Lecturer Dejan ŽIVKOV, PhD
Novi Sad school of business, University of Novi Sad, Serbia
Email: dejanzivkov@gmail.com
Independent researcher Gordana OBRADOVIĆ
Sremska Kamenica, Serbia
Email: obradovic.gordana@gmail.com
Master student Milica GRUJIĆ
Novi Sad school of business, University of Novi Sad, Serbia
Email: grujicmilica82@gmail.com

THE 'METEOR SHOWER' EFFECT BETWEEN PRECIOUS METALS IN SPOT AND FUTURES MARKETS – THE MARKOV SWITCHING PROCESSES IN THE VARIANCE AND MEAN

Abstract: *This paper researches volatility transmission phenomenon between four precious metals – gold, silver, platinum and palladium in spot and futures markets. The unbiased conditional volatilities of the selected assets are computed via the Bayesian Markov switching GARCH model that are subsequently embedded in Markov switching model, which governs the mean process. We disclose that gold has the highest volatility spillover effect to all other precious metals, while all other metals have relatively limited effect towards gold as well as between themselves. This probably happens because gold is the most tradable asset of all metals, which makes that all other metal markets closely follow developments in the gold market. From the portfolio point of view, it means that gold is not particularly appropriate auxiliary asset to be combined with other precious metals. On the other hand, other precious metals could take a role of a secondary instrument in a portfolio with whichever precious metal, due to their relatively limited power of volatility transmission.*

Key words: *precious metals, volatility spillover, Markov switching models*.

JEL Classification:C11, C24, L61

1. Introduction

Precious metals are interesting assets for a number of reasons for risk hedgers, traders, portfolio managers, but also for academics and exporting and importing countries of these commodities. As Eryiğit (2017) contended, precious metals can be

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used for various purposes – from the state point of view, they could serve as monetary media and media of international exchange. On the other hand, from the aspect of common people, they could be used for savings, personal investment, fashion and for medical reasons (see Kirkulak-Uludag and Lkhamazhapov, 2017). In addition, the usage of precious metals in industry is well established and well known for decades. Owing to their desirable characteristics, such as durability and storability, precious metals are well favoured among numerous market agents. However, due to ever increasing usage of precious metals, high price oscillations of these commodities become their common trait, as Figure 1 depicts. Besides, Todorova et al. (2014) asserted that the expectation of market analysts and general public is that high price volatility of precious metals will remain as a feature for years to come. This characteristic of these commodities has profound and far-reaching implications for market stability and market efficiency in both the spot and futures markets.

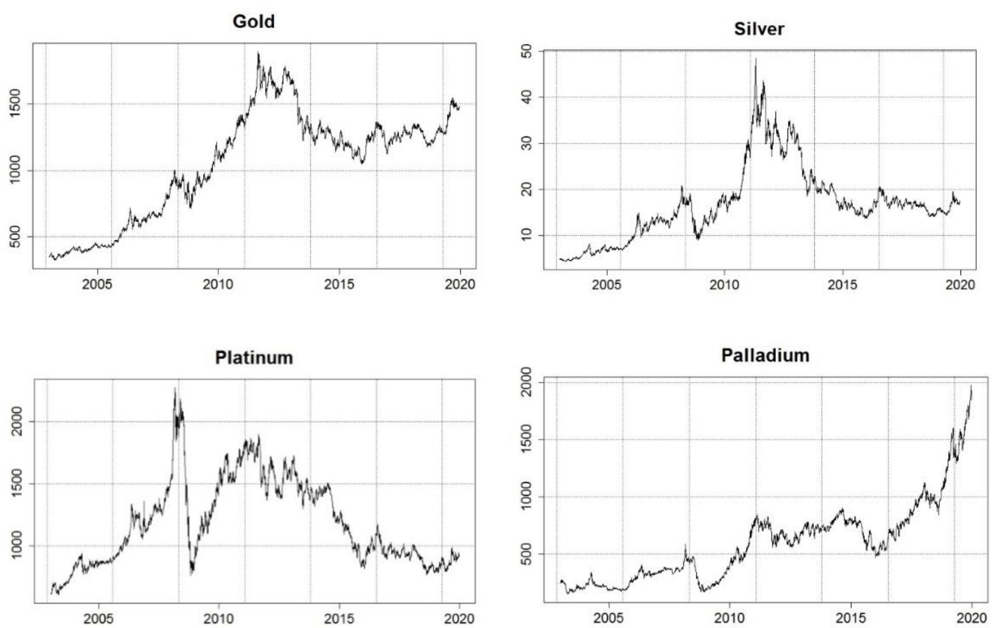

Figure 1. Empirical dynamics of precious metals in spot markets

First of all, it should be said that price discovery is one of the key functions of futures markets, which increases the liquidity of markets, pricing efficiency and risk management. Secondly, futures prices can efficiently transmit information to various

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economic agents, *inter alia* producers and consumers, which subsequently make their supply and demand decisions on the futures contract prices. Mirović et al. (2017) added that gold, as most tradable precious metal, possess very appealing characteristics in a sense that gold has low correlation with other asset classes, including oil, stocks, and bonds, which makes gold as an excellent diversification tool. However, in unstable environment, which is fuelled by the volatility spillover effects from other markets, prices of precious metals can be severely influenced and distorted, which makes these commodities less usable in aforementioned financial processes.

Therefore, this paper tries to investigate the magnitude of volatility transmission phenomenon, also known as the 'meteor shower' effect, which happens between four precious metals – gold, silver, platinum and palladium in both spot and futures markets. We take into account both spot and futures market, because these markets differentiate between each other. As Kaufmann and Ullman (2009) explained, price innovations that appear in spot market are dominantly determined by fundamentals, while price shocks in futures markets are in large extent the consequence of the speculative activities. Unlike most papers that examined return spillover effect in financial and commodity markets, we address the issue of second moment spillover effect. In addition, we explore the field of precious metals, which is vastly unresearched in the literature, and it leaves enough room for our contribution. Also, this study distinguishes itself from the extant papers in a way that it puts an emphasis on the reliability and accurateness of the results. In other words, in order to recognize conditional volatilities of the selected precious metals in both spot and futures markets, we construct conditional volatilities of the selected commodities by using Markov switching GARCH (MS-GARCH) model. We consider this methodology, because we have a reasonable doubt to think that our time-series are polluted with multiple structural breaks. This is a viable assumption due to the fact that we cover relatively long time-span of 17 years, which is permeated with numerous phases of ups and downs in the selected markets (see Figure 1). These undesirable features of time-series could produce biased estimates of conditional volatilities, as Bauwens et al. (2010) explained. If this is the case, the sum of estimated GARCH coefficients is close to or even exceeds one, and Frommel (2010) argued that this drawback could leads to a non-stationary volatility in a single-regime GARCH models, biased conclusions and poor risk predictions. An efficient way to deal with this issue is to estimate Markov switching GARCH model, whose parameters can change over time according to a discrete latent (unobservable) variable. In addition, we introduce one more novelty in the estimation process that very limited number of papers applied, and that is the usage of Bayesian procedure instead of maximum likelihood method. The reason behind this decision lies in a fact that maximum likelihood approach presents some limitations when the errors are heavy tailed, when the convergence rate is slow

