www.ees.uni.opole.pl
ISSN paper version 1642-2597
ISSN electronic version 2081-8319
Economic and Environmental Studies
Vol. 18, No 2 (46/2018), 499-513, June 2018

Volatility and co-movements of the equity markets in Central Europe – evidence from Poland and Hungary

Anna Chmielewska
Warsaw School of Economics, Poland

Abstract:
This article aims at verifying if there has been a structural change in the co-movement pattern of selected Central and Eastern Europe (CEE) over the ten-year period following the financial crisis. The empirical results confirmed that such a change was observed both in the correlation and volatility levels for specific market segments, as well as in the market dynamics. These findings provide a new insight into understanding the shock resilience, which consequently can supplement a wider assessment of the systemic risk in the financial markets. The key results point towards a decreased uncertainty in estimated correlation levels during the post-crisis period. Such findings are consistent with the hypothesis that intermarket linkages are currently better reflected in market prices when compared to the pre-crisis period. While this is clearly a positive signal for future system stability, it also evidences that the widely used GARCH and DCC specifications turn to be relatively narrow and therefore greater caution is highly recommended when interpreting estimation results.

Keywords: correlation, volatility, financial markets, GARCH, financial econometrics, systemic risk, CEE

JEL codes: *G15, C58, G17, G01, D53*

DOI : https://doi.org/10.25167/ees.2018.46.2

1. Introduction

The financial crisis, observed nearly a decade ago, has renewed discussions on interdependence and contagion between financial markets. The crisis uncovered multiple market imperfections, which – if not taken into account when making investment decisions – can lead to suboptimal asset allocation and pose systemic risk. Multiple studies have been conducted analysing how the dynamics of selected financial markets (including that in Poland) changed during the turmoil. The results of those point towards an increased volatility, and – in the case of the Polish market –

Contact details: Anna Chmielewska, Department of Quantitative Economics, Warsaw School of Economics, Tel. 662-480-451, email: anna.chmielewska@sgh.waw.pl

increased correlations between individual market segments, typically associated with capital outflows (Chmielewska, 2012).

The post-crisis market design has been at the heart of recent regulatory debate. Numerous regulatory reforms have been implemented, which aim at changing investors behaviour in a way that would limit systemic risk. This by itself justifies the hypothesis that structural changes in the market dynamics might have occurred. While the implications might have been difficult to assess *ex ante* – at the regulation implementation – the "post-crisis" time series have now become long enough to allow conducting empirical studies. Therefore the old paradigms can now be revisited to verify if they have changed over the last ten years. In the author's view, such verification is necessary before applying any pre-crisis results in the investment or policy decisions.

The aim of this study is to contribute to this research stream by providing some empirical evidence from the Polish and Hungarian stock markets on the character of interdependence and dynamics of selected financial markets in the pre-crisis and post-crisis periods. In particular, the paper verifies whether the stock markets in Poland and Hungary strengthened their interdependencies (which would be consistent with the view that the markets of our region remain to a large extent a portfolio investments, vulnerable to risk aversion). In contrast, weakening of mutual interdependencies could signal that those markets are already sufficiently developed and less vulnerable to external shocks.

The study analyses links between individual financial markets and their segments by looking at conditional volatility and conditional correlation. It differs from previous empirical research on the volatility and correlation in CEE countries, based on the following two features: firstly, it incorporates an exchange rate effect, to take into account the perspective of a foreign investor; secondly, it analysis model outcomes based on stability of impulse response functions. The results are important both for the asset allocation by portfolio investors, as well as in systemic risk assessment by the authorities.

This paper is organised as follows: Section 2 summarises the data used and explains the selected research methodology. Section 3 presents key results of the two-step analysis, of which the initial one is focused on documenting the structural change in co-movement pattern, while the latter concentrates on the shock response resilience. Section 4 summarises key conclusions both in terms of answering the research question, as well as commenting on the identified limitations of the econometric tools widely used in market analyses.

2. Data used and methodology

Data used and preliminary analysis

The research uses financial data between January 2004 and August 2017. It uses four equity indices (BUX, WIG20, DAX and CAC40), as well as the Zloty and the Forint exchange rates against the euro. The choice of Eurozone as the global factor for the Polish and Hungarian markets is justified by the dominant role of Eurozone in the trade relations of the analysed countries. While the S&P index and dollar rates could be seen as a more natural candidates for financial markets, their potential advantages can get overweighed by timing consistency of the data from the European market, being closely correlated.

Even the basic statistics point towards a clear heteroscedasticity of the underlying time series of daily returns. The volatility levels allowed distinguishing three periods, characterized by potentially different dynamics, which were labelled as: (i) the pre-crisis period (until 2007) – being generally regarded as a period of relatively good economic times, (ii) a turmoil period (2008-2012), when the uncertainty related to the credit and subsequent bong crisis were clearly visible and (iii) the post-crisis period starting in 2013. Such a preliminary analysis is consistent with the widely shared view that volatility is substantially higher during the period of turbulence and tends to lower in the post-crisis period. Interestingly, the analysis suggests that in the case of the French and German capital markets, the post-crisis decline in the risk level did not manage to fully off-set the earlier growth, while in the case of the Polish and Hungarian markets they seem to have been more stable recently than in the early years of EU membership.

