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THE POLISH CONTRIBUTION TO FINANCIAL ECONOMETRICS. A REVIEW OF METHODS AND APPLICATIONS[1]

POLSKI WKLAD DO EKONOMETRII FINANSOWEJ. PRZEGLĄD METOD I ZASTOSOWAŃ

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Summary: Since 1982 the term "financial econometrics" has been present in the enormous literature that covers both methodologies and empirical analyses of the processes observed on the financial markets. The purpose of the presented paper is to indicate the milestones in financial econometrics and their usefulness and to show the contribution of the research from Poland into its development. 'Pure' financial econometrics methods are of special interest. The paper is directed at reviewing the recent methodologies and their applications. We focused on the contribution of Polish researchers into financial econometrics over the years, considering both the methodology and the applications. Some of the indicated publications are cited quite often, including international quotations, others are not very popular due to the language of the publication or the local reach of the journal, although many of them can be considered in line with the achievements that are presented in international empirical publications.

Keywords: financial econometrics, volatility models, risk measures, extreme value theory, microstructure, behavioral information.

Streszczenie: Od 1982 roku termin „ekonometria finansowa" jest obecny w niezwykle rozległej literaturze przedmiotu, obejmującej zarówno modele i metody wnioskowania, jak i ich zastosowania w analizach procesów obserwowanych na rynkach finansowych. Celem artykułu jest wskazanie publikacji o charakterze kamieni milowych w rozwoju ekonometrii finansowej, a na ich tle podsumowanie wkładu polskich badaczy w rozwój tej subdyscypliny. Przedmiotem przeglądu badań są modele i metody wykorzystywane w tzw. czystej ekonometrii finansowej. W publikacji uwaga skupiona została na wkładzie polskich badaczy w rozwój zarówno metod, jak i zastosowań oraz na ich miejscu w literaturze światowej. Niektóre spośród wymienionych publikacji są cytowane bardzo często, włączając w to cytowania miedzynarodowe, inne nie są tak bardzo popularne z powodu czy to języka publikacji, czy to

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umieszczenia ich w periodykach o zasięgu lokalnym. Jednakże wiele spośród omawianych prac mieści się w głównym nurcie osiągnięć międzynarodowych.

Słowa kluczowe: ekonometria finansowa, modele zmienności, miary ryzyka, teoria wartości ekstremalnych, mikrostruktura, informacja behawioralna.

1. Introduction

The rapid growth of mathematical, statistical and econometric methodologies that answered the huge demand of financial markets for quantitative analyses has been observed since the early 80s. Since 1982 the term 'financial econometrics' has been present in the enormous literature that covers both methodologies and empirical analyses of different nature. The "Handbook of Financial Econometrics" was edited in 2010 by Y. Aït-Sahalia and L.P. Hansen and the "Journal of Financial Econometrics" started to be published in 2003. The Bank of Sweden honored the financial econometricians with the highest prize – the Nobel Prize in Economics. They were Robert Engle and Clive Granger in 2003 and Lars Peter Hansen in 2013, who shared the prize with the most influential financial analysts Eugene Fama and Robert Shiller.

The process of the intensive expansion of financial econometrics methods was broken by the financial crisis that started in 2007 in the USA and in 2008 in the rest of the world. During this difficult time quantitative methods were suspected of being wrong because they did not predict the crisis which changed the whole world. The purpose of the presented paper is to indicate the milestones in financial econometrics and their usefulness despite the emotional and rational criticism that appeared in the period 2007-2009. An additional aim is to show the contribution of the researchers from Poland into the development of financial econometrics. In the paper we focus on 'pure' financial econometrics leaving aside many relationships with other disciplines, for example financial mathematics, financial engineering and, partially, even empirical finance. Consequently, such elements as capital market equilibrium models, portfolio analysis, asset pricing, financial innovations and hedging remain beyond the scope of the paper. Even such applications of financial econometrics methods like modeling and forecasting commodity markets and energy market are omitted in the paper.

The paper is mostly directed at a synthetic review of the recent methodologies and their applications. Despite a strong aspiration to scientific objectiveness, the selection of the methodologies is both limited to those domains where Polish impact is worth noting and biased by the author's choice, which is hard to avoid.

The paper is organized as follows. In the second section the central goal of financial econometrics was presented with some comment concerning the development of the discipline in question. In the third section volatility modeling was summarized, in the fourth one – risk analysis, distribution models and extreme value theory was discussed, while, in the fifth part, selected methods of analysis dependencies between financial markets were shown. Market microstructure methods in financial econometrics are subject of section six. In section seven – behavioral and qualitative aspects in finance are summarized. The first six sections are usually associated with financial econometrics, while the last one is a little removed. In section eight the conclusions and challenges are presented.

2. Financial econometrics – a brief overview

A central goal of financial econometrics is to reveal a joint distribution function of financial (log) return r_{it} of the following form:

$$F\left(r_{i1},\ldots,r_{iT};\theta\right)=F\left(r_{i1},\theta_1\right)\prod_{i=2}^{T}F\left(r_{iT}\mid r_{iT-1},\ldots,r_{i1},\theta_2\right),$$

where $\theta=\theta_1+\theta_2$ is a unique vector of parameters. The partitioning of the joint distribution function into the marginal and conditional probability functions shows that the main research issue is to find out the specification of conditional distribution $F\left(r_{iT}\mid\cdots\right)$, i.e. the mechanism of how conditional distribution evolves over time [Tsay 2005]. Other aspects of the scope of the financial econometrics can be found in Fan [2004].

Several publications were focused on the developments of financial econometrics. In 2001 Tim Bollerslev [Bollerslev 2001] indicated the milestones in financial econometrics. These are: volatility models and flexible estimation procedures such as non-parametric estimation, including kernel estimation. He indicated the future challenges that require further studies, such as: volatility models, UHF data, long memory, heavy tails, big portfolio systems, flexible estimation procedures and continuous time models. On the other hand, Yongmiao Hong [Hong 2001], marked the following significant development in financial econometrics models and methods: market efficiency and conditional mean models, volatility and conditional variance models, value at risk and conditional quantiles, density models, jump and diffusion modeling as well as market microstructure analysis. In 2007, Krzysztof Jajuga [Jajuga 2007] drew attention to the development of one and multi-dimensional volatility models, cointegration of time series and market microstructure models. Among new fields of development he mentioned multidimensional models, models of distributions, market microstructure, extreme value theory, continuous time models, non-normal innovations, Bayesian analysis and numeric algorithms. Fan [2005], as well as Cai and Hong [2009], revised the selection of achievements in the area of non-parametric methods in finance.

The spread of financial econometrics methods can be justified by the number of citations. In 2013 Chia-Lin Chang, David Allen, Michael McAleer [Chang 2013], based on Thomson Reuters ISI, Google Scholar, Microsoft Academic Search, RePEc [Research Papers in Economics and Finance], and paper downloads and abstract views in SSRN [Social Science Research Network] and RePEc, indicated that research papers in empirical finance and financial econometrics are among the most widely cited, downloaded and viewed articles in the discipline of finance.

In this paper the certain path that financial econometrics has taken up to now is summarized. The motivation comes from the fact that since the very beginning we have participated in both the empirical and theoretical analyses of financial markets in emerging and developed countries. Initially this was related to applying the tools of dynamic econometrics developed in the Department of Econometrics and Statistics of Nicolaus Copernicus University by the team led by Z. Zieliński (see for example: [Zieliński 1979; Talaga and Zieliński 1986]). Early analyses concerning the newly founded capital market in Poland at its very initial level can be found, among others, in [Osińska and Romański 1994; Stawicki, Janiak, Müller-Frączek 1998]. In the more advanced studies we have tried to develop theoretical and empirical research on long memory and ARFIMA models [Kwiatkowski 2000; Kwiatkowski and Osiewalski 2002] spectral analysis of financial returns [Osińska and Górka 2003], stochastic unit root model [Osińska, Kwiatkowski 2003; Osińska (ed.) 2007], nonlinear causality [Osińska and Orzeszko, 2006], non-parametric methods in financial econometrics [Orzeszko 2016], univariate and multivariate GARCH models [Osińska, Hyżyk 2000; Fiszeder 2001; Fiszeder, Romański 2001; Fiszeder 2009], causality in variance and causality in risk [Osińska 2008; Fałdziński Osińska, Zdanowicz 2012a; 2012b], Chinese stock markets [Fałdziński, Osińska, Zdanowicz 2012a; 2012b; 2013] and behavioral heuristics on capital market [Osińska, Pietrzak, Żurek 2011; developed by Żurek 2016]. In 2006 Osińska [Osińska 2006] published a survey of the financial econometrics methods.

3. Volatility modeling and forecasting

Unquestionably the most important achievement that defines the subject of financial econometrics is volatility modeling. Volatility modeling and forecasting was first implemented within the efficient markets hypothesis [Fama 1970] and later on this fitted well within the heterogeneous market hypothesis including short term, medium term and long term volatility [Dacorogna et al. 1998]. Volatility models induced and efficiently inspired the following areas of financial econometrics and empirical finance: risk measurement, hedging strategies, asset pricing, financial engineering, market microstructure, analyses of co-movements, spillovers and contagion, non-linear models and estimation techniques. A very interesting review of different measures of volatility and their usefulness in forecasting and option pricing was provided by Jabłecki et al. [2012].

3.1. Discrete volatility models

Volatility models, starting from Engle's ARCH model, began a revolutionary era that enabled both volatility modeling and forecasting. The innovation of this model was in modeling the second moment of distribution conditionally on the past information while the unconditional second moment remains stable. The volatility process is then conditionally heteroscedastic with respect to its whole history. A conditional variance becomes a straightforward volatility measure, although other volatility measures based on the daily price changes have also been defined (such as [Parkinson 1980; Garman, Klass 1980; Rogers, Satchell 1991] to mention the most popular ones). This allowed for describing many of the typical characteristics of financial time series such as fat tails, leptokurtosis, volatility clustering, negative correlation between returns and all volatility measures and many others described by Cont [2001]. Defining a GARCH model by Bollerslev [1986] as:

$$y_t = x_t' \xi + \varepsilon_t,$$

where x_t – ($k \times 1$) vector of explanatory variables, ξ – ($k \times 1$) vector of parameters, $t = 1, 2, ..., T$;

$$\varepsilon_t \mid \Psi_{t-1} \sim N(0, h_t),$$

$h_t = \alpha_0 + \sum_{i=1}^{q} \alpha_i \varepsilon_{t-i}^2 + \sum_{i=1}^{p} \beta_i h_{t-i}$ where $p \geq 0$, $q > 0$, $\alpha_0 > 0$, $\alpha_i \geq 0$ for $i = 1, 2, ..., q$, $\beta_i \geq 0$ for $i = 1, 2, ..., p$, stimulated formulating a family of univariate GARCH models that includes symmetric and asymmetric GARCH models, IGARCH and FIGARCH models, GARCH-M models and Markow-Swiching GARCH models, covering new and new characteristics of the market uncertainty, such as long memory, leverage effect and heterogeneous investors. The usefulness of the GARCH models is in both a parsimonies parameterization and a straightforward interpretation. Bollerslev et al. [1992], Doman and Doman [2009] as well as Franq and Zakoian [2010], described these models including both theory and applications. Univariate GARCH models were not satisfactory when many instruments or many markets were to be considered.