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or when the estimators is not asymptotically Gaussian, as Virbickaite et al. (2015) asserted.

After the construction of regime switching conditional volatilities, in the second stage of our research, we try to determine nonlinear relationship between these volatilities, allowing these variables to depend on the two independent state regimes in the mean process. In other words, we estimate eight parametric Markov switching models (four for spot and four for futures markets), in which every precious metal takes a position of dependent variable, while other commodities from the other markets correspondingly have an explanatory role. This particular model can distinguish between different regimes endogenously. Numerous authors used the Markov switching model to investigate various economic phenomena (see Jouini, 2018; Yağcibaşi and Yildirim, 2019). As for the robustness check, we calculate Granger causality test.

Besides introduction, the rest of the paper is structured as follows. Second section briefly presents the extant literature. Third section explains used methodologies – Bayesian Markov switching approach and Markov switching mean model. Fourth section shows which dataset is used and how regime switching conditional volatilities are created. Fifth section presents research results and offers a rationale for the findings. The last section concludes.

2. Brief literature review

Regarding the 'meteor shower' phenomenon and precious metals, most of the papers researched the interlink between these commodities and other kind of assets, such as stocks, currencies, oil, agricultural commodities, ETFs, etc. On the other hand, very limited number of papers focused solely on the volatility transmission between precious metals, and the findings of some of them are listed in the following. For instance, Karanasos et al. (2018) researched the link between gold and copper and found the existence of time-varying volatility spillovers between these metals during the different stages of recent global financial crisis. They reported that copper returns volatility affects that of gold returns negatively while the reverse effect is positive. They concluded that the volatilities of copper and gold are inherently linked, although these metals have very different applications. Uddin et al. (2019) investigated the spillover characteristics of returns and volatilities of gold, silver, platinum and palladium. They found evidence of homogenous spillovers between the returns and volatilities of these metals, which they explained by similarities in their cyclical relationship with global and local fundamentals. They disclosed that the largest transmission of net spillovers is exerted by gold and silver. In addition, they asserted that palladium and platinum act mainly as spillover receivers, gold and silver act mainly as transmitters of spillovers. The study of Batten et al. (2015) examined return and volatility spillover effect between four precious metals – gold, silver, platinum and

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palladium, using generalized VAR methodology on weekly data. Their results indicated that gold and silver share the closest relationship. Gold contributes to 27.7% of silvers return and only a small percentage of that of platinum and palladium. Conversely, silver accounts 27.5% of the gold return and similar percentages to that of gold in terms of return to platinum and palladium. As for their volatility spillover findings, they reported significant spillovers from gold and silver to each other, while, according to their results, platinum and palladium are almost insulated from each other. Hammoudeh et al. (2010) researched the conditional volatility and correlation dependency and interdependency for the four precious metals (gold, silver, platinum and palladium), also including geopolitics within a multivariate system. They revealed that significant short-run and long-run dependencies and interdependencies to news and past volatility exist among the selected precious metals. Dutta et al. (2018) tried to find out whether gold and silver markets send shocks and volatility to each other by using the bivariate VAR-GARCH model. He revealed that volatility shocks significantly run from gold VIX (GVZ) to silver VIX (VXSLV), but not the other way around.

3. Used methodologies

3.1. Bayesian Markov switching approach in the variance

According to Ari and Papadopoulos (2016), maximum likelihood estimation (MLE), although appealing because it is easy to use, in GARCH models can generate an implementation problem. Therefore, this paper estimates MS-GARCH model, using a Bayesian inference procedure. Ari et al. (2019) asserted that the Bayesian statistical method efficiently obtain the posterior distribution of any non-linear function of the model parameter, and they showed that as sample size increases the Bayesian estimates perform better than MLE's. Virbickaite et al. (2015) claimed that the state variables are treated as random variables in the Bayesian context, which enables researchers to construct the likelihood function easily. In other words, a posterior distribution is built using priors, which integrate the posterior density function with respect to parameters and state variables.

As for our computations, we assume an AR(1) process for the conditional mean of all precious metal commodities, whereby residuals of the model follow the normal distribution $\varepsilon_t|I_{t-1}\sim N(0,h_{it}).I_{t-1}$denotedthe information set up to time t-1. Markov switching GARCH specification can be written as in equation (1):

$$h_t = \omega_{st} + \alpha_{st}\varepsilon_{t-1}^2 + \beta_{st}h_{t-1} \tag{1}$$

where ω_{st} is state dependent constant, whereas ε_{t-1,S_t}^2 and h_{t-1,S_t} are ARCH and GARCH effect under two volatility regimes – low volatility and high volatility. The

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non-negativity of h_t is ensure if we set following restrictions: $\omega_{S_t} \geq 0$, $\alpha_{S_t} \geq 0$ and $\beta_{S_t} \geq 0$. Volatility persistence in state i is measured by $\alpha_i + \beta_i$.

