practice in the presentation entitled *Early warning indicator for the banking sector*.

The project most similar in the terms of a topic to the cycle of articles, present as a habilitation accomplishment, is the grant of the National Science *Center On the use of hidden Markov models in the analysis of income-level and cyclical convergence with emphasis on the turning points*, implemented jointly with dr. hab. Mariusz Próchniak, prof. SGH and dr. hab. Bartosz Witkowski, prof. SGH. The basis for research conducted under this grant is the procedure based on HMM and Viterbi paths described in the previous sections. Research from this grant has so far resulted in publications [7], [8], [28] and [29], as well as eight presentations at scientific conferences (including five international conferences). During the review process, there is currently one more article, and three consecutive presentations at scientific conferences have already been accepted.

From the other projects, which I was one of the investigators, it is worth mentioning the following:

- *Optymalizacja poziomu i struktury rezerw w walutach obcych oraz zadłużenia zagranicznego względem stabilności makroekonomicznej* financed by the National Bank of Poland with dr. hab. Łukasz Goczek being the head of the project. I developed the optimization method and its application to the generalization of the theoretical model concerning foreign exchange reserves and foreign debt.
- *Morfa* – a project implemented in 2007-2013 from the funds of the Innovative Economy Operational Program. As a numerical expert, I co-created the Morfa package – an

innovative computing environment that allows, among others, for defining new classes of econometric models with the estimation of their parameters.

- *Stworzenie systemu prognozowania rozwoju przestępczości jako elementu budowania strategii bezpieczeństwa i porządku publicznego* – project financed by the National Center for Research and Development under the 7th competition of projects in the area of security and defense of the state with prof. dr hab. Brunon Hołyst as the head of the project. As an investigator, I was responsible, among others, for the preparation of data and methods for forecasting the development of crime, as well as the determination of predictions for selected crime categories.
- *Anti-Bot and Trolls Shield* (ABTSHIELD) – Edge NPD project, recognized in 2017 as one of the 100 most outstanding innovators in Central and Eastern Europe. The funding of the project is provided by a Google grant, and the project itself is based on the possibility of researching Internet traffic at the level of publishers and advertisers. My role in the project concerned the expert development of the potential of methods and algorithms for filtering Internet traffic and detection of bots and Internet trolls.

4. Achievements in the field of teaching

An important part of my professional activity is teaching, including conducting classes and scientific care over students, as well as creating new ones and coordinating existing didactic offers.

Since 2011, I have promoted 41 bachelor's theses and 14 master's theses. To my achievement, I can also add scientific care over three Ph.D. students as a supporting supervisor. The first of the thesis (in English) entitled *Financial Crisis: Estimating the Effect of Changes in Aggregate Bank Capital Requirements on Loan Portfolio Decisions (An Empirical Evidence for UK banks)* ended on June 28, 2018, when Kazeem Olayimik Salaam was awarded the doctoral degree by the Council of the Faculty of Management at the University of Economics in Krakow. The supervisor of the Ph.D. was prof. dr hab. Małgorzata Iwanicz-Drozdowska. One of the key chapters of this work contained an empirical analysis including econometric modeling aimed at confirming the research hypotheses. Under my supervision, a dozen or so regression models were constructed, which provided unique information on the behavior of the banking market in the period before and after the crisis.

The second Ph.D. dissertation titled *Wspieranie stabilności finansowej za pomocą antycyklicznych rozwiązań w regulacjach bankowych* prepared by mgr Anna Kozłowska under

the scientific supervision of prof. dr hab. Małgorzata Iwanicz-Drozdowska in the Collegium of Management and Finance at the Warsaw School of Economics has already received one positive review (with a request for distinction). The work consists of five chapters, two of which are "clearly empirical and represent the most original part of the dissertation (presentation of the assumptions of the author's index of financial pressure and its evaluation)"[8]. While writing these two chapters, the Ph.D. student largely benefited from my help and econometric experience.