The natural move was then to construct a multivariate volatility model. Kraft and Engle [1982], introduced the multivariate GARCH [p,q] model in the form of the Vech GARCH model that skipped any conditional co-variances and focused only on variances. Sequent models were systematically improved considering specifications and estimation. More advanced MGARCH class of models consists of CCC and DCC GARCH, BEKK, Factor GARCH and many others (see [Engle and Kroner, 1995; Franq, Zakoian 201]. The MGARCH model called BEKK [Baba et al. 1990]) takes the following form:

$$H_t = C^* C^{*'} + \sum_{k=1}^{K} \sum_{i=1}^{q} D_{ik}^{*} \varepsilon_{t-i} \varepsilon_{t-i}^{'} D_{ik}^{*'} + \sum_{k=1}^{K} \sum_{j=1}^{p} E_{jk}^{*} H_{t-j} E_{jk}^{*'},$$

where: C^*, D_{ik}^* and E_{ik}^* are (N x N) matrices.

The problems with the MGARCH class of models are at least the following two. The first one concerns the fact that GARCH generalizations are parameter rich and extremely difficult to estimate due to complicated constraints on the parameter space. The second one is that such recent versions of multivariate ARCH models have become so simplified that they are unlikely to satisfactorily approximate the complexities of the data (comp. [Chib, Nardari, Shephard 2006]). That is why new concepts of volatility modeling were developed. Nevertheless, nowadays a large class of GARCH models is considered standard in both teaching students, computer packages, like EViews, Gretl, G@RCH to mention only a few, as well as financial applications.

The idea of GARCH modeling was not satisfactory when large changes in volatility were observed. Then the SV class of models became more useful. As GARCH-type models covered volatility changing over time but not stochastic, SV models let the volatility to be stochastic and consequently defined a new stochastic process. Such a modification was however complicated for the sake of introducing an innovation to the volatility model. The SV processes have been known since 1973 but they were not widely used in the 70s. Their advantage lies in the fact that they have a solid theoretical base, because process ε_t described by discrete Basic Stochastic Volatility Process of the form

$$\varepsilon_t = v_t \sqrt{h_t}\ ,$$
$$\log h_t = \gamma + \varphi \log h_{t-1} + \sigma_h \eta_t,$$

where $v_t \sim N(0,1)$, $\eta_t \sim N(0,1)$; v_t and η_t are orthogonal, represents a discrete diffusion model with $\log h_t$ which is the Ornstein and Uhlenbeck process. A continuous representation of the SV model will be discussed in the next section. It can be noticed that the flow of new information takes place through the innovations η_t thus higher volatility can be explained and described by the model in comparison to the GARCH-type models. Other types of SV models were also formulated similarly to the GARCH-type class. These are the FSV and CSV models (see [Pajor 2003]). The basic problem with the applications of SV lies in the estimation which requires many numerical procedures. Pajor [2003], indicates three groups of methods for the estimation of SV models, i.e. methods based on likelihood function estimation [Danielsson 1994], methods omitting estimation of likelihood function [Ruiz 1994] and Bayesian methods of estimation [Jaquier, Polson, Rossi 1994]. Here we mentioned only those papers that were historically the first in developing the methods of estimation.

A class of multivariate stochastic volatility [MSV] models has been developed as a natural continuation of univariate specification. It became clear that multivariate stochastic volatility models [MSV] are able to cover heavy-tailed error distributions as well as series-specific jump components, features that are important in financial time series analysis (see: [Asai, McAleer, Yu 2006; Chib, Nardari, Shephard 2006]). In the Polish literature the MSV models were analyzed, developed and applied by Pajor [2010].

There are many surveys that try to sum up the impact of GARCH–type models on financial econometrics. One can study Bollerslev, Chou and Kronner [1992], Lunde and Hansen [2005], Bauwens, Laurent and Rombouts [2006] or books by Gourieroux [1997], Xekalaki and Degiannakis [2009], Franq and Zakoian [2010] among many others. The applications of volatility models in practice were straightforward. The main applications of the GARCH-type models in finance, i.e. option pricing, risk measurement and large portfolios construction required volatility forecasting. Although they seem to be obvious nowadays, they were however the subject of many investigations.

3.2. Jump and diffusion models

In the econometric literature, continuous models for financial time series are also introduced and applied. They are based on stochastic difference equations developed on the grounds of contemporary mathematics. Concerning the concept of stochastic volatility a continuous diffusion model can be defined as well. Barndorff-Nielsen and Shephard [2006], defined a continuous stochastic volatility semi-martingale process (*SVSM)*. It is rarely assumed that the financial return process is fully continuous, but it is locally continuous with some discontinuities called jumps. The representation of the return is given as:

$$dX_t = \mu(X_{t,} \theta_1)dt + \sigma(X_{t,} \theta_2)dB_t,$$

where: B_t denotes standard Brownian motion, $\mu(X_t, \theta_1)dt$ is a drift function and $\sigma(X_t, \theta_2)$ is a diffusion function and $\theta = (\theta_1\ \theta_2)'$ denotes a vector of parameters.

Among the most popular models of jump and diffusion are such distinguishing ones as the Vašíček model [1977] and the Heston model [1993], which were basically used in option pricing models like the famous Black-Scholes formula awarded the Nobel prize in economics in 1997 for Robert C. Merton and Myron S. Scholes who developed a pioneering formula for the valuation of stock options.

Forecasting volatility was a very difficult task for the reason of calculating the 'real' values of an unobserved component. The paper of Anderson and Bollerslev [1998] was the first one that answered the question of *ex post* forecasting accuracy of volatility models, including both a discrete one and a continuous one. The answer was positive because their concept of realized volatility, derived from a continuous model of log return, became the most effective measure for the accuracy of volatility prediction. From the point of view of some authors, volatility models are good but unsatisfactory for forecasting a huge collapse, see for example Brownlees, Engle and Kelly [2011]. It seems to be natural that the models that are based on historical data are fitted to the data and replicate the patterns known from the past, so if the prediction of significant changes is to be made, additional information is required. That is the reason why so much interest is put on diagnostics of the jumps. The main issues related with the jump and diffusion models are the following: estimation techniques and jumps identification (comp. [Aït-Sahalia 2004; Barndorff-Nielsen and Shephard 2006]).

In Polish literature there are several important publications which subscribe into the econometric modelling of financial time series using jump and diffusion models. These are, among others, Kliber and Kliber [2010], Kostrzewski [2012; 2013] and Kliber [2013].

3.3. Contribution of Polish researchers in the area of volatility modelling and forecasting

The impact of Polish researchers in the field of volatility modeling and forecasting is quite important. Some of the most significant publications have already been mentioned.

First of all, Bayesian techniques for volatility modeling, forecasting and model selection were improved and developed. The Department of Econometrics in The University of Economics in Cracow has become the leader in that field. Among the most widely cited publications in this field concerned Bayesian analysis of GARCH models are: Osiewalski and Pipień, [1999; 2003a; 2003b; 2004] and Pipień [2006a]. Bayesian analysis of SV models was provided by Pajor [2003] for univariate SV models and Pajor [2010] for Multivariate SV models. The next important achievement of the Polish team from Cracow led by J. Osiewalski was developing a hybrid type of the volatility model consisting of a combination of the two multivariate GARCH and SV models [Osiewalski 2009], particularly the MSF-SBEKK model [see: Osiewalski, Pajor 2009; 2010; Osiewalski, Osiewalski 2012; 2013]. On the other hand, Kostrzewski [2013] analysed jump and diffusion models from the Bayesian perspective.

The second aspect of the Polish impact on volatility investigation is of both a theoretical and empirical nature. In this part a very wide range of papers using a classical (non-Bayesian) approach is shown and discussed. This is closely related to analyses prepared for the Polish capital market and comparing it to other emerging and developed financial markets. Starting from the early 1990s such analyses were hard to be fully applied because the Warsaw Stock Exchange was still not well developed. With the further development of the capital market in Poland, which happened after 1997, the following publications opened a wide stream of modeling volatility in Polish capital markets: Osińska and Hyżyk [2000], Fiszeder [2001], Osińska and Witkowski [2004], Piontek [2004]. It is worth particularly emphasizing that in the University of Economics in Poznań and Adam Mickiewicz University in Poznań a strong center for financial econometrics was founded by M Doman and R Doman. Among its achievements, Doman and Doman [2004a; 2004b; 2004c; 2005; 2009a; 2009b] widely analyzed the volatility of different segments of Polish financial markets including the stock market, the exchange rate market and the short-term interest rates market with different types of volatility models. They also compared the forecasting ability of different volatility models and compared the young Polish capital market with others. A. Kliber [2009], described and verified stochastic volatility models for interest rates and exchange rates observed in Central European states and EU members that entered the structures of the EU in 2004. Płuciennik [2010], analysed and predicted stock indices and exchange rates using jump and diffusion models. Kliber P. [2013], provided a wide comparison of jump and diffusion models with applications. Będowska-Sójka [2014], analysed macroeconomic news from the perspective of the price creation process.