We estimate the Bayesian MS-GARCH model[1] with Markov Chain Monte Carlo (MCMC) procedure, which requires the evaluation of the likelihood function. Following Ardia (2009), we define $y_t \in \mathbb{R}$ as the (percentage) log return of the selected assets at time t, and regroup the model parameters into the vector $\mathbf{\Psi}$. Accordingly, the conditional density of y_t in state $st = k$, given $\mathbf{\Psi}$and I_{t-1} is presented as $f(y_t|st = k, \mathbf{\Psi}, I_{t-1})$. The discrete integration is subsequently obtained as follows:

$$f(y_t|\,\mathbf{\Psi}, I_{t-1}) = \sum_{i=1}^{K}\sum_{j=1}^{K} p_{i,j}\eta_{i,t-1} f(y_t|st = j, \mathbf{\Psi}, I_{t-1}) \qquad (2)$$

where $\eta_{i,t-1} = \mathrm{P}(s_{t-1} = i|\,\mathbf{\Psi}, I_{t-1})$ denotes the filtered probability of state i at time t-1 and where $p_{i,j}$ stands for the transition probability, moving from state i to state j. The likelihood function can be obtained from equation (2) in the following way:

$$L(\mathbf{\Psi}|\mathrm{y}) = \prod_{t=1}^{T} f(y_t|\,\mathbf{\Psi}, I_{t-1}) \qquad (3)$$

According to Ardia (2009), in the case of MCMC estimation, the likelihood function is combined with a diffuse (truncated) prior $f(\mathbf{\Psi})$to build the kernel of the posterior distribution $f(\mathbf{\Psi}|\mathrm{y})$.

3.2. Regime switching process in the mean

In the second stage of our two-step procedure, we aim to capture the nonlinear volatility spillover linkage between the selected precious metals in spot and futures markets. This is done by applying the Markov regime-switching model, which assumes two different regimes. In other words, when (S_t) value is equal to 1 than particular market is in state of increased market turbulence, whereas state 2 describes calm market period. The presentation of regime states in MS model is diametrically different in regard to MS-GARCH model, where state 1 depicts tranquil regime, while state 2 stands for turbulent periods.S_t follows a first order Markov chain with transition matrix $P = (p_{ij})$with elements $p_{ij} = Pr[S_t = i, S_{t-1} = j]$. Switching between regimes does not occur deterministically but with a certain degree of probability (see Šoltés et al., 2017). According to Živkov et al. (2019), when the unobserved and discrete state variable S_t depends serially on $S_t - 1, S_t - 2, \ldots, S_t - n$,

[1]Estimation of the Bayesian MS-GARCH model was done via 'MSGARCH' package in 'R' software.

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this is called the n^{th} order Markov switching process, which is governed by expression (4):

$$\left.\begin{array}{l} P(S_t = 1|S_{t-1} = 1) = p_{11} \\ P(S_t = 1|S_{t-1} = 2) = p_{12} \\ P(S_t = 2|S_{t-1} = 1) = p_{21} \\ P(S_t = 2|S_{t-1} = 2) = p_{22} \end{array}\right\} \text{where} p_{11} + p_{12} = p_{21} + p_{22} = 1 \quad (4)$$

Transition probabilities given in equation (4) determine the probability at each point in time in which a specific state occurs, rather than imposing particular dates a priori. In such way, the empirical data may indicate the nature and incidence of the regime changes.

Regarding four precious metals, regime switching equations that measure volatility transmission effect are presented in the following equations (5)-(8):

$$h_{GLD,t} = \theta_{st} + \omega_{st} h_{SLV,t} + \omega_{st} h_{PLT,t} + \omega_{st} h_{PLD,t} + \varsigma_t, \qquad \epsilon_{GLD,t} \sim N(0, \sigma^2_{st,h}) \quad (5)$$

$$h_{SLV,t} = \theta_{st} + \omega_{st} h_{GLD,t} + \omega_{st} h_{PLT,t} + \omega_{st} h_{PLD,t} + \varsigma_t, \qquad \epsilon_{SLV,t} \sim N(0, \sigma^2_{st,h}) \quad (6)$$

$$h_{PLT,t} = \theta_{st} + \omega_{st} h_{GLD,t} + \omega_{st} h_{SLV,t} + \omega_{st} h_{PLD,t} + \varsigma_t, \qquad \epsilon_{PLT,t} \sim N(0, \sigma^2_{st,h}) \quad (7)$$

$$h_{PLD,t} = \theta_{st} + \omega_{st} h_{GLD,t} + \omega_{st} h_{SLV,t} + \omega_{st} h_{PLT,t} + \varsigma_t, \qquad \epsilon_{PLD,t} \sim N(0, \sigma^2_{st,h}) \quad (8)$$

where h represents regime switching conditional variance, constructed *via* Bayesian MS-GARCH model, while subscripts GLD, SLV, PLT and PLD describe gold, silver, platinum and palladium, respectively. All residuals (ϵ_t) in MS model follow Gaussian distribution, with zero mean and variance, which is state dependent.

4. Dataset and construction of regime switching conditional variances

This paper uses daily closing prices in spot and futures markets of four precious metals – gold, silver, platinum and palladium. The sample covers the period of 17 years, between January 2003 to December 2019, and all time-series are collected from the Thomson Reuters Datastream International website. We transform the empirical closing prices (P) of the selected precious metals into log returns (r) according to the expression $r_{i,t} = 100 \times \log(P_{i,t}/P_{i,t-1})$, where i stands for particular precious metal. Due to unavailability of some empirical data, we synchronize all precious metals log returns according to the existing observations. Table 1 contains stylized facts of the selected empirical time-series. It is obvious that all precious metals have positive daily average return, whereby these returns are more left-asymmetric, fat-tailed and high-peaked than the Gaussian distribution. LB(Q) and LB(Q^2) tests

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indicate the presence of autocorrelation and heteroscedasticity, which means that some form of ARMA-GARCH model might be appropriate.

Table 1. Descriptive statistics of log-returns of the metals in spot and futures markets

		Mean	St. dev.	Skewness	Kurtosis	JB	LB(Q)	LB(Q^2)
Spot	Gold	0.032	1.120	-0.341	8.832	6120.7	0.000	0.000
	Silver	0.026	1.961	-1.140	12.248	16107.6	0.000	0.000
	Platinum	0.008	1.406	-0.504	7.519	3805.6	0.000	0.000
	Palladium	0.048	2.011	-0.514	8.014	4651.7	0.000	0.000
Futures	Gold	0.034	1.120	-0.363	9.684	7941.8	0.000	0.000
	Silver	0.032	1.968	-0.904	9.450	7884.1	0.000	0.000
	Platinum	0.009	1.379	-0.460	6.943	2880.9	0.000	0.000
	Palladium	0.054	1.951	-0.559	6.349	2189.7	0.000	0.000

Notes: JB stands for p-value of Jarque-Bera coefficients of normality.