Additionally, the preliminary analysis of correlation of daily returns suggests that in the post-crisis period the interdependence of CEE markets with Western EU markets is clearer than pre-crisis. This is consistent with the ongoing convergence process of the CEE economies, which are expected to stabilize and strengthen market interconnections. At the same time visible correlations between the stock and FX market movements, justify taking into account the dynamics of the exchange rate when analysing market dynamics.

Model specifications

The study uses a multivariate GARCH approach when analysing the conditional volatility and the conditional correlation of CEE stock and currency markets and market reaction to external shocks. The literature offers variable modelling approaches (see, for example, Bauwens

et al., 2006, Silvennoinen and Teräsvirta, 2009, Virbickaite et al., 2015).

A key factor in deciding on the specification is the problem of too high a number of estimated parameters. The narrow group of four countries and two market segments offers some flexibility in the choice of econometric models, while covering a larger number of markets is typically limited to DCC for numeric reasons (Caporin and McAleer, 2012). The nature of the research questions asked in this study favours relatively flexible models, therefore the basic BEKK model (Engle and Kroner, 1995) was selected as the starting point.

The BEKK model (1,1,1) using the delayed values from one period (as assumed in this study) can be summarized as follows:

$$\Omega_t = C'C + A'\Omega_{t-1}A + B'r_{t-1}r_{t-1}'B$$

where Ω_t is the variance-covariance matrix at time *t*; A, B, C are matrices of estimated parameters (n×n), of which C is upper triangular; n is the number of variables (assets); r_{t-1} - columnar vector (size n × 1) of filtered logarithmic daily returns at t-1.

Unfortunately, even with this data-set, the full BEKK specification was only possible to be estimated based on the full sample. For the sub-period analysis model simplification was necessary. Therefore this study uses diagonal version of the BEKK model (see e.g. Caporin and McAleer, 2012), which assumes that A and B are diagonal matrices. This approach seems to, on the one hand, maintain sufficient model flexibility, while – on the other hand – it remains usable on the basis of several-year time series, as well as several-year subsamples.

The diagonal BEKK is the common alternative to the widely used DCC (Engle, 2002). While DCC allows for dynamic correlation, the transfer of shocks between markets under DCC specification takes place only through the correlation of rates of return. This assumption was considered too restrictive in the light of broad evidence of market contagion and financial derivatives, which allow arbitraging between various market segments.

Different specifications containing two asset classes (stock and currency markets) and four analysed geographic markets have been estimated using Oxford MFE Toolbox library (Sheppard, 2013). All-time series were filtered using the ARMA model (1,1). Given consistency of model specification across periods is at the heart of this study; the specification was estimated based on both a full sample ("full sample model") and three separate subsamples ("split sample models"), representing periods identified as mentioned above.

Impulse response

From the policy perspective, the main reason to analyse market interdependence is to understand the market dynamics and relative importance of various market interlinkages. For that reason, the impulse response function is at the heart of the analysis for volatility and correlation paths and was the second step of this research

One of the problems with the BEKK models is that their strongly non-linear nature does not give a direct economic interpretation of the model parameters. For this reason, the analysis of stability over time of the estimates of individual parameters does not allow for a convincing analysis of the changes in the nature of economic processes which stand behind the observed returns.

To address this problem, different model specifications are compared not on the parameter by parameter basis, but rather by comparing the resulting impulse response paths. It requires simulation of impulse response functions (based on models estimated earlier), whose distribution can be treated as a measure correlated with the confidence interval. Such a comparison is a relatively new approach (see works of Allen et al. (2017), Hafner and Herwatz (2006) and Jin and An (2016)) and remains underutilised in the studies concerning CEE markets.
For the purpose of this study the global shocks were assumed to affect all markets in parallel. The shocks to all the analysed stock and currency markets were defined as one-off volatility increase up to the level corresponding to three times the crises period standard deviation of DAX and EURPLN markets volatility, respectively. Impulse response models were simulated for 250 session days (which corresponds to one calendar year) and in each case 1000 replications were generated.

3. Key results

Level of volatility and correlation in full-sample and split sample approach

Firstly, an attempt was made to assess whether crisis turbulence led to a structural change in the level of volatility of and correlation between individual market segments in different geographic markets. Previous studies, including the author's own research (Chmielewska, 2012) confirmed that during the crisis the nature of interdependence changed. Currently – a decade after the crisis inception – it is possible to verify if this change is only a reaction to a temporary shock (related to the collapse in the credit markets) following which markets are expected to stabilise at