The third Ph.D. student, Norbert Paska, writes a work entitled *Zastosowanie uogólnionych liniowych modeli mieszanych w taryfikacji ubezpieczeń komunikacyjnych* in the Collegium of Economic Analysis of the Warsaw School of Economics with prof. SGH, dr. hab. Bartosz Witkowski as a supervisor. In January 2019, the work on the dissertation was considered advanced enough to begin the formal procedures[9]. The work concerns the class of GLMM models. Due to the fact that the available software does not offer libraries for the automatic selection of parameters of these models, it is necessary to independently develop non-trivial algorithms (along with the optimal stopping criteria) and their implementation. My mentoring in this area results from having specialist IT knowledge and the ability to use it in econometrics.

Since 2018 I am the scientific supervisor of the Students' Scientific Association of Management in Sport and since 2010 the supervisor of the largest student organization at the Warsaw School of Economics, namely the Academic Sports Association of the Warsaw School of Economics. I also act as the President of this organization.

Since 2014, I have been a coordinator (with dr. Anna Decewicz) of the course *Econometrics*, which is the basic lecture in most of the bachelor studies at the Warsaw School of Economics. I am also the author and coordinator of the following courses at undergraduate studies:

- *Wprowadzenie do metod numerycznych*,
- *Wychowanie fizyczne – ćwiczenia z różnych obszarów kultury fizycznej* (Polish version) oraz *Physical Education – classes on different aspects of physical culture* (English version),

and graduate studies:

- *Metody numeryczne* (Polish version) oraz *Numerical methods* (English version),
- *Podstawy analizy danych w e-biznesie*.

[8] Quote from the review of dr hab. Monika Wieczorek-Kosmala, prof. UE.
[9] The detailed information are included in Attachment 4, point III K).

In 2011-2012, as part of the Global SGH program, I created from scratch a program and materials for the courses *Mathematical Analysis* and *Algebra*. So far they have been conducted at the undergraduate level (in English).

Od 2009 roku regularnie przepracowuję wiele godzin ponad obowiązujące mnie pensum prowadząc Konwersatorium dla doktorantów oraz wiele przedmiotów na studiach licencjackich i magisterskich, w tym:

Since 2009, I have been regularly working many hours over the obligatory pensum, conducting the Seminar for Ph.D. students and many courses at undergraduate and graduate studies, including:

- *Mathematics* (in English) – lecture and classes,
- *Matematyka* – classes,
- *Ekonometria* – laboratories,
- *Mathematical Analysis* (in English) – lecture and classes,
- *Algebra* (in English) – lecture and classes,
- *Metody numeryczne* – laboratories,
- *Numerical methods* (in English) – laboratories,
- *Wprowadzenie do metod numerycznych* – laboratories,
- *Algebra i Analiza Matematyczna* – classes,
- *Podstawy analizy danych w e-biznesie* – laboratories,
- *Budowa i eksploatacja baz danych* – laboratories.

In 2009, I created and since then I have been the supervisor of two inter-faculty specialties: *Operational research and decisions*, one in the undergraduate and second in the graduate studies.

I have conducted many courses on econometric modeling and learning how to use computer programs and programming, among others for the Central Statistical Office (Analysis of time series), Office of Electronic Communications (Programming in the R environment), National Bank of Poland (Analysis and interpretation of survey results, Matlab – good programming practices, Statistical analysis and presentation of data, Statistical research and data analysis, Implementation new and advanced SAS solutions in creating programs for processing and analyzing survey data, Panel models in the STATA environment, Advanced programming in the R environment).

Several times I used the opportunity to learn and gain new experiences as part of educational trips in the Erasmus+ program. In 2016, I conducted classes with students in the subject of *Sampling and data analysis* at the University of Alicante (Spain), in 2017 in the subject of *Applied econometrics* at the Lebanese American University in Beirut (Lebanon).