Since our sample covers relatively long time-span, it could be expected that all daily time-series are subject to multiple structural breaks, which in turn reflects on the accuracy of the estimated conditional volatilities in the GARCH process. In order to solve this problem, we utilize MS-GARCH model, which can recognize structural breaks endogenously.

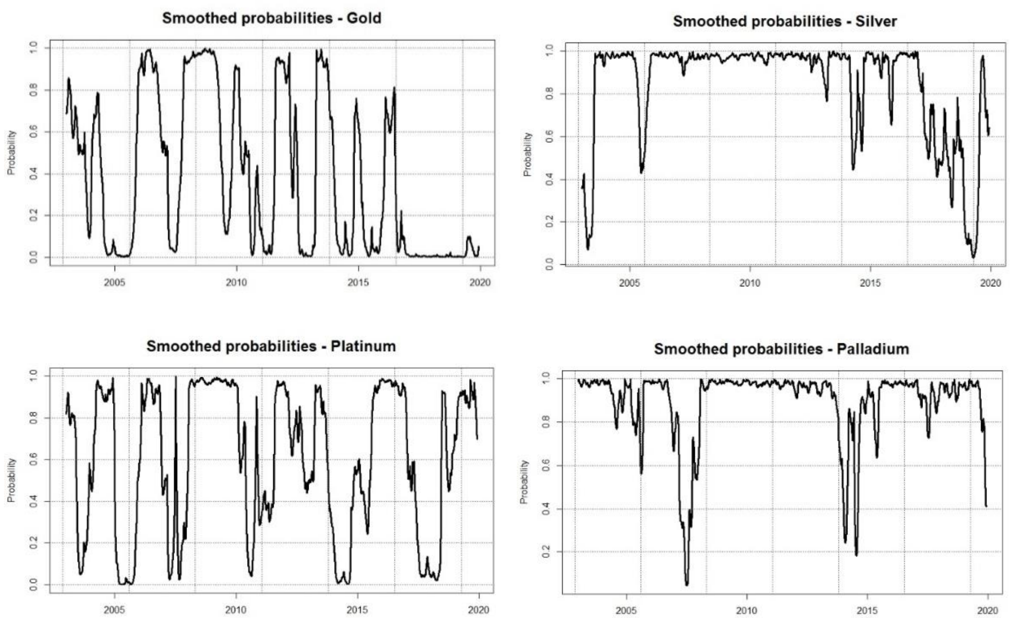

Figure 2. Plotted smooth probabilities of staying in low volatility regime for the assets in spot markets

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Figure 2 confirms that structural shifts are present in the variance, which means that the choice of MS-GARCH model is justifiable. Table 2 contains values of probabilities that suggest what is the likelihood of staying in regime of low volatility (P11) and regime of high volatility (P22). As Table 2 shows, all precious metals in both spot and futures markets are dominantly characterized by low volatility regime. Also, it can be seen that gold and silver spend somewhat more time in high volatility regime in futures markets in comparison to all the commodities in spot market. However, this should not be unexpected, having in mind that gold and silver are the assets that are most widely traded among the precious metals, whereby futures markets are well known for speculative activities. Therefore, a new arrival of information reflects itself most directly in gold and silver futures markets, which produces longer periods of higher volatilities in these markets that is detected by the MS-GARCH model.

Table 2. Regime switching probabilities for the metals in spot and futures markets

	Spot markets				Futures markets			
	Gold	Silver	Platinum	Palladium	Gold	Silver	Platinum	Palladium
P11	0.86	0.93	0.90	0.83	0.75	0.76	0.93	0.91
P22	0.14	0.07	0.10	0.17	0.25	0.24	0.07	0.09

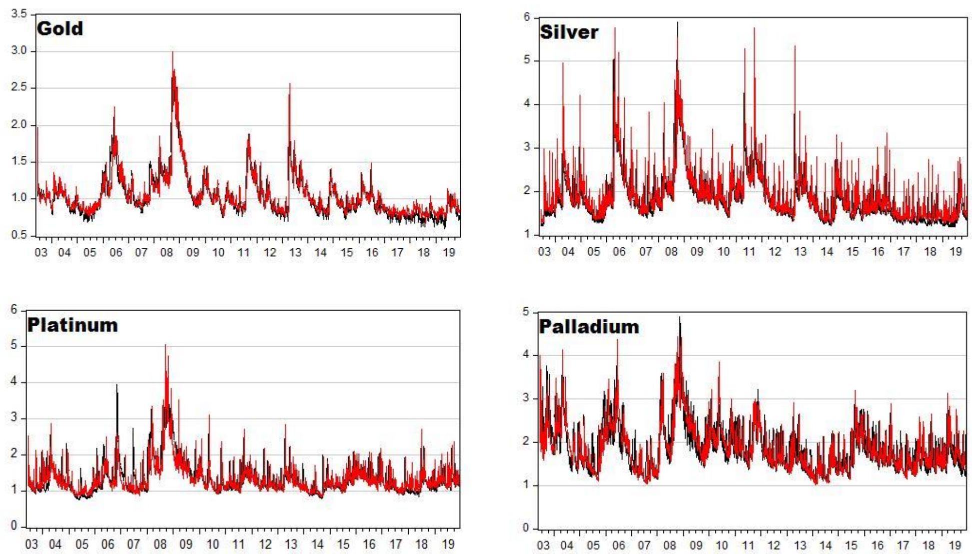

Figure 3. Regime switching conditional volatilities for the assets in spot and futures markets

Note: Red (black) line depicts conditional volatilities for the metals in spot (futures) markets

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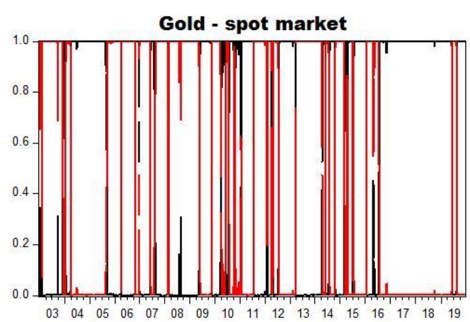
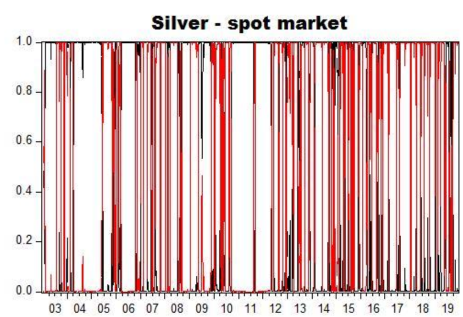
Figure 3 presents constructed regime switching conditional volatilities of the precious metals in both spot and futures markets, and it can be seen that dynamics of these volatilities are very similar between spot and futures markets, but some tiny differences can be spotted. This is expected, because spot and futures markets offer opportunities for risk-free price arbitrage, thus high discrepancy in prices and volatilities in these two markets is not realistic to be present.