Furthermore, Brzeszczyński and Kelm [2002] and Syczewska [2007], considered GARCH models for exchange rates modeling, while Rubaszek and Serwa [2009] used the ARCH-M model for modeling risk premium for the exchange rates of USD/EUR, USD/PLN and EUR/PLN, and Osińska [2010] compared the forecasting ability of the volatility models in the context of forecasting BRIC-countries exchange rates against USD. Fiszeder [2009], summed up different applications of a broad class of multivariate GARCH models. Gurgul and Wójtowicz [2008], examined the FIGARCH models and long memory on the Stock Exchange in Warsaw. The newest publications, Gębka and Serwa [2015], used Markow-Swiching GARCH models for evaluating the impact of heterogeneous investors on trading on large international stock markets. Fiszeder and Perczak [2013 and 2016] showed that information (based on volatility estimators like Parkinson's and others) about maximum, minimum high and low prices can help both volatility modeling and forecasting.

Different non-linear models acted as an alternative and/or complement to volatility models. There were, among others, the stochastic unit root models introduced by Granger and Swanson [Granger and Swanson 1997] and analyzed by Osińska et al [in: Osińska (ed.) 2007], and the RCA models proposed in 2003 by Nicholls and Quinn [see Nicholls and Quinn 2012] and developed by Górka [2012]. On the other hand, deterministic models generated by deterministic chaos were never a good alternative for volatility models [Orzeszko 2005]. Markow chains were often used in the Bayesian estimation of econometric models but Stawicki [2004], used them in the analysis of the processes observed on the capital market.

4. Models for error distribution, risk measures and extreme value theory

A particularly important development of financial econometrics comes from the fact that non-normal distributions started to be widely applied in model construction and estimation. This is due to the well- known stylized fact of heavy tails and asymmetry of empirical distributions of time series. Modeling distributions, such as α-stable class of distributions [Mandelbrot 1963], GED distribution [Giller 2005] and the most popular t-Student distribution in a traditional and skewed versions [McDonald, Xu 1995; Theodossiou 1998], can be thought of as another effect of the development of financial econometrics, particularly that based on volatility modeling and forecasting. In Poland, Pipień [2006; 2008a; 2008b], work out the conclusions concerning the utility of conditional skewness in modelling the volatility and the relationships between risk and return. Piontek [2007a], presented the way of identification of skewness in a financial time series. Papla and Piontek [2009], used α-stable distribution and copulas for estimating value at risk, Kliber P. [2013] analysed and used the Levy process for modelling financial data in Poland. In the first chapter of the book, co-edited by Weron [Cizek, Härdle, Weron (eds.) 2011], a set of heavy tails models for financial assets is the subject of the study.

The results for univariate case enabled constructing more and more complicated modes based on multivariate skew normal distribution [Azzalini, Dalla-Valle 1996; Adcock, Shutes 2012] and on multivariate skew-Student-t [Branco and Dey, 2001; Azzalini and Genton, 2008]. This allowed to go further into multivariate GARCH model with skewed t-distribution [Osiewalski and Pipień 2002; Bauwens, Laurent 2005], multivariate SV models with t distribution [Pajor 2010] or multivariate GARCH-SV hybrid models with different types of posterior distributions which were hard to imagine before [Osiewalski, Pajor 2009].

Another important field that determined the development of financial econometrics was measuring financial risk. Starting from a quantile-type of measures like Value at Risk [VaR], it was obvious that volatility models can serve as a basis for forecasting financial time series and financial risk management. In 1998, coherent risk measures were defined by Artzner et al. [1998], and it became clear that Value at Risk was not a satisfactory risk measure. The important question was about the magnitude of risk that can be accepted. New risk measures such as expected shortfall [ES] [Acerbi, Tasche 2002], and a class of spectral risk measures [SRM] [Acerbi 2002], accessed more precise information of risk acceptance level. There are several ways of estimating VaR, ES or SRM. One of them is applying volatility models to estimate and forecast future volatility values and use them in these computations [Degiannakis, Floros, Livada 2012]. In numerous publications these measures were used as instruments of comparing volatility models (see: [Doman, Doman 2004a; 2009b; Pipień 2005; Piontek 2007b; Fiszeder 2009; Osiewalski, Pajor 2012; Fałdziński 2014]; to mention only a few publications by Polish authors).

When financial risk has been increasing over time, the extreme value theory [EVT], known previously from seismology or hydrology, becomes very helpful and important. The EVT enables to decide which risk limit is to be hedged. Furthermore, it can be considered together with volatility models. Then the most important is the Peaks over Threshold [POT] method defined by McNeil and Frey [2000], based on the theorem by Pickands [1975], and Balkema and de Haan [1974]. Therefore, the risk measures basically calculated on the EVT methods are usually better and supported by the data. The only disadvantage of the EVT is that it cannot predict the moment in time where an extreme event will take place. In finance we call this a “black swan”.

In Polish literature the extreme value theory in financial applications was initially analyzed by Jajuga [2006], Osińska and Fałdziński [2007], Trzpiot [2012] and widely explored by Fałdziński [2014], who compared both the parametric and non-parametric methods of estimating the characteristics of extreme distributions of financial time series. The parametric approach is much more relevant for financial applications. For example, Osińska and Fałdziński [2007], used the GARCH and SV models together with the POT method to estimate the frequency of extreme values in the main stock market indices, such as DAX, SP500, DJIA and FTSE. They found that the models based on the EVT methodology outperformed other models in this period. In these particular cases the SV model with Peaks over Threshold was the leader in the ranking. Yet another approach to EVT application is represented in Majewska, Trzpiot [2013] who examined the tail independence tests in the extreme value models and applied them to the Polish stock market. In 2012 Trzpiot [2012] examined the extreme quantile regression method.

5. Modeling and testing the relationships between financial markets or portfolios

In this field three main branches can be distinguished. The first one is simply the application of multivariate volatility models, taking into account the dynamics of conditional correlations, which were the subject discussed in Section 3. The second is one is related to the Granger causality in risk concept and the third one to using copulas. In this section we concentrate on the last two cases.

It should be mentioned that different regression models based on the classical financial models are also applied and developed while the dependence between the markets (or portfolios) is analyzed. Classical models such as the Capital Asset Pricing Model (CAPM), the Arbitrage Pricing Model (APT) or the simplest Single Index model are considered as the general framework for the analyses made on financial markets and the departures from that framework are subjects of special interest. The Foreign Information Transmission, called the FIT model, is one of the important examples of using a time varying parameters (TVP) approach. The theoretical background of the model, as well as its usefulness for regional and interregional dependence, was provided by Ibrahim and Brzeszczyński [Ibrahim, Brzeszczyński 2009].

Granger causality in risk should be understood in terms of the co-dependence between different financial instruments, portfolios or markets that occurred if the risk limits are broken. This means that breaking the VaR [or ES or SRM] in one market results in exceeding the maximum risk levels in different markets. Such a situation may correspond with the co-movement or spillover effect, or contagion phenomenon. On the other hand, it can be associated with positive impulses spreading all over the world depending on the position of investors and the range of analyses. A formal definition of Granger causality in risk was provided by Hong [2001]. Osińska [2011] provided an interpretation for this phenomenon in comparison with the classic definition of causality in the Granger-sense [Granger 1969]. It is worth noting that in the classic approach systematic elements are taken into account, while in the case of causality in risk, short term news is much more important because it stimulates risk transfer and spillover effect with bad news coming from the markets. The causality in risk concept is naturally based on volatility models and breaking the risk measures like VaR, ES or SRM.

Different testing procedures can be applied to analyze empirical co-movements on financial markets. Among the most popular, Cheung and Ng [1996], Caporale et al. [2002] and Haffner and Hervatz [2004], tests for causality in variance should be recognized. Osińska [2008] showed the limits for using the Cheung and Ng test for causality in variance [Cheung and Ng 1996] when normality assumption is violated. It was indicated that starting from 8 degrees of freedom in Student distribution in the error term in the GARCH model, it is possible to use the Cheng and Ng test despite the fact that it requires Gaussian distribution. For a lower number of degrees of freedom the results are highly uncertain. It should be noted that the Cheung and Ng test concern univariate volatility representations [usually GARCH but the SV model can be used as well] while the two other tests are fitted to the multivariate GARCH models.

Testing procedures related directly with causality in risk are directed more onto the risk spillover rather than the co-movements. These are the Hong test [Hong 2001a; Hong et al. 2009], and the Candelon et al. [2013] test. Fałdzinski, Osińska and Zdanowicz [2012a and 2012b], determined the relationships between Chinese stock markets and the rest of the world using Hong et al. test, while Fałdziński and Osińska [2016], analyzed the Hong et al. and Candelon et al. testing results from the perspective of risk transfer from emerging to developed markets with the additional application of the extreme values approach.

As spillover can be a source of contagion, it is worth noting that there is an extensive literature in this field that applies tools typical for financial econometrics, among others. Recently, Burzała [2014], has provided a survey of the methods of analysis within the framework of contagion.

Another approach is related to the application of copulas introduced by Sklar in 1959 (comp. [Doman 2011]). A copula is a multivariate probability distribution for which the marginal probability distribution of each variable is uniform. The copula theory is generally applied to describe the dependence between random variables. In finance it is applied in particular in: the stock market analysis and simultaneous pricing of many derivatives – both dependent and independent; tail dependence; correlation of financial instruments and market and credit risk assessment. The well-known book by Cherubini, Luciano and Vecchiato [2006], provides a broad survey of copula methods. The first publications on copulas prepared by Polish authors were by Jajuga and Papla [2005; 2006], and Papla and Piontek [2009]. Kuziak [2013], analyzed the sensitivity of the Copula-VaR approach for misspecifications.

However the deepest approach to copula analysis and applications can be found in the book by Doman [2011]. He not only provided applications of different copula models in analysis of interdependencies between different financial markets but also proposed some modifications of the models such as including dynamic approach to the relationships changing over time and using different copulas in different regimes identified by the Markov chain. In Doman and Doman [2014], a wide range of copulas has been applied to analysing the relationships between selected pairs of exchange rates, based on long time series data.

6. Market microstructure and UHF data

In the beginning of the XXI century, Engle drew attention to ultra-high frequency data (UHF) data as the most important problem of analyzing financial processes in real time [Engle 2000]. Almost up to that time it was difficult to analyze real time transactions due to both the lack of appropriate computer systems and the lack of the methods of analysis of such big databases. Due to the rapid development of computer methods and information systems, all this has changed beyond all recognition. It then became possible to fit and verify the microstructure models that were formulated mainly in the late 1980s (although the first papers by Bagehot were published in the early 1970s. [Bagehot 1971].