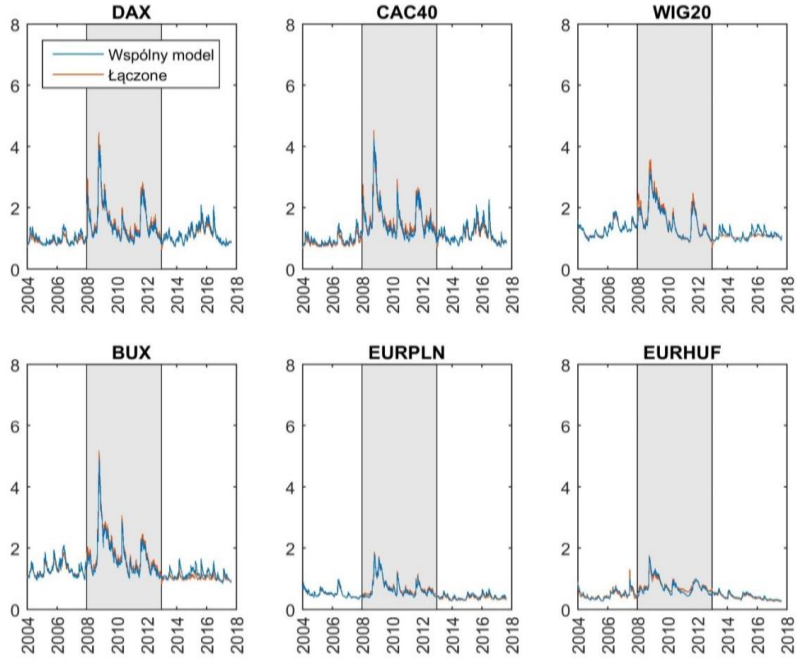
nearly an unchanged level. The positive answer would be a prerequisite to apply any of the empirical results based on pre-crisis data.

The first analysis compared correlation and volatility estimates from the diagonal BEKK specifications covering (i) full sample and (ii) three separate sub-samples. Model outcomes are charted in Figure 1 and Figure 2, respectively. These suggest that the both modelling specifications produced very similar results, while the largest differences are visible in the crisis period.

In line with the expectation, the full-sample model is in a sense an "averaging" model, and thus tends to slightly underestimate the crises-related volatility spike when compared with split-sample specification. In addition, the results of the both models indicate that the estimated volatility of individual markets during the crisis period is at a level very close to that observed during pre-crises (see also, for example, Beirne et al., 2009, Zivkov et al., 2015).

It can be noted that for the French and German stock market pair the correlation level is very high and remains relatively stable during a turmoil, while the cross-correlation between the Polish and Hungarian markets, as well as their correlation with the developed market returns is much less stable. Except for the correlation between the German and the French stock markets returns, the correlation increased during the period of turmoil. Such results are consistent with the phenomenon of capital outflow from equity markets.

Figure 1. Conditional volatility based on full sample (blue) and three separate samples (red) estimations of diagonal BEKK specification



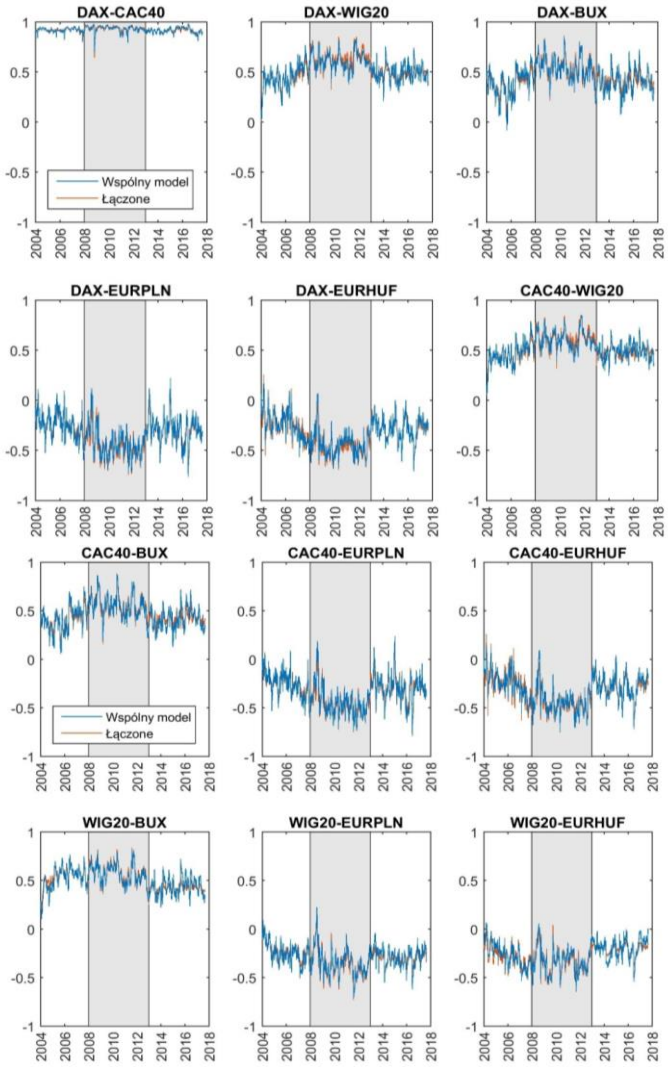
Source: estimation results

The inclusion of the FX rate made it possible to verify to what extent the Polish and Hungarian stock markets are still treated as higher risk ones. Up until the early 21st century it seemed that the rapid outflows of capital – which characterise the dynamics of emerging markets – will no longer apply to those markets thanks to their gradual convergence with EU markets. Before the crisis, despite the absence of strong mutual trade relations and major differences between Polish and Hungarian economic and political situations, a relatively strong (but gradually decreasing) interdependence between returns in these markets had been observed. While the credit market turmoil did not directly impact key financial entities in either of these two countries, some negative consequences were observed in the both, leading to – what seemed to be – a temporarily increased correlation between the underlying market returns.