5. Research results

This section presents the results of nonlinear volatility transmission effect that is estimated between four precious metals in both spot and futures markets, whereas Tables 3 and 4 present these findings. Having a proper knowledge about volatility spillover effect between the precious metals is very important for investors in these markets, since it could provide an information about how they can construct their trading and hedging strategies, enter or leave particular market or rebalance their portfolios (see e.g. Shimada et al., 2009; Bala and Takimoto, 2017). According to Panel B in Tables 3 and 4, it seems that different regimes shift between each other very fast, i.e. their duration intervals are relatively short. In fact, we find that high volatility regime in spot gold market has the longest duration, amounting 95 days, while all other markets have expected duration well below this time-span. This could be an evidence that precious metal markets are very active, and that they are subjected to various external shocks, whereby the shocks from neighbouring metals markets are one of them. Figure 4 witnesses about rapid changes between regimes in both spot and futures markets.





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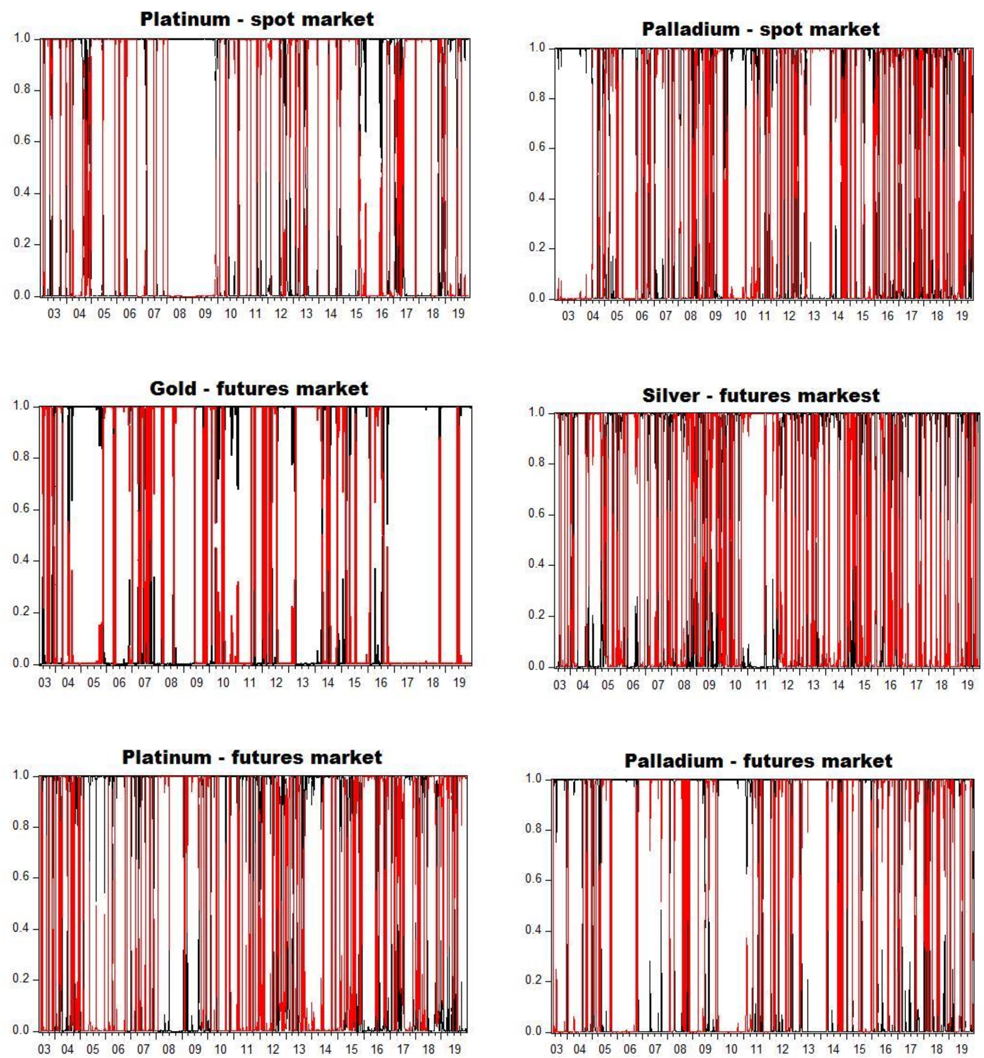

Figure 4. Smooth probabilities for the metals in both spot and futures markets

Note: Black (red) line depicts smooth probabilities for regime 1 (regime 2).

Observing the regime-switching results in both spot and futures market, it can be seen that almost all regime-switching parameters are highly statistically significant, whereby the magnitude of the estimated parameters differentiates between spot and futures markets, which justifies our approach to analyse spot and futures markets

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jointly. This suggests that volatility transmission between these markets can be regarded as a common phenomenon and it happens in regular basis, which implies that these markets are highly integrated. As for the values of the estimated parameters, it is interesting to notice that gold exerts the highest volatility impact on other three precious metals, and this is true for both spot and futures markets. For instance, regarding the spot market, 100% volatility increase in gold market affect silver market by 133% in high volatility regime in silver market. Palladium is affected by 121%, and platinum by 54% in high volatility regime. In low volatility regime, silver endures 94% of volatility spillover, and platinum 34%, whereas in palladium market, 100% volatility increase in gold market actually decreases volatility in palladium market by 6.5%. On the other hand, in futures markets, silver experience the highest volatility transmission effect from gold in high volatility regime, while palladium and platinum follow. In low volatility mode, all precious metals endure positive spillover effect from gold market, whereby silver is a leader, while platinum and palladium are in the second and third place.