One of the purposes of market microstructure analysis was the process of discounting the information in prices and the mechanism of revealing private information by outsiders. Microstructure models offer an appropriate method for comparing the dynamics of different financial instruments because they make a precise inference about short-term market sensitivity. Investors usually act based on contemporaneous and historical information combined with their own opinions. Microstructure models take into account heterogeneous investors on the market. Many theoretical models concerning an ideal market that reflects all possible information have been constructed [see, for example, Russell and Engle 2010]. Two streams can be noticed when examining the models, starting with Bagehot [1971], and Grossman and Stiglitz [1980], through more complicated models formulated by Kyle [1985], Admati and Pfleiderer [1988], Hasbrouck [2002] and recently by Kyle and Obizhaeva [2016]. In the first one the division of financial markets models into a price-driven and an order-driven market models can be noticed. The second one is the evolutionary complication of the models. All the mentioned models and many others are discussed in Polish literature detail by Doman [2011] and Bień--Barkowska [2016].

The empirical analyses of the financial markets' microstructure became popular starting from the seminal book by O'Hara [1995], and further publications [Easley et al; 1996; 1997] and they are currently of great importance due to the development of emerging markets, foreign exchange market analysis and market stability policy after the financial crisis of 2007-2009. The econometric models that can be applied for microstructure processes are the GARCH-type models. It can be noted that particularly the EGARCH model became useful for such analyses (see: [Bollerslev, Mikkelsen 1996]). Next, the Autoregressive Conditional Intensity model [ACI] was developed by Russel [1999], Autoregressive Conditional Duration [ACD] was introduced [Engle, Russell 1998] and the Autoregressive Conditional Volume [ACV] model for volume [Manganelli 2005]. The three latter models are based on the volatility type of the models but they focus on the non-synchronous trade within the trading day and use different distributions' forms. As the main achievement of market microstructure analysis, one can indicate the explanation of the mechanisms of information flow in the financial markets [Baruch, Karolyi, Lemmon 2007]. Modeling the UHF data required non-standard estimation procedures. The most significant contributor in the area is Y. Aït-Sahalia [Aït-Sahalia, Yu 2009; Aït--Sahalia, Mykland, Zhang 2011].

In Poland the contribution of two authors, M. Doman and K. Bień-Barkowska, should be considered as particularly important. M. Doman [2011], not only discussed and compared a variety of theoretical models of market microstructure from the perspective of three groups of investors and market liquidity, but also performed a wide empirical discussion on the microstructure of selected processes observed on the Stock Exchange in Poland. Furthermore, together with Doman R. [Doman, Doman 2010], the author examined the dependencies between price duration, volatility, volume and return on the Warsaw Stock Exchange according to an extended Manganelli model.

Bień-Barkowska examined a large number of intraday transactions, covering both the stock market microstructure [Bień 2006a; 2006b] and, the exchange rates market microstructure [Bień 2010; Bień- Barkowska 2012; 2014; 2015]. The attention was concentrated on the interbank FX spot market. Furthermore, they contributed to the theoretical development of financial econometrics in the area of microstructure by extending the model AACD by Bauwens and Giot [2003, see: Bień-Barkowska 2011]. In the paper [Bień, Nolte and Pohlmeier 2007], a model for the conditional inflated multivariate density of integer count variables was developed. An investigation of the transaction process dynamics based on the UHF data led by Bień-Barkowska has been recently summarized in her latest book, which covers the market microstructure models and empirical issues in the most complex way [Bień-Barkowska 2016].

Another consideration is the subject of publication prepared by Będowska-Sójka [2014], which concentrated on the impact of a certain set of information on financial prices creation using intra-day data. High-frequency and ultra-high-frequency data are present in numerous empirical analyses in which the financial econometric models are used. The following need to be mentioned: Strawiński and Ślepaczuk [2008], Ślepaczuk and Zakrzewski [2009].

7. Behavioral hypotheses and qualitative data in financial econometrics

Recently great attention has been paid to behavioral aspects in finance. In 1979 Kahneman and Tversky published their prospect theory which resulted in the Nobel Prize for Daniel Kahneman for his contribution to behavioral finance, and Vernon Smith for his contribution to empirical economics in 2002. Since that point such a theory was taken into account when non-economic causes of decision-making process were being considered. Behavioral inclinations were taken as causes of investors' errors in opinions and preferences. According to microstructure models it is assumed that the noise traders make more mistakes than the informed [rational] traders on the heterogeneous market.

Then the question arises of whether financial econometrics is able to consider such psychological or behavioral information. Considering the psychological findings, it can be stated that the Structural Equations Model [SEM], being an econometric technique, has been widely developed and used in psychology for a long time [Brzeziński 2003; Kline 2006; Konarski 2010]. Structural Equations Models have been applied to reveal behavioral inclinations on financial markets [Lampenius, Zickar 2005; Wang, Shi and Fan 2006; Hui 2009; Żurek 2016].

This aspect of financial econometrics is slightly different because it is no longer based on the time series data but on survey data. It can be linked with the market microstructure because the structural equations models help to identify the characteristics of different groups of investors, mainly uninformed [noise] investors who are present in each market but strongly affect less liquid or less developed markets. In Poland the important publications on behavioral finance by Tyszka and Zielonka [2002], Dacey and Zielonka [2008], Szyszka [2009], Zielonka [2011] and the review by Borowski [2014], should be recognized. in particular, Dacey and Zielonka defined a model based on investor's subjective asset pricing. Such models give a new insight into the theory of finance. However, the empirical analyses are very important as well. Osińska, Pietrzak and Żurek [2011], attempted to explain empirically the magnitude of the impact of psychological factors on both the propensity to risk and the level of expected return exhibited by individual investors actively quoting on the Stock Exchange in Warsaw (n = 315). Identifying and describing the relationship between unobservable factors such as behavioral inclinations, propensity for risk, ability to use technical analysis, as well as market quality are made with the application of the Structural Equation Model. The hypothesis that errors in the opinions and preferences cause an increase in individual propensity for risk, as well as the increase in the level of expected and satisfactory return. The empirical results are promising for two reasons. Firstly, they are logically acceptable and secondly, they are statistically well fitted with the values of IFI = 0.999 and RMSEA = 0.006. The model shows that the errors in opinions increase strongly [+0.697] the tendency towards risk among individual investors. The errors in opinion consist of the illusion of control and unreasonable optimism. Investors cannot value the facts properly and they make risky decisions. Żurek [2016] verified these findings on two other samples of investors. Kliber et al. [2016], considered the impact of the socio-demographic characteristics of individual investors on their decision-making process.

It is important to realize that behavioral aspects are very important not only in financial analysis but in entire economic theory and practice. Perhaps the findings of behavioral heuristics on financial markets are still behind the computational methods or quantitative methods, but it is inevitable that they systematically improve the understanding of the decision-making process on both individual and group level.

Further development in econometric techniques dedicated to financial process modeling with the application of qualitative information is related to several areas. The first of them is analyzing the impact of periodically or non-periodically announced news on the price creation process. This is in accordance with the event analysis developed by MacKinley [1997]. In Polish econometric literature on event-study, Gurgul [2012] and Będowska-Sójka should be mentioned. Będowska-Sójka in particular has made great effort to find out the impact of announcements of macroeconomic news on price creation indicating that news coming from the USA is of the greatest importance.

Another type of qualitative information is related to the division of the news into “good” and “bad”. Some news items are given directly and some of them are only “guessed” by the empirical models. Different techniques are then applied. Among econometric techniques, asymmetric GARCH models, discussed in Section 3, are usually estimated. In line with the latest publications, Chlebus [2016], proposed a regime-switching model based on qualitative information, called Early Warning System-GARCH. Kostrzewski [2015], examined the impact of good and bad information on jumps’ sizes.

8. Conclusions

The exceptional dynamics of financial econometrics methods, observed since 1982, was the motivation for summing up the development of the methods and applications present in the hitherto quantitative analyses of financial processes. The dynamics was broken by the financial crisis in the USA experienced since 2007 and caused global financial and economic recession all over the world. Its lowest level occurred in 2009 when most economies suffered from negative growth rates. This brought up a question of the role of financial econometrics, and its application in an early warning system and detecting market dependencies in a globalized world. Seven years after the recession it is certain that financial econometrics methods cannot be suspected of being a possible source of the crisis. The information coming from the models was often neglected by the decision-makers, who tried to act in the standard way of not being able to break the negative trend. This was well pictured even in such popular movies as *Margin Call* directed in 2011 by J.C. Chandor, and *Big Short* directed by A. McKay and produced in 2015.

The unprecedented and distinguishing progress in econometric techniques development, based on the trio of theoretical, i.e. economic and financial concepts, mathematical and statistical solutions as well as the enormous increase in computational power have become the fact. Nowadays, one can observe new ideas in financial econometrics such as including qualitative and behavioral information into the models used with a great care. What should be emphasized looking back at the development of financial econometrics is the significant dominance of volatility models in almost all areas of financial econometrics and the complexity of the models covering different aspects of changes that happen on the markets. The intensity of the data available for immediate analysis creates a demand for such models and the methods of their estimation as well as their identification.

The challenges of contemporary financial markets are related to individual attitudes towards investments, interdependencies, co-movements and contagion on the global financial markets, and the security of the financial data. These create demand for more and more complex methods of analysis and prediction. One of the examples is the systemic risk model [SRM]. The basic idea of the SRM model is to combine standard techniques from the modern quantitative market and credit risk management with a network model of the banking system. In contrast to standard risk management models, SRM makes the step from the individual institution perspective to the system level. Central banks in different countries have been working on such models (comp. [Boss et al. 2006; Hansen 2013; Jajuga 2014; Płuciennik et al. 2013; Kliber 2016].

In the paper we focused on the contribution of Polish researchers into financial econometrics over the years, considering the methodology and applications. Some of the indicated publications are internationally recognizable, quite frequently cited and gradually entering the international bases of citations, the others are not very popular due to the language of the publication or the local range of the journal, although they can be considered in line with the achievements that are presented in international empirical publications.

The picture of Polish financial econometrics that comes from the analysis prepared in this paper is quite optimistic, although the present number of international quotations can be the basis for reflection on how to select the areas of interest and to internationalize the publication policy in this domain. Such journals as *Central European Journal of Econometric Modelling and Econometrics*, *Dynamic Econometric Models*, *Equilibrium* and *Econometric Research in Finance* have started this process with the promise of a success. The number of publications by Polish authors in the influential journals and international textbooks is growing as well.