When looking at FX-correlations (Figure 2), the Zloty-Forint correlation significantly strengthened during the turmoil. An increase in the negative correlation between the stock markets returns and their underlying currency rate returns has been noted. This suggests that when the Zloty or the Forint depreciate, one is likely to observe decreases in the respective stock markets. This is consistent with the intensification of the outflow of capital from markets which

are regarded more risky, and suggests that Poland and Hungary are still considered to be higher risk countries in relation to the core of the European Union.

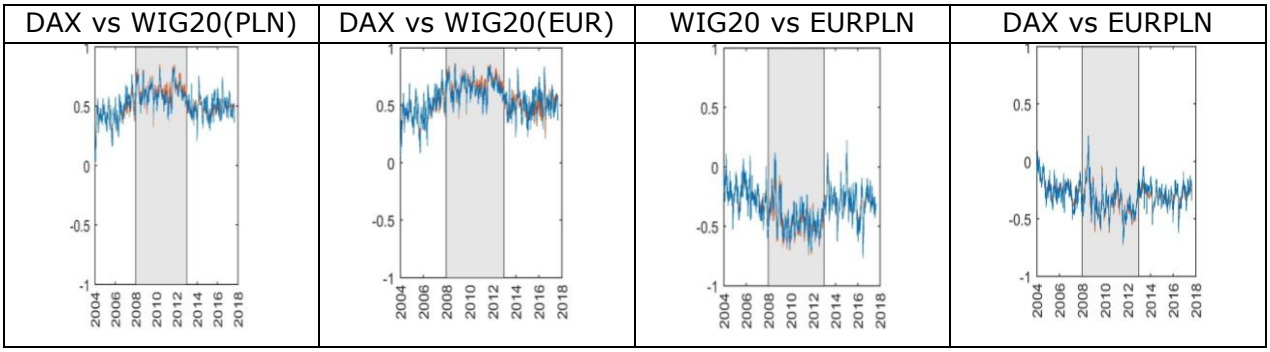
Figure 2. Conditional correlation based on full sample (blue) and three separate samples (red) estimations of diagonal BEKK specification



Source: estimation results

The next step was to look at the returns from the perspective of foreign investors. For most foreign investors it remains possible to cheaply hedge FX risk only in short term, the profitability of investment in Polish or Hungarian shares over extended investment period needs taking into account also the exchange rate movements. Even if the stock price remains unchanged, the unhedged foreign investor records returns following the exchange rate fluctuations.

Figure 3. Foreign investors' perspective – WIG20 and DAX based on full sample (blue) and three separate samples (red) estimations of diagonal BEKK specification



Source: estimation results

As evidenced in Figure 3, the correlation level estimates remain significantly unchanged, following FX adjustments. Low FX volatility translates into only a small strengthening of the stock market correlations. Yet, the negative correlation between the French/German stock markets and Polish and Hungarian currency rates should not be ignored. With the availability of financial derivatives, the exchange rate position can be easily built without significant currency adjustments. It is therefore important to note that the negative correlation between EU stock markets and the Zloty and the Forint FX rates strengthened during the financial turmoil. This is consistent with the outflow of foreign capital from CEE countries, which indeed was observed during that period. It may therefore be an important indication for investors constructing investment portfolios, suggesting that in certain situations currency exposure may be treated as a certain (imperfect) substitute, or (in the case of a short position) a partial risk mitigant for equity exposure. During significant distress it may be easier to open significant FX position than to exit large equity portfolio.

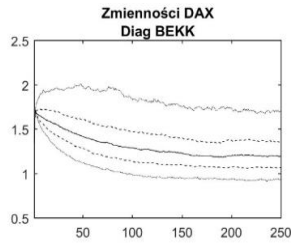
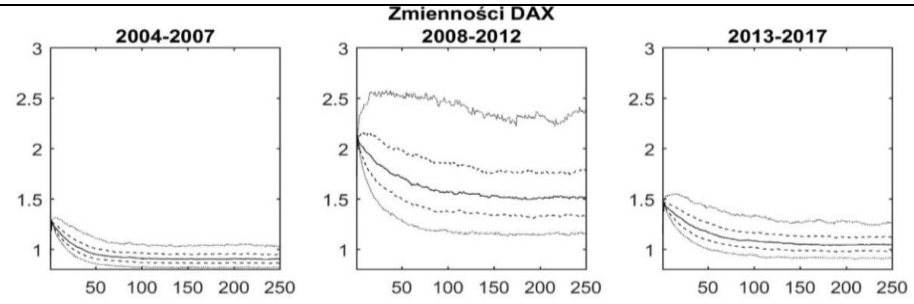
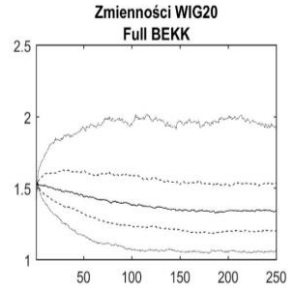
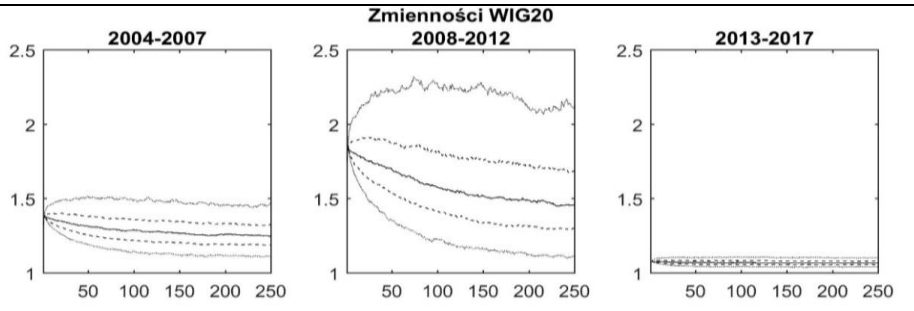
The full sample model specification resulted in similar levels of estimated volatility and correlations as were implied by the split sample approach. Both confirm the changing character of market volatility and correlation, especially their increase during market turmoil. At the same time, however, the proximity of the results of both specifications, seems to confirm the fact that the diagonal BEKK specification proves sufficiently flexible to reflect changes in volatility and correlation.