Table 3. Volatility spillover effect between the precious metals in spot markets

Gold		Silver		Platinum		Palladium	
Panel A. Estimated regime switching parameters							
$\omega_{\_1\_silver}$	0.148***	$\omega_{\_1\_gold}$	1.333***	$\omega_{\_1\_gold}$	0.544***	$\omega_{\_1\_gold}$	1.206***
$\omega_{\_2\_silver}$	0.325***	$\omega_{\_2\_gold}$	0.941***	$\omega_{\_2\_gold}$	0.343***	$\omega_{\_2\_gold}$	-0.065**
$\omega_{\_1\_platinum}$	0.099***	$\omega_{\_1\_platinum}$	0.086***	$\omega_{\_1\_silver}$	0.251***	$\omega_{\_1\_silver}$	-0.033
$\omega_{\_2\_platinum}$	0.187***	$\omega_{\_2\_platinum}$	0.247***	$\omega_{\_2\_silver}$	0.077***	$\omega_{\_2\_silver}$	0.202***
$\omega_{\_1\_palladium}$	0.049***	$\omega_{\_1\_palladium}$	-0.036*	$\omega_{\_1\_palladium}$	0.187***	$\omega_{\_1\_platinum}$	0.102***
$\omega_{\_2\_palladium}$	0.046***	$\omega_{\_2\_palladium}$	-0.021***	$\omega_{\_2\_palladium}$	0.044***	$\omega_{\_2\_platinum}$	0.650***
σ^2_1	-2.69***	σ^2_1	-0.90***	σ^2_1	-1.26***	σ^2_1	-0.75***
σ^2_2	-2.01***	σ^2_2	-2.38***	σ^2_2	-2.17***	σ^2_2	-1.74***
Panel B. Regime properties							
P11	0.99	P11	0.95	P11	0.97	P11	0.95
P22	0.99	P22	0.96	P22	0.98	P22	0.96
ED 11	95.2	ED 11	20.3	ED 11	28.6	ED 11	20.6
ED 22	89.3	ED 22	27.2	ED 22	45.7	ED 22	23.1

Notes: ED stands for expected duration. P11 and P22 are the probabilities of staying in each regime. σ_1^2 and σ_2^2 are regime-specific error variances. ***p < 0.01; **p < 0.05; *p < 0.1.

Table 4. Volatility spillover effect between the precious metals in futures markets

Gold		Silver		Platinum		Palladium	
Panel A. Estimated regime switching parameters							
$\omega_{\_1\_silver}$	0.104***	$\omega_{\_1\_gold}$	1.173***	$\omega_{\_1\_gold}$	0.356***	$\omega_{\_1\_gold}$	0.486***
$\omega_{\_2\_silver}$	0.321***	$\omega_{\_2\_gold}$	0.740***	$\omega_{\_2\_gold}$	0.528***	$\omega_{\_2\_gold}$	0.153***
$\omega_{\_1\_platinum}$	0.047***	$\omega_{\_1\_platinum}$	0.140***	$\omega_{\_1\_silver}$	0.079***	$\omega_{\_1\_silver}$	0.039*
$\omega_{\_2\_platinum}$	0.194***	$\omega_{\_2\_platinum}$	0.255***	$\omega_{\_2\_silver}$	0.143***	$\omega_{\_2\_silver}$	0.093***

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$\omega_{\_1\_palladium}$	0.065^{***}	$\omega_{\_1\_palladium}$	0.026^{***}	$\omega_{\_1\_palladium}$	0.103^{***}	$\omega_{\_1\_platinum}$	0.622^{***}
$\omega_{\_2\_palladium}$	0.062^{***}	$\omega_{\_2\_palladium}$	0.175^{***}	$\omega_{\_2\_palladium}$	0.286^{***}	$\omega_{\_2\_platinum}$	0.583^{***}
σ^2_1	-2.73^{***}	σ^2_1	-2.18^{***}	σ^2_1	-2.29^{***}	σ^2_1	-1.24^{***}
σ^2_2	-1.95^{***}	σ^2_2	-0.77^{***}	σ^2_2	-1.35^{***}	σ^2_2	-1.67^{***}
Panel B. Regime properties							
P11	0.98	P11	0.94	P11	0.96	P11	0.96
P22	0.98	P22	0.90	P22	0.94	P22	0.97
ED 11	63.8	ED 11	17.9	ED 11	23.9	ED 11	26.1
ED 22	48.8	ED 22	9.8	ED 22	16.1	ED 22	35.6

Notes: ED stands for expected duration. P11 and P22 are the probabilities of staying in each regime. $\sigma_1^2$and$\sigma_2^2$are regime-specific error variances. ***p < 0.01; **p < 0.05; *p < 0.1.

Finding that gold has the highest effect on all other precious metals, particularly on silver, should not be surprising, because gold is the most widely traded commodity asset among the metal commodities with broad spectrum of usage in jewellery industry and as a safe haven investment. Table 5 confirms that gold is significantly more tradable commodity than any other precious metal.

Table 5. Average trading volumes in futures markets in 2019

Gold	Silver	Platinum	Palladium
343688.4	95940.7	23282.3	5044.6

Source: darastream.com

In that regard, Hammoudeh et al. (2010) asserted that the common practice in metal markets is that investors flood into silver when gold seems strong, which increases price and volatility in silver market rapidly, whereas when gold weakens, many quit investing in silver. The same authors also reported that when it comes to the opposite effect, from silver to gold, the spillover effect is very low or statistically insignificant. This coincide with our findings very well, since we find that silver affect gold around 15%, which is relatively low, and that happens when gold market is in a state of high turbulence, while this effect rises to 32% in the periods when gold market is in state of tranquillity. We also like to mention the results of Morales and Andreosso-O'Callaghan (2011) and Sensoy (2013). The former paper investigated volatility spillover effects between the four precious metals and disclosed a bidirectional linkage, which perfectly coincides with our results. Their finding also indicated that strong volatility interlinkages among these markets is not present, which concur with our results, but they contended that general pattern suggest that gold tends to dominate other markets, which is also the case with our findings. They found little evidence that other precious metals influence the gold market, which is in support with our results.

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As for other two precious metals, platinum and palladium, Tables 3 and 4 indicate that these metals have very little volatility spillover effect on gold and silver, since most of the regime-switching parameters in spot market are below 10%, and below 20% in futures markets. The paper of Sensoy (2013) researched the four precious metals and reported that gold has a volatility shift contagion effect on all precious metals, but other metals do not have such an effect on gold. On the other hand, they found that silver has a unidirectional volatility shift contagion effect on platinum and palladium, but platinum and palladium have no volatility shift contagion effect on any others. These results are similar to ours, because we also find very weak volatility transmission effect from platinum and palladium towards gold and silver. Also, Uddin et al. (2019) concluded that palladium and platinum act mainly as spillover receivers, while gold and silver act predominantly as volatility transmitters, which can be applied to our results in great extent.