Bibliography

Acerbi C., 2002, *Spectral measures of risk: A coherent representation of subjective risk aversion*, Journal of Banking and Finance, 26, pp. 1505-1518.

Acerbi C., Tasche D., 2002, *On the coherence of expected shortfall*, Journal of Banking & Finance, 267, pp. 1487-1503.

Adcock C.J., Shutes K., 2012, *On the multivariate extended skewnormal, normal-exponential, and normal-gamma distributions*, Journal of Statistical Theory and Practice, 6(4), pp. 636-664.

Admati A.R., Pfleiderer P., 1988, *A theory of intraday patterns: volume and price*, The Review of Financial Studies, 1, pp. 3-40.

Aït-Sahalia, Y., 2004, *Disentangling diffusion from jumps*, Journal of Financial Economics, 74(3), pp. 487-528.

Ait-Sahalia Y., Hansen L.P. (eds), 2004, *Handbook of Financial Econometrics*, North-Holland, Elsevier Science.

Aït-Sahalia Y., Yu J., 2009, *High frequency market microstructure noise estimates and liquidity measures*, The Annals of Applied Statistics, 3, pp. 422-457.

Aït-Sahalia Y., Mykland P., Zhang L., 2011, *Ultra high frequency volatility estimation with dependent microstructure noise*, Journal of Econometrics, 160, pp. 160-175.

Andersen L., Andersen J., 2000, *Jump-diffusion models: volatility smile fitting and numerical methods for pricing*, Rev. Derivatives Research, 4, pp. 231-262.

Andersen T.G., Bollerslev T., 1997, *Heterogeneous information arrivals and return volatility dynamics: uncovering the long-run in high frequency returns*, Journal of Finance, 52, pp. 975-1005.

Angelidis T., Degiannakis S., 2006, *Backtesting VaR Models: An Expected Shortfall Approach*, Working Papers, University of Crete, Athens University of Economics and Business.

Appelbaum D., 2004, *Levy Processes and Stochastic Calculus,* Cambridge University Press.

Araujo Santos P., Fraga Alves I., Hammoudeh S., 2013, *High quantiles estimation with quasi-PORT and DPOT: an application to Value-at-Risk for financial variables*, North American Journal of Economics and Finance, 26, pp. 487-496.

Artzner P., Delbaen F., Eber J.M., Heath D., 1999, *Coherent measures of risk*, Mathematical Finance, 9, pp. 203-228.

Asai M., McAleer M., Yu J., 2006, *Multivariate stochastic volatility: a review*, Econometric Reviews, 25, pp. 145-175.

Azzalini A., Genton M.G., 2008, *Robust likelihood methods based on the skew-t and related distributions*, International Statistical Review, 76, pp. 106-129.

Baba Y., Engle R.F., Kraft D., Kroner K.F., 1990, *Multivariate simultaneous generalized GARCH*, UCSD, Department of Economics, mimeo.

Bagehot W., 1971, *The only game in town*, Financial Analyst Journal, 22(27), pp. 12-14.

Balkema A.A., De Haan L., 1974, *Residual life time at great age*, Annals of Probability, 2(5), pp. 792-804.

Barndorff-Nielsen O.E., Shephard N., 2006, *Econometrics of testing for jumps in financial economics using bipower variation*, Journal of Financial Econometrics, 4(1), pp. 1-30.

Baruch S., Karolyi A.G., Lemmon M.L., 2007, *Multimarket trading and liquidity: theory and evidence*, The Journal of Finance, 62(5), pp. 2169-2200.
Bauwens L., Giot P., 2000, *The logarithmic ACD model: an application to the bid-ask quote process of three NYSE stocks*, Annuls of Economy and Statistic, 60, pp. 117-149.
Bauwens L., Veredas D., 2004, *The stochastic conditional duration model: a latent variable model for the analysis of financial durations*, Journal of Econometrics, 119, pp. 381-412.
Bauwens L., Laurent S., 2005, *A new class of multivariate skew densities, with applications to GARCH Models*, Journal of Business and Economic Statistics, 23, pp. 346-354.
Będowska-Sójka B., 2014, *Wpływ informacji na ceny instrumentów finansowych. Analiza danych śróddziennych*, Wyd. Uniwersytetu Ekonomicznego w Poznaniu, Poznań.
Będowska-Sójka B., 2015, *Daily VaR Forecasts with Realized Volatility and GARCH models*, Argumenta Oeconomica, 34, 1, pp. 157-173.
Będowska-Sójka B., Kliber A., 2010, *Realized volatility versus GARCH and stochastic volatility models. The evidence from the WIG20 index and the EUR/PLN Foreign Exchange Market*, Przegląd Statystyczny, 4, pp. 105-127.
Bień K., 2006a, *Zaawansowane specyfikacje modeli ACD – prezentacja oraz przykład zastosowania*, Przegląd Statystyczny, 53(1), pp. 90-108.
Bień K., 2006b, *Model ACD – podstawowa specyfikacja i przykład zastosowania*, Przegląd Statystyczny, 53(3), pp. 83-97.
Bień K., Nolte I., Pohlmeier W., 2007, *An inflated multivariate integer count hurdle model: an application to bid and ask quote dynamics*, Journal of Applied Econometrics, 26, pp. 549-714.
Bień K., 2010, *Przepływ zleceń a kurs walutowy – badanie mikrostruktury rynku międzybankowego*, Bank i Kredyt, 41(5), pp. 5-40.
Bień-Barkowska K., 2011, *Distribution choice for the asymmetric ACD models*, Dynamic Econometric Models, 11, pp. 55-72.
Bień-Barkowska K., 2014a, *Capturing order book dynamics in the interbank EUR/PLN spot market*, Emerging Markets Finance and Trade, 50, pp. 93-117.
Bień-Barkowska K., 2014b, *Every move you make, every step you take, I'll be watching you – the quest for hidden orders in the interbank FX spot market*, Bank i Kredyt, 45(3), pp. 197-224.
Bień-Barkowska K., 2015, *Econometric modeling of inter-order durations*, Acta Physica Polonica, A, 127, A-7.
Bień-Barkowska K., 2016, *Mikrostruktura rynku. Ekonometryczne modelowanie dynamiki procesu transakcyjnego*, Oficyna Wydawnicza SGH.
Bollerslev T., 1986, *Generalized autoregressive conditional heteroskedasticity*, Journal of Econometrics, 31(3), pp. 307-327.
Bollerslev T., 2001, *Financial econometrics: Past developments and future challenges*, Journal of Econometrics, 100(1), pp. 41-51.
Bollerslev T., Chou R.Y., Kroner K.F., 1992, *ARCH modelling in finance. A review of the theory and empirical evidence,* Journal of Econometrics, 52.
Bollerslev T., Mikkelsen H.O., 1996, *Modeling and pricing long memory in stock market volatility*, Journal of Econometrics, 73(1), pp. 151-184.
Boss M., Krenn G., Puhr C., Summer M., 2006, *Systemic risk monitor: A model for systemic risk analysis and stress testing of banking systems*, Financial Stability Report, 11, pp. 83-95.
Borowski K., 2014, *Finanse behawioralne. Modele*, Diffin, Warszawa.
Brownlees Ch., Engle R., Kelly B., 2011/12, *A practical guide to volatility forecasting through calm and storm*, The Journal of Risk 14(2), pp. 3-22.
Brzeszczyński J., Kelm R., 2002, *Ekonometryczne modele rynków finansowych. Modele kursów giełdowych i kursów walutowych*, WIG Press.
Brzeziński J., 2003, *Metodologia badań psychologicznych*, Wydawnictwo Naukowe PWN.

Burzała M., 2014, *Wybrane metody badania efektów zarażania na rynku kapitałowym*, Wyd. UEP, Poznań.
Cai Z., Hong Y., 2009, *Some recent developments in nonparametric finance*, Advances in Econometrics, 25, pp. 379-432.
Campbell J.Y., Lo A.W., MacKinlay A.C., 1997, *The Econometrics of Financial Markets*, Princeton University Press.
Candelon B., Joëts M., Tokpavi S., 2013, *Testing for granger causality in distribution tails: an application to oil markets integration*, Economic Modelling, 31, pp. 276-285.
Caporale G.M., Pittis N., Spagnolo N., 2002, *Testing for causality-in-variance: an application the East Asian markets*, International Journal of Finance and Economics, 7, pp. 236-245.
Chang C.L., Allen D., McAleer M., 2013, *Recent developments in financial economics and econometrics*: *An overview*, The North American Journal of Economics and Finance, 26, pp. 217-226.
Cherubini U., Luciano E., Vecchiato W., 2006, *Copula Methods in Finance*, J. Wiley.
Cheung Y.W., Ng L.K., 1996, *A causality in variance test and its application to financial market prices*, Journal of Econometrics, 72, pp. 33-48.
Chib S., Nardari F., Shephard N., 2006, *Analysis of high dimensional multivariate stochastic volatility models*, Journal of Econometrics, 134(2), pp. 341-371.
Chlebus M., 2016, *EWS-GARCH: New Regime Switching Approach To Forecast Value-At-Risk*, Working Papers 2016-06, Faculty of Economic Sciences, University of Warsaw.
Cizek P., Härdle W., Weron R., (eds), 2011, *Statistical Tools for Finance and Insurance*, *Extended and Revised Edition with Codes in Matlab and R*, 2nd edition, Springer-Verlag, Berlin.
Clark P.K., 1973, *A subordinated stochastic process model with fixed variance for speculative prices*, Econometrica, 41, pp. 135-156.
Cont R., 2001, *Empirical properties of asset returns: stylized facts and statistical issues*, Quantitative Finance, 1(2), pp. 223-236.
Dacey R., Zielonka P., 2008, *A detailed prospect theory explanation of the disposition effect*, The Journal of Behavioral Finance, 9(1), pp. 43-50.
Dacorogna M., Ulrich M., Richard O., Oliveier P., 2001, *Defining efficiency in heterogeneous markets*, Quantitative Finance, 1, 198-201.
Danielsson J., 1994, *Stochastic volatility in asset prices: estimation with simulated maximum likelihood*, Journal of Econometrics, 64, pp. 375-400.
Degiannakis S., Floros C., Livada A., 2012*, Evaluating Value-At-Risk models before and after the financial crisis of 2008*, Managerial Finance, 38 (4), pp. 436-452.
Delavande A. Giné X., McKenzie D., 2010, *Measuring Subjective Expectations in Developing Countries: A Critical Review and New Evidence*, mimeo.
Doman M., 2011, *Mikrostruktura giełd papierów wartościowych*, Wydawnictwo UE, Poznań.
Doman M., Doman R., 2004a, *Ekonometryczne modelowanie dynamiki polskiego rynku finansowego*, Wyd. AE, Poznań.
Doman M., Doman R., 2004b, *Stochastic volatility models of exchange rates in Central European countries: effects of exchange rate Regimes*, Przegląd Statystyczny, 4, pp. 37-55.
Doman M., Doman R., 2004c, *Testowanie nieliniowości w zwrotach indeksów GPW w Warszawie*, [in:] *Matematyka w ekonomii*, E. Panek (ed.), Wyd. AE, Poznań, pp. 179-192.
Doman M., Doman R., 2005, *Dynamika zmienności stóp procentowych WIBOR i WIBID*, Zeszyty Naukowe AE Poznań, 52.
Doman M., Doman R., 2009a, *Forecasting the end-of-the-day realized variance*, Metody Ilościowe w Badaniach Ekonomicznych, 10, pp. 67-75.
Doman M., Doman R., 2009b, *Modelowanie zmienności i ryzyka: metody ekonometrii finansowej*, Wolters Kluwer business, Kraków.
Doman M., Doman R., 2010, *Dependencies between price duration, volatility, volume and return on the Warsaw Stock Exchange*, Journal of Modern Accounting and Auditing, 6(10), pp. 27-38.