Impulse response – market dynamics analysis

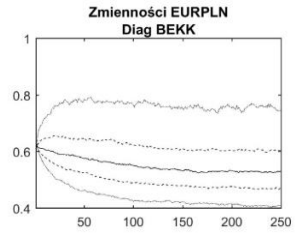
However, the similarity of selected estimated results is insufficient to opine of the quality of model specification. As the second step of this research, the system dynamics – understood as estimates reaction to the shock observed in a mature market – was analysed. This was to both comment on the possible contagion effect and resilience of these markets, but would also help to understand if both modelling approaches result in similar market dynamics.

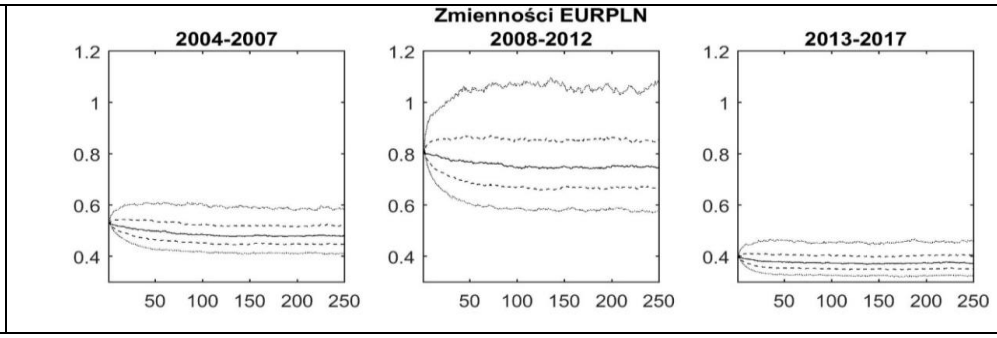
This section – for the purpose of illustration – uses a 5% daily drop in the share prices on the DAX as the initial shock. This is intended to represent a global shock, therefore a parallel shift in other markets based on the variance-covariance matrix was assumed. Selected impulse response functions associated with this shock are presented in Figure 4. 1000 simulations were used to analyse this impact, therefore in each of the graphs in Figure 4 the solid line represents the median value of impulse response function, while the dotted lines denote the 25th and 75th centiles of the distribution of this variable, and the grey lines represent the 10th and 90th centiles. Such a simulation was conducted separately for the full sample and each of the three sub-sample specifications.

Figure 4. Impulse response after DAX shock in line with full sample (left hand side) and separately for each of the three sub-sample specifications (right-hand side)

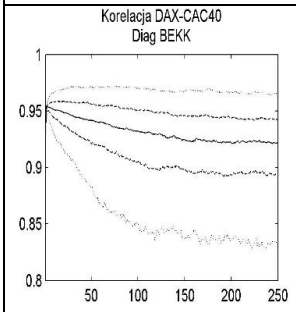
Full sample	Split sample specifications
Impulse response after DAX shock – impact on DAX volatility	
	
Impulse response after DAX shock – impact on WIG20 volatility	
	

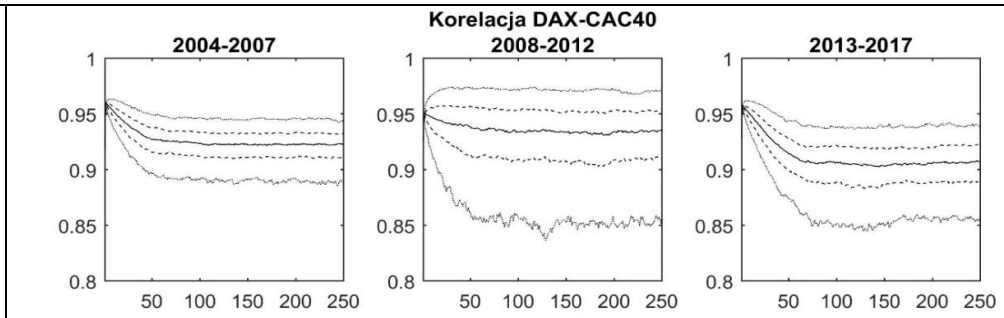
Impulse response after DAX shock – impact on EURPLN volatility