I also prepared lectures for high school students, including a lecture on the basics of econometrics and operational research for students of the Secondary School King Casimir the Great in Olkusz as part of the SGH Academic Class program and a presentation on "Real Time Bidding" as part of Open Lectures at the Warsaw School of Economics. For an even younger target group, I had presentations "Mathematics in sport, games, and fun" at the 4th Festival of Mathematics organized by Gazeta Wyborcza.

5. Organizational achievement

The organizational activity at the Warsaw School of Economics and outside it takes me a significant amount of time. For the 2015-2016 and 2016-2020, I was elected a member of the University Senate as a representative of the post-doc academic staff. In the years 2016-2020 I am also a member of the Council of Collegium of Economic Analysis of the Warsaw School of Economics.

In 2016, I was elected a member of the member of the electoral council of the Warsaw School of Economics and participated in the procedure of choosing the authorities of the Warsaw School of Economics, being twice the secretary and once the vice-chairman of the electoral commission.

In the years 2013-2014, I was a member of the Committee for selection of the participants project *Rozwój nauki – rozwojem regionu – stypendia i wsparcie towarzyszące dla mazowieckich doktorantów* appointed by the Department of Public Education and Sport of the Marshal's Office of the Mazowieckie Voivodship in Warsaw.

Since 2012, I have been a co-organizer of the annual Nation Scientific Conference Modeling Panel Data: Theory and Practice. In 2019, its eighth edition will take place, and in recognition of the high substantive level for many years, the honorary patronage includes the Statistical and Econometric Committee of the Polish Academy of Sciences. Reviewed publications of selected speeches from this conference are published in Annals of the Collegium of Economic Analyzes of the Warsaw School of Economics, of which I am a scientific co-editor.

In 2014 and 2017, I was also a member of the organizing committee of the National Scientific Conference on Actuarial Issues: Theory and Practice, which is highly recognized in the scientific and insurance environment. In 2016, on the other hand, I co-organized the National Conference “Ubezpieczenia – branża wielkich możliwości”.

After a scientific and research internship held in 2012 at the Laboratory for Energy Conversion in ETH Zurich, I have been cooperating with them for many years. My work in Switzerland on risk management related to the construction of wind farms and optimizing the location of wind farms in Poland resulted in a project *Systematic Planning for Development of Wind Energy in Lubelskie* implemented in 2012-2014, completed in Zurich in 2015 by a two-day NEO Implementation & Execution Workshop, which I co-organized.

A large part of my organizational activity is related to sport, above all academic. At the Warsaw School of Economics, since 2015, I have been the Head of the Center of Physical Education and Sports, coordinating the work of 19 teaching staff and two in the administrative position. In 2016, I extended my organizational activity in the field of academic sport to the regional level, being elected a member of the Management Board of the Warsaw Academic Sports Association for 2016-2020, and the national level becoming a member of the Economic Council of the Academic Sports Association for 2017-2018 and a member of the Management Board of the Academic Sports Association for 2018-2019. What's more, for the years 2017-2020 I was appointed the Chairman of the Commission for Road and Cross-country Running of the Polish Athletics Association, the oldest Polish sports association.

I also use my knowledge and IT skills in the organizational field. For many years I have been running the website of the "Annals" of the Collegium of Economic Analysis, and I am responsible for indexing in the RePEc database of four journals issued by the Collegium of Economic Analysis of the Warsaw School of Economics. In addition, in 2017-2018 I was the main investigator in the organizational project *Działalność Upowszechniająca Naukę: Stworzenie i udostępnienie w sieci Internet elektronicznego repozytorium artykułów naukowych opublikowanych w "Pracach i Materiałach Instytutu Rozwoju Gospodarczego SGH".*

6. Awards and distinction

For my organizational activity, four times I have been honored the reward of his Magnificence Rector of the Warsaw School of Economics. In 2013, it was a second-degree collective award, in 2016 an individual third-degree award, while in 2017 and 2018, a second-degree individual award.

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