Doman M., Doman R., 2014, *Dynamic linkages in the Pairs (GBP/EUR, USD/EUR) and (GBP/USD, EUR/USD): how do they change during a day?*, Central European Journal of Economic Modelling and Econometrics (CEJEME), 6(1), pp. 33-56.

Doman R., 2011, *Zastosowania kopuli w modelowaniu dynamiki zależności na rynkach finansowych*, Wydawnictwo UEP, Poznań.

Doman R., Doman M., 2010, *Copula based impulse response analysis of linkages between stock markets*, Available at SSRN: http://ssrn.com/abstract=1615108.

Dowd K., Cotter J., Sorwar G., 2008, *Spectral risk measures: properties and limitations*, Journal of Financial Services Research, 34, pp. 61-75.

Easley D., Kiefer N., O'Hara M., Paperman J., 1996, *Liquidity. Information and infrequently traded stocks*, Journal of Finance, 51, pp. 1405-1436.

Easley D., Kiefer N., O'Hara M., 1997, *One day in the life of a very common stock*, Review of Financial Studies, 10, pp. 805-835.

Embrechts P., Klüppelberg C., Mikosch T., 2003, *Modelling Extremal Events for Insurance and Finance*, Springer, Berlin.

Engle R.F., 1982, *Autoregressive conditional heteroscedasticity with estimates of the variance of United Kingdom inflation*, Econometrica, 50.

Engle R.F., 2000, *The econometrics of ultra-high-frequency data*, Econometrica, 68, pp. 1-22.

Engle R., 2012, *Forecasting intraday volatility in the US equity market. Multiplicative component GARCH*, Journal of Financial Econometrics, 10(1), pp. 54-83.

Engle R.F., Ito T., Lin W-L., 1990, *Meteor showers or heat waves? Heterokedastic intra-daily volatility in the foreign exchange market*, Econometrica 58, pp. 525-542.

Engle R.F., Russell J.R., 1998, *Autoregressive conditional duration: A new model for irregularly spaced transaction data*, Econometrica, 66, 1127-1162.

Engle R.F., 2000, *The econometrics of ultra-high-frequency data*, Econometrica, vol. 68, pp. 1-22.

Engle R.F., Lange J., 1997, *Measuring, forecasting and explaining time varying liquidity in the stock market*, Tech. Rep. National Bureau of Economic Research.

Engle R.F., Russell J.R., 1998, *Autoregressive conditional duration: A new model for irregularly spaced transaction data*, Econometrica, 66, pp. 1127-1162.

Kraft D.F., Engle R.F., 1983, *Autoregressive Conditional Heteroskedasticity in Multiple Time Series Models*, Department of Economics, UC San Diego, mimeo.

Engle R.F., Kroner K.F., 1995, *Multivariate simultaneous generalized ARCH*, Econometric Theory, 11(01), pp. 122-150.

Fałdziński M., 2014, *Teoria wartości ekstremalnych w ekonometrii finansowej*, Wyd. UMK, Toruń.

Fałdziński M., Osińska M., 2016, *Volatility estimators in econometric analysis of risk transfer on capital markets*, Dynamic Econometric Models, forthcoming.

Fałdziński M., Osińska M., Zdanowicz T., 2012a, *Econometric analysis of the risk transfer on capital markets. A case of China*, Argumenta Oeconomica, 229, pp. 139-164.

Fałdziński M., Osińska M., Zdanowicz T., 2012b, *Detecting risk transfer in financial markets using different risk measures*, Central European Journal of Economic Modelling and Econometrics CEJEME, 14, pp. 45-64.

Fama E., 1970, *Efficient capital markets*: *A review of theory and empirical work*, Journal of Finance, 25(2), pp. 383-417.

Fan J., 2004, *An Introduction to Financial Econometrics*, Department of Operation Research and Financial Engineering, Princeton University, Princeton.

Fan J., 2005, *A selective overview of nonparametric methods in financial econometrics*, Statistical Science, 20(4), pp. 317-337.

Fiszeder P., 2001, *Zastosowanie modeli GARCH w analizie krótkookresowych zależności pomiędzy Warszawską Giełdą Papierów Wartościowych a międzynarodowymi rynkami akcji*, Przegląd Statystyczny, 48(3-4), pp. 345-364.

Fiszeder P., 2009, *Modele klasy GARCH w empirycznych badaniach finansowych*, UMK, Toruń.
Fiszeder P., Perczak G., 2013, *A new look at variance estimation based on low, high and closing prices taking into account the drift*, Statistica Neerlandica, 67(4), pp. 456-481,
Fiszeder P., Perczak G., 2016, *Low and high prices can improve volatility forecasts during periods of turmoil*, International Journal of Forecasting, pp. 398-410.
Fiszeder P., Romański J., 2001, *Modelling Polish Stock Returns with GARCH Models*, [in:] *Macromodels 2000: Proceedings of the Twenty Seventh International Conference Macromodels*, W. Welfe (ed.), Absolwent, Łódź.
Frank N., 2009, *Linkages between Asset Classes During the Financial Crisis. Accounting for Market Microstructure Noise and Non-Synchronous Trading Oxford-Man Institute of Quantitative Finance and Department of Economics*, University of Oxford, U.K.
Francq C., Zakoian J.M., 2011, *GARCH Models: Structure, Statistical Inference and Financial Applications*, John Wiley & Sons.
Garman M.B., 1976, *Market microstructure*, Journal of Financial Economics, 1976, vol. 3(3), pp. 257-275.
Garman M.B., Klass M.J., 1980, *On the estimation of security price volatilities from historical data*, Journal of Business, 53, pp. 67-78.
Gębka B., Serwa D., 2015, *The elusive nature of motives to trade: evidence from international stock markets*, International Review of Financial Analysis, 39, pp. 147-157.
Giller G.L., 2005, *A Generalized Error Distribution*, mimeo.
Giot P., 2001, *Time transformations. Intraday data. and volatility models*, Journal of Computational Finance, 4, pp. 93-109.
Ghysels E., Jasiak J., 1998, *GARCH for irregularly spaced financial data: the ACD-GARCH model*, Studies in Nonlinear Dynamics & Econometrics, vol. 2, no. 4. pp. 1-19.
Gourieroux C., 1997, *ARCH Models and Financial Applications*, Springer.
Górka, J., 2012, *Modele klasy Sign RCA GARCH: własności i zastosowanie w finansach*, Wydawnictwo Naukowe Uniwersytetu Mikołaja Kopernika, Toruń.
Górka J., Osińska M., 2003, *Analiza spektralna stóp zwrotu z inwestycji w akcje*, Nasz Rynek Kapitałowy, 3(147), pp. 138-143.
Górka J., Osińska M., 2007, *Istota procesów STUR i ich identyfikacja*, [in:] *Procesy STUR: modelowanie i zastosowanie do finansowych szeregów czasowych*, M. Osińska (ed.), Towarzystwo Naukowe Organizacji i Kierownictwa „Dom Organizatora", pp. 35-74.
Górka J., Kwiatkowski J., Osińska M., 2007, *Zastosowanie procesów STUR do modelowania finansowych szeregów czasowych*, [in:] *Procesy STUR: modelowanie i zastosowanie do finansowych szeregów czasowych*, M. Osińska (ed.), Towarzystwo Naukowe Organizacji i Kierownictwa Dom Organizatora, Toruń, pp. 131-162.
Granger C.W.J., 1969, *Investigating causal relations by econometric models and cross-spectral methods*, Econometrica, 373, pp. 424-438.
Granger C., Joyeux R., 1980, *An introduction to long-memory time series models and fractional differencing*, Journal of Time Series Analysis, 1, pp. 15-29.
Granger C.W., Swanson N.R., 1997, *An introduction to stochastic unit-root processes*, Journal of Econometrics, 80(1), pp. 35-62.
Grossman S.J., Stiglitz J.J., 1980, *On the Impossibility of Informationally Efficient Markets*, American Economic Review, 70, pp. 393-408.
Gurgul H., 2012, *Analiza zdarzeń na rynkach akcji: wpływ informacji na ceny papierów wartościowych*, Wolters Kluwer, Warszawa.
Gurgul H., Wójtowicz, T., 2008, *FIGARCH models and long memory*, Statistics in Transition, 9(2), pp. 297-310.
Haffner C.M, Herwatz H., 2004, *Testing for causality in variance using multivariate GARCH Models*, Metrika, 67, pp. 219-239.

Hansen L.P., 2013, *Challenges in Identifying and Measuring Systemic Risk*, NBER Chapters, [in:] *Risk Topography: Systemic Risk and Macro Modeling*, pp. 15-30.

Hansen P.R., 2005, *An test for superior predictive ability*, Journal of Business and Economic Statistics, 23, pp. 365-380.

Hansen P.R., Lunde A., Nason J.M., 2003, *Choosing the best volatility models: the model confidence set approach*, Oxford Bulletin of Economics and Statistics, 65, pp. 839-861.