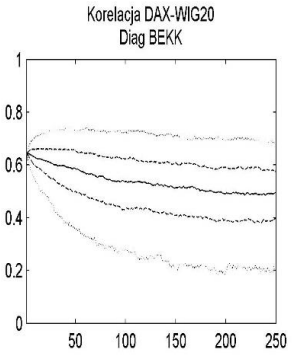


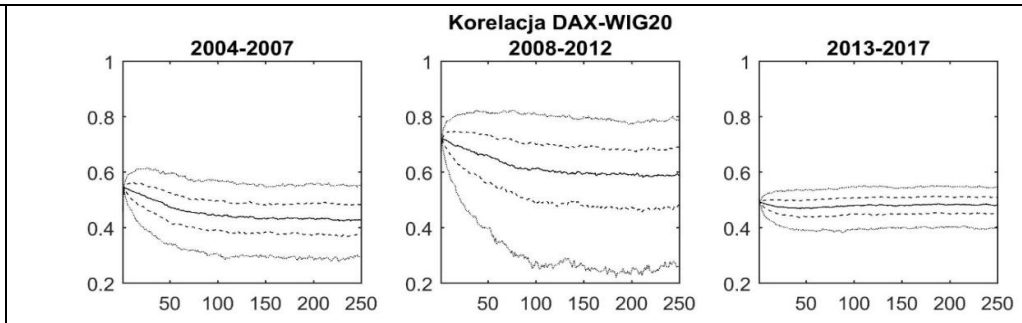
Impulse response after DAX shock – impact on CAC-DAX correlation



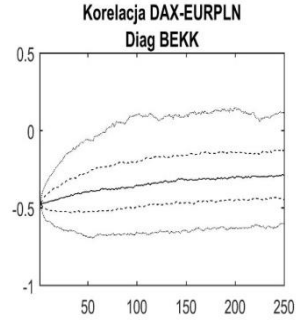


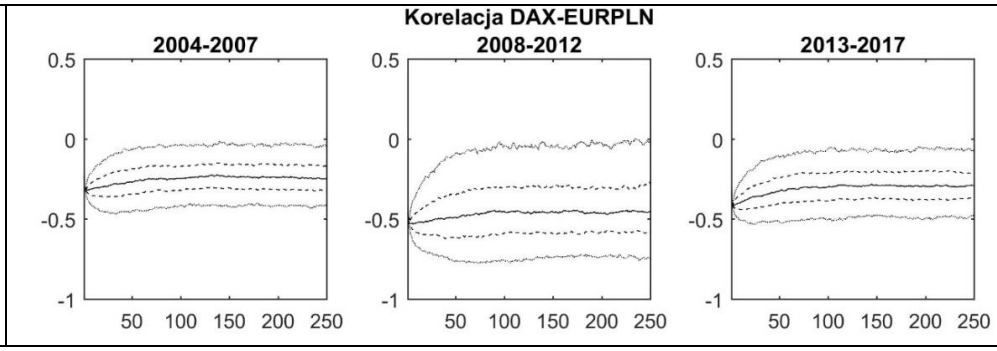
Impulse response after DAX shock – impact on WIG20-DAX correlation