In addition, although palladium and platinum have very modest effect on gold and silver, we find that the effect between these two metals is relatively high. For instance, in spot market, palladium affects platinum in the amount of 18.7% and 4.4%, while palladium is affected by platinum in the extent of 10.2% and 65%, regarding both low and high volatility regimes. This effect is even stronger in futures market with the level of 10.3% and 28.6% that goes from palladium to platinum, and 62.2% and 58.3% that goes in the reverse direction. The rationale for these convincing findings could be the fact that platinum and palladium are fully effective substitutes for main industrial application, that is, in production of automobile catalytic converters. As a matter of fact, platinum was the original metal used in all catalytic converters for years, but two decades ago, automakers started to use palladium for most car engines, because palladium was many hundreds of dollars per ounce cheaper than platinum. In other words, it means that whichever metal (platinum or palladium) soars in price, the automobile industry chooses the other one, cheaper material, in the production process, whereby the spillover effects automatically came to the fore between the markets. This is the probable reason why we find such close ties, mirrored in relatively high spillover effect, between these metals in both spot and futures markets. More precisely, the amount of the spillover effect is higher in futures markets, probably because in futures markets information travels faster, while futures trading is induced by speculative activities.

At the end, we comment the findings of the regime-specific error variances (σ^2). These indicators have negative sign in Tables 3 and 4, but since the variances are shown in quadratic form, they should be observed in absolute values. These parameters refer to the standard deviation of each regime, showing the level of the volatility in each state. In can be seen that in three out of four cases in spot markets, σ^2 is higher in low volatility regime, which suggests that variabilities are more intense in low-volatility state in spot markets. On the contrary, in futures markets we find, in all the

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cases, that variabilities are more pronounced in high-volatility state, which is somewhat expected, since high presence of speculative activities can be found in these markets.

In order to put more credibility in our results, we calculate Granger causality test, which serve us as robustness check. This test is used to examine directional causality between precious metals markets (see Poměnková and Kapounek, 2009), and Table 6 contains F-statistics and p-value, which test the hypothesis that Granger causality does not exist. The lag length is specified according to the Schwarz–Bayesian information criterion. Table 6 shows that all markets are both receivers and transmitters of volatility shocks at very high probability rate, which coincides very well with our regime-switching spillover parameters, since almost all MS parameters are statistically significant. Granger causality test additionally strengthen our assurance that volatility transmission effect between four precious metals is an intrinsic feature of these markets, regardless of whether we talk about spot or futures markets. Therefore, the overall results speak about close connectedness between precious metals markets, which lead us to the believe that the analysed precious metals can be classified as a single asset class.

Table 6. Granger causality test between precious metals in both spot and futures markets

Spot markets			Futures markets		
Causality direction	F-statistics	p-value	Causality direction	F-statistics	p-value
Gold → Silver	23.0	0.000	Gold → Silver	75.9	0.000
Silver → Gold	455.8	0.000	Silver → Gold	319.9	0.000
Gold → Platinum	18.4	0.000	Gold → Platinum	31.8	0.000
Platinum → Gold	98.6	0.000	Platinum → Gold	158.1	0.000
Gold → Palladium	18.9	0.000	Gold → Palladium	15.1	0.000
Palladium → Gold	54.9	0.000	Palladium → Gold	49.8	0.000
Silver → Platinum	12.7	0.000	Silver → Platinum	13.0	0.000
Platinum → Silver	5.0	0.000	Platinum → Silver	11.9	0.000
Silver → Palladium	24.7	0.000	Silver → Palladium	9.0	0.000
Palladium → Silver	5.0	0.000	Palladium → Silver	20.7	0.000
Platinum → Palladium	15.2	0.000	Platinum → Palladium	8.7	0.000
Palladium → Platinum	14.7	0.000	Palladium → Platinum	14.3	0.000

6. Discussion and conclusion

This paper investigates the volatility spillover effect between four precious metals – gold, silver, platinum and palladium, taking into account both spot and futures markets. In order to be accurate in measurement of conditional volatilities as much as possible, and to avoid biased estimates at the same time, we use novel and elaborate

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econometric tool – the Bayesian Markov switching model. After the construction of regime-switching conditional variances, we embed these time-series into two state Markov switching model that governs the mean process.

Based on our results, we have several noteworthy findings to report. First, we find that almost all regime-switching parameters are highly statistically significant. This means that bidirectional spillover nexus exists between the metals, which indicates that these markets are highly integrated. Secondly, we report that gold exerts the highest volatility impact on other three precious metals, and this is true for both spot and futures markets, but gold receives significantly lower amounts of volatility shocks from other three markets. On the other hand, all other precious metals (silver, platinum and palladium) transmits notably lower spillover effect towards other precious metals from the group. This particular situation probably happens due to the fact gold is incomparably more tradable asset in regard to all other precious metals, and owing to that, all other metal markets closely follow developments on the gold market. Therefore, any unexpected shifts in gold market transfer in high degree to all other metal markets. This assertion is further backed up by the fact that higher spillover parameters are found in high volatility regime. Thirdly, our results indicate that platinum and palladium transmit relatively high volume of volatility shocks between each other, and the reason could be the fact that platinum and palladium are fully effective substitutes for the production of catalytic converters in automobile industry.

These results are interesting for investors who make portfolio with the precious metals, because if volatility from one financial market transmits to another, then assets from such markets cannot be included in the same portfolio with the other one. In other words, due to the fact that volatility from gold market significantly influence volatilities in other three metal markets, it means that gold is not suitable auxiliary asset to be combined with other precious metals. On the other hand, other precious metals could serve well as second instrument in a portfolio where gold is a primary asset, because other precious metals have very small volatility transmission effect on gold. In addition, due to relatively limited volatility spillover effect that exists between silver, platinum and palladium, these metals can be safely combined with each other. It is particularly suitable to combine palladium with silver in spot markets, whichever regime is in question, because volatility increase in palladium market actually decreases volatility in silver market. The same scenario applies when gold is combined with palladium in calm periods and when silver is combined with palladium in spot market in turbulent times.