Harmantzis F.C., Miao L., Chien Y., 2006, *Empirical study of value at risk and expected shortfall models with heavy tails*, Journal of Risk Finance, 7(2), pp. 117-126.

Hasbrouck J., 2002, *Stalking the "efficient price" in market microstructure specifications: an overview*, Journal of Financial Markets, 5, pp. 329-339.

Heston S.L., 1993, *A closed solution for options with stochastic volatility, with application to bond and currency options*, Review of Financial Studies, 6(2), pp. 327-343.

Hong Y., 2001, *A test for volatility spillover with applications to exchange rates*, Journal of Econometrics, 103(1-2), pp. 183-224.

Hong Y., Liu Y., Wang S., 2009, *Granger causality in risk and detection of extreme risk spillover between financial markets*, Journal of Econometrics, 150(2), pp. 271-287.

Hui H., 2009, *Effect of Financial News on Investors – Trading Behavior*, City University of Hong Kong WP.

Ibrahim B.M., Brzeszczyński J., 2009, *Inter-regional and region-specific transmission of international stock market returns: the role of foreign information*, Journal of International Money and Finance, 28, pp. 322-343.

Jabłecki J., Kokoszczyński R., Sakowski P., Ślepaczuk R., Wójcik P., 2012, *Pomiar i modelowanie zmienności – przegląd literatury*, Ekonomia, Uniwersytet Warszawski, 31, pp. 22-55.

Jajuga K., 2005, *Copula approach in two-stock portfolio analysis*, Prace Naukowe Akademii Ekonomicznej we Wrocławiu, 1088, pp. 203-209.

Jajuga K., 2006, *Application of extreme value analysis in portfolio analysis*, Prace Naukowe Akademii Ekonomicznej we Wrocławiu, 1133, pp. 130-138.

Jajuga K., 2007, *25 lat ekonometrii finansowej*, Zeszyty Naukowe Uniwersytetu Szczecińskiego, *Finanse*. *Rynki finansowe. Ubezpieczenia*, 6, pp. 91-100.

Jajuga K., 2014, *Systemic Risk and Financial Stability in Insurance: Macroprudential Policy Concerns*, [in:] *Macroprudential Supervision in Insurance: Theoretical and Practical Aspects*, J. Monkiewicz and M. Małecki (eds), Palgrave Macmillan UK, London, pp. 136-152.

Jajuga K., Papla D., 2005, *Extreme Value Analysis and Copulas*, [in:] *Statistical Tools in Finance and Insurance*, P. Cizek, W. Hardle, R. Weron (eds.), Springer.

Jajuga K., Papla D., 2006, *Copula Functions in Model Based Clustering*, [in:] *From Data and Information Analysis to Knowledge Engineering*, Springer, Berlin, pp. 606-613.

Kahneman D., Tversky A., 1979, *Prospect theory: an analysis of decision under risk*, Econometrica, 47(2), pp. 263-292.

Kliber A., 2009, *Stopy procentowe i kursy walutowe. Zależność i powiązania w gospodarkach środkowoeuropejskich*, Wolters Kluwer.

Kliber A., 2016, *The leverage effect puzzle: the case of European sovereign credit default swap market*, Review of Derivatives Research, 19(3), pp. 217-235.

Kliber A., Kliber P., 2010, *Zależności między kursami walut środkowoeuropejskich w okresie kryzysu 2008*, Przegląd Statystyczny, 57(1), pp. 3-16.

Kliber A., Łęt B., Rutkowska A., 2016, *Socio-demographic characteristics of investors in the Warsaw Stock Exchange – how they influence the investment decision*, Bank i Kredyt, 47(2), pp. 91-118.

Kliber P., 2013, *Zastosowanie procesów dyfuzji ze skokami do modelowania polskiego rynku finansowego*, Wydawnictwo Uniwersytetu Ekonomicznego w Poznaniu, Poznań.

Kline R.B., 2005, *Principles and Practice of Structural Equation Modeling*, The Guilford Press.

Kokoszczyński R., Sakowski, P., Ślepaczuk, R., 2010, *Midquotes or Transactional Data? The Comparison of Black Model on HF Data*, Faculty of Economic Sciences Working Papers, University of Warsaw.

Konarski R., 2010, *Modele równań strukturalnych. Teoria i praktyka*, PWN, Warszawa.

Kostrzewski M., 2012, *On the existence of jumps in financial time series*, Acta Physica Polonica B, 10(43), pp. 2001-2021.

Kostrzewski M., 2013, *Bayesian inference for the jump-diffusion model with M jumps*, Communications in Statistics – Theory and Methods, 43(18), pp. 3955-3985.

Kostrzewski M., 2015, *Bayesian DEJD model and detection of asymmetry in jump sizes*, Central European Journal of Economic Modelling and Econometrics (CEJEME), 7(1), pp. 43-70.

Kraft D.F., Engle R.F., 1982, *Autoregressive Conditional Heteroskedasticity in Multiple Time Series Models*, Department of Economics, UC San Diego, mimeo.

Kuziak K., 2013, *Vulnerability of Copula-VaR to Misspecification of Margins and Dependence Structure*, [in:] *Algorithms from and for Nature and Life*, Lausen B., Van den Poel D., Ultsh A. (eds.), Studies in Classification, Data Analysis, and Knowledge Organization, Springer, pp. 387-395.

Kwiatkowski J., 2000, *Bayesian analysis of long memory and persistence using ARFIMA models with an application to Polish stock market*, Dynamic Econometric Models, 4, pp. 199-210.

Kwiatkowski J., Osiewalski J., 2002, *Modele ARFIMA: podstawowe własności i analiza bayesowska*, Przegląd Statystyczny, 49(2), 105-122.

Kyle A., 1985, *Continuous auctions and insider trading*, Econometrica, 22, pp. 477-498.

Kyle A.S., Obizhaeva A.A., 2016, *Market microstructure invariance: empirical hypotheses*, Econometrica, 84(4), pp. 1345-1404.

Lampenius N., Zickar M.J., 2005, *Development and validation of a model and measure of financial risk-taking*, The Journal of Behavioral Finance, 6.

Lua B., Song X., Li X., 2010, *Bayesian analysis of multi-group nonlinear structural equation models with application to behavioral finance*, Quantitative Finance, 10.

Lunde A., Hansen P.R., 2005, *A forecast comparison of volatility models: does anything beat a GARCH(1,1)?*, Journal of Applied Econometrics, 20(7), pp. 873-889.

MacKinlay A.C., 1997, *Event studies in economics and finance*, Journal of Economic Literature, 35, pp. 13-39.

Majewska J., Trzpiot G., 2013, *The Power of Tail Independence Tests in Extreme Value Models. An Application for Stock Exchange Markets*, Proceedings of the 59th World Statistics Congress of the International Statistical Institute, ISI2013 Hong Kong, The Hague, The Netherlands.

Mandelbrot B., 1963, *The variation of certain speculative prices*, The Journal of Business, 36(4), pp. 394-419.

Manganelli S., 2005, *Duration, volume and volatility impact of trades*, Journal of Financial Markets, 8, pp. 377- 399.

McDonald J.B., Xu Y.J., 1995, *A generalization of beta distribution with applications*, Journal of Econometrics, 66, pp. 133-152.

McNeil J.A., Frey F., 2000, *Estimation of tail-related risk measures for heteroscedastic financial time series: an extreme value approach*, Journal of Empirical Finance, 7, pp. 271-300.

Nelson D., 1991, *Conditional heteroskedasticity in asset returns: a new approach*, Econometrica, 59, pp. 347-370.

Nicholls D.F., Quinn B.G., 2012, *Random coefficient autoregressive models: an introduction: an introduction*, vol. 11, Springer Science & Business Media.

Manganelli S., 2005, *Duration, volume and volatility impact of trades*, Journal of Financial Markets, 8, pp. 377-399.

O'Hara M., 1995, *Market Microstructure*, Blackwell Publishers, Cambridge, UK.

Orzeszko W., 2005, *Identyfikacja i prognozowanie chaosu deterministycznego w ekonomicznych szeregach czasowych*, Fundacja Promocji i Akredytacji Kierunków Ekonomicznych, Warszawa.

Orzeszko W., 2016, *Nieparametryczna identyfikacja nieliniowości w finansowych i ekonomicznych szeregach czasowych*, Wydawnictwo Naukowe UMK, Toruń.

Osiewalski J., 2009, *New hybrid models of multivariate volatility a Bayesian perspective*, Przegląd Statystyczny, 56, pp. 15-22.

Osiewalski J., Osiewalski K., 2012, *Missing observations in daily returns – Bayesian inference within the MSF-SBEKK model*, Central European Journal of Economic Modelling and Econometrics, 4, pp. 169-197.

Osiewalski J., Osiewalski K., 2013, *A long-run relationship between daily prices on two markets: the Bayesian VAR2-MSF-SBEKK Model*, Central European Journal of Economic Modelling and Econometrics, 5, pp. 65-83.

Osiewalski J., Pajor A., 2009, *Bayesian analysis for hybrid MSF-SBEKK models of multivariate* volatility, Central European Journal of Economic Modelling and Econometrics, vol. 1, issue 2, pp. 179-202.

Osiewalski J., Pajor A., 2010, *Bayesian Value-at-Risk for a portfolio: multi- and univariate approaches using MSF-SBEKK models*, Central European Journal of Economic Modelling and Econometrics, 2(4), pp. 253-277.

Osiewalski J., Pajor A., 2012, *Bayesian Value-at-Risk and expected shortfall for a large portfolio multi- and univariate approaches*, Acta Physica Polonica A(121), B101-B109.

Osiewalski J., Pipień M, 2003a, *Bayesian analysis and option pricing in univariate GARCH models with asymmetries and GARCH-in-mean effects*, Przegląd Statystyczny, 50, pp. 5-29.

Osiewalski J., Pipień M., 1999, *Bayesowskie testowanie modeli GARCH i IGARCH*, Przegląd Statystyczny, 461, pp. 5-23.

Osiewalski J., Pipień M., 2002, *Multivariate t-GARCH Models: Bayesian analysis for Exchange Rates*, Modelling Economies in Transition. Proceedings of the Sixth AMFET Conference, ed. W. Welfe, Łódź, pp. 151-167.

Osiewalski J., Pipień M., 2003b, *Bayesian estimation of a bivariate BEKK-GARCH process – the conditional ECM framework*, Prace Naukowe Akademii Ekonomicznej we Wrocławiu, 1006, pp. 161-172.