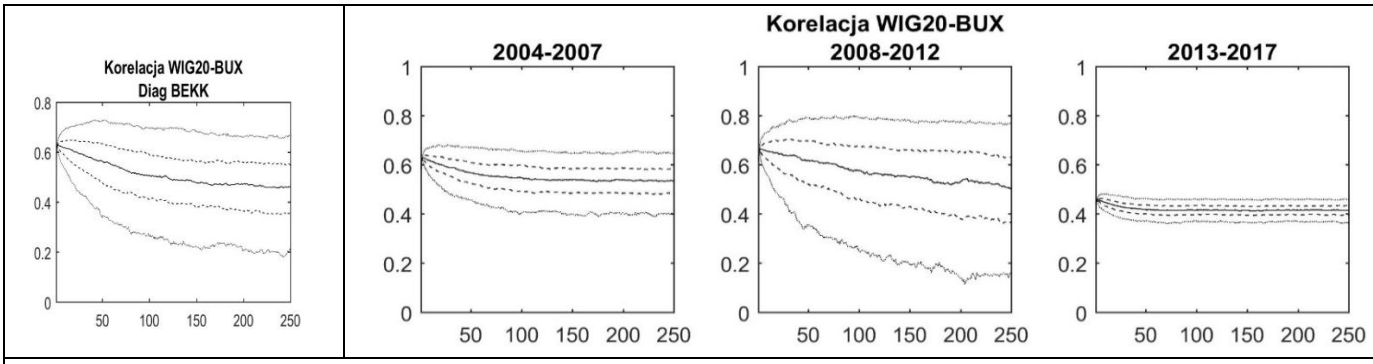


Impulse response after DAX shock – impact on DAX-EURPLN correlation

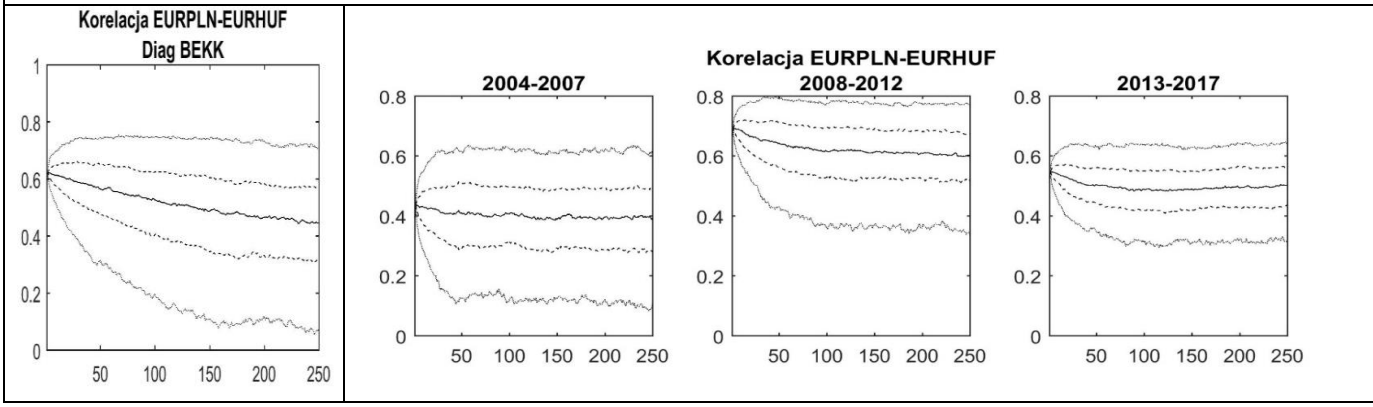




Impulse response after DAX shock – impact on WIG20-BUX correlation



Impulse response after DAX shock – impact on WIG20-BUX correlation



Source: estimation results

Contagion effect is clearly visible. The global shock not only temporarily increased the volatility across equity markets, but also led to a small increase in the volatility of exchange rates. Such findings are consistent with the hypothesis that a shock within one market segment can be easily translated into various different geographic markets. At the same time, it indirectly suggests that DCC specification may be too narrow, as its structure prevents such cross-market direct volatility spill-overs.

Moreover, the shock on DAX appears to have strengthened the correlation both between stock markets (including cross-correlation between the Polish and Hungarian markets) as well as the negative correlation between the stock market and the euro (expressed in the Zloty or the Forint). This may suggest that the phenomenon of shocks in the first place strengthens the volatility of directly related markets and the correlation of individual segments of financial markets (in other words, the contagion happens parallel to the relation to the level of volatility and correlation), while only thereafter changes are passed onto the volatility of other segments.

As evidenced in Figure 4, the comparison of full sample and split sample results is quite surprising. Several volatility and correlation reaction paths stabilize at different levels and differ significantly in the percentile spread.

The first conclusion could be expected in the light of the previously presented first step analysis, which pointed to different level of volatility and correlation during sub-periods. The full sample median "steady-state" level seems to be closest to the results obtained, based on the initial sub-period, which call for verification if the estimation methodology does not favour early observations.

The second conclusion is however more puzzling. The percentile spread observed in some cases consistently exceeds 0.5 in the case of correlation, and twice the standard deviation in the case of volatility. Such high uncertainty is not intuitive, especially when looking at moderate shifts observed, based on the full sample model. One could try to intuitively explain it by the uncertainty of results, being the consequence of a smaller dataset. This however would not explain very narrow percentile spread reported in post-crises estimation. The split sample model suggests that a wide spread is a reflection of increase in uncertainty during the turmoil time.

It is also worth noting that the results of the impulse-response analysis performed on the basis of the model calculated on the full sample suggest stabilization at a level which is different from that in individual subsamples. While it seems consistent with the "resultant" reaction of three models, it confirms that the averaging effect (embedded when using the full-sample model) can be misleading both during good and weak market conditions, especially as in many cases the median level estimated on the basis of crisis period is outside the percentile spread estimated by the full sample model. This means, using the full sample approach could lead to significant underestimation, particularly when applied for the risk assessment purpose.

The fact that the both model approaches gave such different shock reactions is very interesting, especially in the light of very similar results obtained from the both model specifications at the first step. In the authors' opinion, it points towards different market dynamics during crises and stable times, which would encourage the use of partial models.

Another interesting finding is that post-crises results indicate much narrower percentile spread even when compared with the pre-crises period. This is consistent with the hypothesis, that investors learnt their lessons and the market–interdependence is now better reflected in the observed market prices. Such a learning process would remove an element of uncertainty and

therefore could justify better predictive power of the models estimated on the basis of the last sub-period. An alternative justification would include increased integration with EU markets, which might have stabilised the character of cross market interdependencies.