We believe that the results from this paper can be useful for investors who perform in precious metals markets, in a sense that they can comprehend better the volatility linkages between these markets. Consequently, they can make proper decisions about which precious metals are suitable to combine in a portfolio, taking

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into account both tranquil and crisis period, which will result in enhancement of their diversification and hedging benefits.

REFERENCES

[1]**Ardia, D. (2009),** ***Bayesian Estimation of a Markov-Switching Threshold Asymmetric GARCH Model with Student-T Innovations*****.** *Econometrics Journal*, 12(1), 105–126;

[2]**Ari, Y., Keykubat, A.A., Papadopoulos, A. (2019),** ***Bayesian Estimation of Student-t GARCH Model Using Lindley's Approximation*****.** *Economic Computation and Economic Cybernetics Studies and Research*, 53(1), 75-88;

[3]**Ari, Y., Papadopoulos, A. (2016),** ***Bayesian Estimation of the Parameters of the Arch Model with Normal Innovations Using Lindley's Approximation*****.** *Economic Computation and Economic Cybernetics Studies and Research*, 50(4), 217-234;

[4]**Bala, D.A., Takimoto, T. (2017),** ***Stock Markets*** **Volatility Spillovers** ***during Financial Crises: A DCC-MGARCH with Skewed-T Density Approach*****.** *Borsa Istanbul Review*, 17(1), 25-48;

[5]**Batten, J.A., Ciner, C., Lucey, B.M. (2015),** ***Which Precious Metals Spill Over on Which, When and Why? Some Evidence*****.** *Applied Economic Letters*, 22(6), 466–473;

[6]**Bauwens, L., Preminger, A., Rombouts, J.V.K. (2010),** ***Theory and Inference for a Markov Switching GARCH Model*****.** *Econometrics Journal*, 13(2), 218-244;

[7]**Dutta, A. (2018),** ***A Note on the Implied Volatility Spillovers between Gold and Silver Markets.*** *Resources Policy*, 55, 192–195;

[8]**Eryiğit, M. (2017),** ***Short-Term and Long-Term Relationships between Gold Prices and Precious Metal (Palladium, Silver and Platinum) and Energy (Crude Oil And Gasoline) Prices.*** *Economic Research-Ekonomska Istraživanja*, 30(1), 499-510;

[9]**Frommel, M. (2010),** ***Volatility Regimes in Central and Eastern European Countries' Exchange Rates.*** *Czech Journal of Economics and Finance*, 60(1), 2-21;

[10]**Hammoudeh, S., Yuan, Y., McAleer, M., Thompson, M. (2010),** ***Precious Metals-exchange Rate Volatility Transmissions and Hedging Strategies*****.** *International Review of Economics and Finance*,19(4), 633–647;

[11]**Jouini, J. (2018),** ***Measuring the Macroeconomic Impacts of Fiscal Policy Shocks in the Saudi Economy: A Markov Switching Approach .*** *Romanian Journal of Economic Forecasting*, 21(4), 55-70;

[12]**Karanasos, M., Ali, F.M., Margaronis, Z., Nath, R. (2018),** ***Modelling Time Varying Volatility Spillovers and Conditional Correlations across Commodity Metal Futures*****.** *International Review of Financial* Analysis, 57, 246–256;

DOI: 10.24818/18423264/54.4.20.17

[13]**Kaufmann, R.K., Ullman, B. (2009),** ***Oil Prices, Speculation, and Fundamentals: Interpreting Causal Relations among Spot and Futures Prices*****.** *Energy Economics*, 31(4), 550–558;

[14]**Kirkulak-Uludag, B., Lkhamazhapov, Z. (2017),** ***Volatility Dynamics of Precious Metals: Evidence from Russia*****.** *Czech Journal of Economics and Finance*, 67(4), 300-317;

[15]**Mirović, V., Živkov, D., Njegić, J. (2017),** ***Construction of Commodity Portfolio and Its Hedge Effectiveness Gauging – Revisiting DCC Models.*** *Czech Journal of Economics and Finance*, 67(5), 396-422;

[16]**Morales, L., Andreosso-O′Callaghan, B. (2011),** ***Comparative Analysis on the Effects of the Asian and Global Financial Crises on Precious Metal Markets*****.** *Research in International Business and Finance*, 25(2), 203–227;

[17]**Poměnková, J., Kapounek, S. (2009),** ***Interest Rates and Prices Causality in the Czech Republic – Granger Approach*****.** *Agricultural Economics–Zemedelska Ekonomika*, 55(7), 347-356;

[18]**Sensoy, A. (2013),** ***Dynamic Relationship between Precious Metals.*** *Resources* Policy, 38, 504–511;

[19]**Shimada, J., Tsukuda, Y., Miyakoshi, T. (2009),** ***Asymmetric International Transmission in the Conditional Mean and Volatility to the Japanese Market from the US: EGARCH versus SV Models*****.** *Singapore Economic Review*, 54(1), 123-134;

[20]**Šoltés, M., Škrovánková, L., Buleca, J. (2017),** ***Using Markov Chains in the Social Security System*****.** *Economic Computation and Economic Cybernetics Studies and Research*, 51(1), 223-232;

[21]**Yağcibaşi, Ö.F., Yildirim, M.O. (2019),** ***Estimating Taylor Rules with Markov Switching Regimes for Turkey*****.** *Romanian Journal of Economic Forecasting*, 22(3), 81-95;

[22]**Todorova, N., Worthington, A., Souček, S. (2014),** ***Realized Volatility Spillovers in the Non-Ferrous Metal Futures Market*****.** *Resources Policy*, 39, 21–31;

[23]**Uddin, G.S., Shahzad, S.J.H., Boako, G., Hernandez, J.A., Lucey, B.M. (2019),** ***Heterogeneous Interconnections between Precious Metals: Evidence from Asymmetric and Frequency-Domain Spillover Analysis*****.** *Resources Policy*, 64, 101509;

[24]**Virbickaite A, Ausin M.C., Galeano P. (2015),** ***Bayesian Inference Methods for Univariate and Multivariate GARCH Models: A Survey.*** *Journal of Economic Surveys*, 29(1), 76-96;

[25]**Živkov, D., Đurašković, J., Manić, S. (2019),** ***How Do Oil Price Changes Affect Inflation in Central and Eastern European Countries? A Wavelet-Based Markov Switching Approach*****.** *Baltic Journal of Economics*, 19(1), 84-104.

DOI: 10.24818/18423264/54.4.20.17