Osiewalski J., Pipień M., 2004a, *Bayesian pricing of an European call option using a GARCH model with asymmetries*, Acta Universitatis Lodziensis – Folia Oeconomica, 177, pp. 219-238.

Osiewalski J., Pipień M., 2004b, *Bayesian comparison of bivariate ARCH-type models for the main exchange rates in Poland*, Journal of Econometrics, 123, pp. 371-391.

Osińska M., 2006, *Ekonometria finansowa*, PWE, Warszawa.

Osińska M. (ed.), 2007, *Procesy STUR – modelowanie i zastosowanie do finansowych szeregów czasowych*, Wyd. Dom Organizatora, TNOiK, Toruń.

Osińska M., 2008, *Ekonometryczna analiza zależności przyczynowych*, Wydawnictwo Naukowe UMK, Toruń.

Osińska M., 2010, *Quality of the forecasts of currencies exchange rates volatilities*, International Research Journal of Finance and Economics, 60.

Osińska M., 2011, *On the interpretation of causality in Granger's sense*, Dynamic Econometric Models, 11, pp. 129-139.

Osińska M., Fałdziński M., 2007, *GARCH and SV models with application of the extreme value theory*, Dynamic Econometric Models, vol. X, Toruń, pp. 45-52.

Osińska M., Hyżyk S., 2000, *Wykorzystanie zmienności wariancji warunkowej do opisu i prognozowania kursów walutowych*, Acta Universitatis Nicolai Copernici, Ekonomia XXX.

Osińska M., Kwiatkowski J., 2003, *Procesy zawierające stochastyczne pierwiastki jednostkowe – identyfikacja i zastosowanie*. *Dynamiczne modele ekonometryczne*, Wyd. UMK, Toruń.

Osińska M., Orzeszko W., 2006, *Detecting Nonlinear Causality at Financial Markets*, [in:] *Financial Markets. Principles of Modeling, Forecasting and Decision-Making*, W. Milo, P. Wdowiński (eds), Lodz, pp. 259-276.

Osińska M., Pietrzak M.B., Żurek M., 2011, *Ocena wpływu czynników behawioralnych i rynkowych na postawy inwestorów indywidualnych na polskim rynku kapitałowym za pomocą modelu SEM*, Przegląd Statystyczny, 3-4, pp. 175-194.

Osińska M., Romański J., 1994, *Econometric Analysis of the Warsaw Stock Exchange*, Research memorandum of the ACE Project, University of Leicester.

Pajor A., 2003, *Procesy zmienności stochastycznej SV w bayesowskiej analizie finansowych szeregów czasowych*, Monografie: Prace Doktorskie, nr 2, Wyd. AE w Krakowie.

Pajor A., 2010, *Wielowymiarowe procesy wariancji stochastycznej w ekonometrii finansowej ujęcie bayesowskie*, Wyd. UEK Kraków.

Papla D., Piontek K., 2009, *Zastosowanie rozkładów a-stabilnych i funkcji powiązań (copula) w obliczaniu wartości zagrożonej (VaR)*, [in:] *Wyzwania współczesnych finansów*, K. Jajuga (ed.), Uniwersytet Ekonomiczny we Wrocławiu, Wrocław.

Parkinson M., 1980, *The extreme value method for estimating the variance of the rate of return*, Journal of Business, 53, pp. 61-65.

Pickands J., 1975, *Statistical inference using extreme order statistics*, Annals of Statistics, 3(1), pp. 119-131.

Piontek K., 2004, *Zastosowanie modeli klasy ARCH do opisu własności szeregu stóp zwrotu indeksu WIG*, Prace Naukowe AE we Wrocławiu nr 1021, Ekonometria, 14, pp. 152-169.

Piontek K., 2007a, *Pomiar i testowanie skośności rozkładów stóp zwrotu instrumentów finansowych*, PN AE we Wrocławiu, 1169, Taksonomia 14, *Klasyfikacja i analiza danych – teoria i zastosowania,* pp. 122-130.

Piontek K., 2007b, *Przegląd i porównanie metod oceny modeli VaR Matematyczne i ekonometryczne metody oceny ryzyka finansowego*, PN AE w Katowicach, P. Chrzan (ed.), pp. 113-124.

Pipień M., 2004a, GARCH *Processes with Skewed-t and Stable Conditional Distribution. Dynamic Bayesian Comparison for WIBOR Interest Rates*, Proceedings of the 34-th International Conference Macromodels, Welfe A., W. Welfe (eds.), Łódź.

Pipień M., 2004b, *Procesy GARCH o warunkowym rozkładzie skośnym-t lub a-stabilnym. Bayesowskie porównanie mocy wyjaśniającej*, [in:] *Metody ilościowe w naukach ekonomicznych*, Welfe A. (ed.), Wydawnictwo SGH, Warszawa.

Pipień M., 2005a, *Procesy GARCH o warunkowym skośnym-t lub a-stabilnym rozkładzie prawdopodobieństwa. Bayesowskie porównanie mocy wyjaśniającej*, [in:] *Metody ilościowe w naukach ekonomicznych*, Piąte warsztaty doktorskie z zakresu Ekonometrii i Statystyki, A. Welfe (ed.), Szkoła Główna Handlowa, Warszawa, pp. 187-211.

Pipień M., 2005b, *Wykorzystanie rozkładów predyktywnych w prognozie VaR i rezerw kapitałowych związanych z ryzykiem rynkowym*, Materiały IX Konferencji „Dynamiczne modele ekonometryczne", 6-8 września 2005, UMK, Toruń, pp. 83-91.

Pipień M., 2006a, *Wnioskowanie bayesowskie w ekonometrii finansowej*, Seria Specjalna: Monografie nr 176, Wydawnictwo Akademii Ekonomicznej w Krakowie, Kraków.

Pipień M., 2006b, *Bayesian comparison of GARCH processes with skewness mechanism in conditional distributions*, Acta Physica Polonica B. 37(11), pp. 3105-3121.

Pipień M., 2007, *Bayesowskie porównanie procesów GARCH o rozkładach warunkowych dopuszczających grube ogony i asymetrię*, [in:] *Metody ilościowe w naukach ekonomicznych*, Welfe A. (ed.), Wyd. SGH, Warszawa.

Pipień M., 2008a, *Introducing skewness into conditionally fat tailed GARCH processes: a Bayesian comparison*, Przegląd Statystyczny, 552, pp. 89-116.

Pipień M., 2008b, *On the empirical importance of the conditional skewness in modelling the relationship between risk and return*, Acta Physica Polonica A, 114(3), pp. 517-524.

Pluciennik P., 2010, *Forecasting financial processes by using diffusion models*, Dynamic Econometric Models, 10, pp. 51-60.

Pluciennik P., Kliber A., Kliber P., Piwnicka M., Paluszak G., 2013, *Wpływ światowego kryzysu gospodarczego 2007-2009 na rynek międzybankowy w Polsce*, National Bank of Poland Working Papers, 288, pp. 5-128.
Rogers L.C.G., Satchell S.E., 1991, *Estimating variance from high, low and closing prices*, Annals of Applied Probability, 1, pp. 504-512.
Rubaszek M., Serwa D., 2009, *Analiza kursu walutowego*, [in:] *Analiza kursu walutowego*, Marcinkowska-Lewandowska (ed.), Wyd. Beck, Warszawa.
Ruiz E., 1994, *Quasi-maximum likelihood estimation of stochastic volatility models*, Journal of Econometrics, 63(1), pp. 289-306.
Russell J.R., 1999, *Econometric modeling of multivariate irregularly-spaced high-frequency data*, Manuscript, GSB, University of Chicago.
Stawicki J., 2004, *Wykorzystanie łańcuchów Markowa w analizie rynku kapitałowego*, Uniwersytet Mikołaja Kopernika, Toruń.
Stawicki J., Janiak E., Müller-Frączek I., 1998, *Fractional differencing of time series: Hurst exponent, fractal dimension*, Dynamic Econometric Models, 3, pp. 17-25.
Strawiński P., Ślepaczuk R., 2008, *Analysis of high frequency data on the warsaw stock exchange in the context of efficient market hypothesis*, Journal of Applied Economic Sciences, 3(5), pp. 306-319.
Syczewska E.M., 2007, *Ekonometryczne modele kursów walutowych*, Monografie i Opracowania, Szkoła Główna Handlowa, Warszawa.
Szyszka A., 2009, *Finanse behawioralne. Nowe podejście do inwestowania na rynku kapitałowym*, Wyd. UEP, Poznań.
Ślepaczuk R., Zakrzewski G., 2009, *High-Frequency and Model-Free Volatility Estimators*, Faculty of Economic Sciences Working Papers, University of Warsaw, 13(23).
Talaga L., Zieliński Z., 1986, *Analiza spektralna w modelowaniu ekonometrycznym*, PWN, Warszawa.
Theodossiou P., 1998, *Financial data and the skewed generalized T distribution*, Management Science, 44, pp. 1650-1661.
Trzpiot G., 2012, *Ekstremalna regresja kwantylowa*, Studia Ekonomiczne Uniwersytetu Ekonomicznego w Katowicach – Zeszyty Naukowe Wydziałowe nr 91, Katowice, pp. 11-20.
Tsay R., 2005, *Analysis of Financial Time Series*, Wiley, New York.
Tyszka T., Zielonka P., 2002, *Expert judgments: Financial analysts versus weather forecasters*, The Journal of Psychology and Financial Markets, 3(3), pp. 152-160
Xekalaki E., Degiannakis S., 2009, *ARCH models for Financial Applications*, Wiley.
Wang X.L., Shi K., Fan H.X., 2006, *Chinese stock markets, psychological mechanisms, investment behaviors, risk perception, individual investors*, Journal of Economic Psychology, 27.
Vašíček O., 1977, *An equilibrium characterisation of the term structure*, Journal of Financial Economics, 5(2), pp. 177-188.
Zieliński Z., 1979, *Analiza dynamiki i rytmiczności zjawisk gospodarczych*, PWN, Warszawa.
Zielonka P., 2011, *Giełda i psychologia: behawioralne aspekty inwestowania na rynku papierów wartościowych*, CeDeWu, Warszawa.
Żurek M., 2016, *Inklinacje behawioralne na rynkach kapitałowych w świetle modeli SEM*, Wydawnictwo Naukowe UMK, Toruń.