4. Conclusion

The study presented in this paper confirmed that the financial crisis observed a decade ago has significantly changed the market dynamics of the Polish and Hungarian equity markets. The key findings suggest that the mutual market interdependencies are currently more carefully taken into account by market participants, and thus are better reflected in market prices. While the study was limited to the Polish and Hungarian equity markets, it would be interesting to verify it, based on other geographical and asset markets.

The most surprising conclusion from the conducted research is the systemic change in the impulse-response in the pre- and post-crisis periods. Such findings have a significant impact on how those markets can be modelled. While the diagonal BEKK model was relatively useful when estimating the conditional volatility and correlations, it proved to be too narrow when faced with modelling impulse response. This calls for significant caution when using GARCH models based on very long time series to model system dynamics. Such models should ideally be adjusted to allow for certain changes in the nature of mutual relations over time (dynamic specifications). If this turns out not possible, the results shall be cross-checked with models based on shorter subsamples. While it may not solve the modelling problem, it can help an informed expert to interpret the model results and opine on their reliability.

Literature

Allen D.E., M. McAleer, R. Powell, A.K. Singh (2017), Volatility spillover and multivariate volatility impulse response analysis of GFC news events, Applied Economics, vol. 49, 3246-3262.

Bauwens L., S. Laurent, J.V.K. Rombouts (2006), Multivariate GARCH models: A survey, Journal of Applied Econometrics, vol. 21, 79-109.

Beirne J., G.M. Caporale, M. Schulze-Ghattas, N. Spagnolo (2009), Volatility spillovers and contagion from mature to emerging stock markets, ECB Working Paper Series No. 1113.

Caporin C., M. McAleer (2012), Do we really need both BEKK and DCC? A tale of two multivariate GARCH models, Journal of Economic Surveys, vol. 26, 736-751.

Chmielewska A. (2012), Kryzys a dynamika zmienności wybranych rynków finansowych, In: Alińska A. (ed.) „Polityka monetarna i fiskalna a stabilność sektora finansowego" Warszawa, Wydawnictwo CeDeWu 2012.

Engle R., Kroner F.K. (2002), Dynamic conditional correlation: a simple class of multivariate generalized autoregressive conditional heteroskedasticity models, Journal of Business and Economic Statistics, vol. 20, 339-350.

Engle R.F., K.F. Kroner (1995), Multivariate simultaneous generalized ARCH, Econometric Theory, vol. 11, 122-150.
Hafner Ch.M., H. Herwartz (2006), Volatility impulse responses for multivariate GARCH models: An exchange rate illustration, Journal of International Money and Finance, vol. 25, 719-740.
Jin A., X. An (2016), Global financial crisis and emerging stock market contagion: A volatility impulse response function approach, Research in International Business and Finance, vol. 36, 179-195.
Sheppard K. (2013), Oxford MFE Toolbox, https://www.kevinsheppard.com/MFE_Toolbox.
Silvennoinen A., T. Teräsvirta (2009), Multivariate GARCH models, In: T.G. Andersen, R.A. Davis, J.P. Kreiss, T. Mikosch (eds), (2009), Handbook of Financial Time Series, Springer, 201-229.
Virbickaite A., M.C. Ausín, P. Galeano (2015), Bayesian inference methods for univariate and multivariate GARCH models: a survey, Journal of Economic Surveys, vol. 29, 76-96.
Zivkov D., J. Njegic, I. Milenkovic (2015), Bidirectional Volatility Spillover Effect between the Exchange Rate and Stocks in the Presence of Structural Breaks in Selected Eastern European Economies, Finance a Uver, vol. 6, 477-498.
Engle R., Kroner F.K. (1995), Multivariate simultaneous generalized ARCH, Econometric Theory, vol. 11, 122-150.

Zmienność i współzależność rynków akcji w Europie Środkowo Wschodniej na przykładzie rynków Polski i Węgier

Streszczenie

Przedstawione badanie koncentruje się na analizie zmienności i współzależności polskiego i węgierskiego rynku akcji. Wielowymiarowa analiza GARCH pozwala potwierdzić strukturalny charakter zmian w funkcjonowaniu rynków finansowych obserwowanych po kryzysie na rynkach kredytowych. Szczegółowe badanie wąskiej grupy rynków uwzględnia analizę opartą o symulacje reakcje na impuls. Analiza ta uwidoczniła zmiany w dynamice rynków i odporności na szoki zewnętrzne. Zmniejszona niepewność obserwowana w okresie pokryzysowym jest spójna z hipotezą uczenia się rynków finansowych. Sugeruje ona, że powiazania rynkowe są obecnie w lepszym stopniu uwzględniane w wycenach instrumentów finansowych. Taki wniosek, choć wymaga dalszego potwierdzenia, wydaje się korzystny z punktu widzenia analizy ryzyka systemowego. Jednocześnie jednak przeprowadzone badanie unaocznia konieczność modyfikacji i dostosowania metodyki analizy rynków, wskazując, że relatywnie dokładne oszacowania zmienności i korelacji mogą tylko pozornie potwierdzać właściwość specyfikacji stosowanych modeli.

Słowa kluczowe: korelacja, zmienność, rynki finansowe, GARCH, ekonometria finansowe, ryzyko systemowe