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THE WARSAW STOCK EXCHANGE INDEX WIG: MODELING AND FORECASTING***

Abstract. In this paper we have assessed an influence of the NYSE Stock Exchange indexes (DJIA and NASDAQ) and European Stock indexes (DAX and FTSE) on the Warsaw Stock Exchange index WIG within a framework of a GARCH model. By applying a procedure of checking predictive quality of econometric models as proposed by Fair and Shiller (1990), we have found that the NYSE market has relatively more power than European market in explaining the WSE index WIG.

Keywords: Warsaw Stock Exchange, stock index, GARCH model, forecasting.

JEL Classification: C2, C5, C6, G1.

1. INTRODUCTION

The problem of searching for the influence of large markets on others has been well-known from literature for years. However, this kind of relationship has been widely studied through analyzing correlations between individual indexes representing different markets (e.g. Erb et al. 1994; Bracker and Koch 1999).

In this paper we try to find such dependence between WIG index and foreign stock market indexes (DJIA, NASDAQ and DAX, FTSE) by estimating parameters in regressions of WIG.

The estimates show which foreign stock market affects Polish stock exchange index more strongly. We also test it by the forecasting approach using forecast errors of WIG index obtained in individual regressions. We use also the idea of combined forecasts.

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There are many methods used to combine forecasts (e.g. Clemen 1989; Granger 1989). As shown by Clemen and Winkler (1986), simple combination methods often work better than more complex approach. The aim of combining forecasts is to investigate whether the forecast combination plays an important role in the improvement of forecasting accuracy. The well-known way of combining forecasts is to compute linear combination of forecasts generated by alternative models or obtained by using different forecasting methods (e.g. Billio et al. 2000, Claessen and Mittnik 2002).

Dependence between stock markets in different countries has been tested for years. Many analyzes deal with measuring correlation between returns and diversified international portfolios (e.g. Grubel 1968, Levy and Sarnat 1970, Agmon 1972, Fiszeder 2003).

In the 1990s there appeared research of how changes to stock prices on one market affect other markets (e.g. Hamao et al. 1990, King and Wadhvani 1990, Engle and Susmel 1993, Fiszeder 2001).

The focus of this paper is to find the influence of American and European indexes on Warsaw Stock Exchange index WIG. There is a lot of research which prove that this influence does exist. We aim to examine which market – American or European – has a stronger impact on WIG index.

The paper is structured as follows. In Section 2 we give a brief overview of the GARCH methodology. In Section 3 we test for influence of foreign stock indexes on WIG index. Combined forecasting of WIG index is applied in Section 4, and finally we give concluding remarks.

2. THE GARCH METHODOLOGY

Many models have been proposed to describe volatility of returns. Now there is a comprehensive literature with several specifications of autoregression models. Many empirical analyzes, however, have shown that GARCH approach is the most appropriate. We also apply GARCH modeling in this paper. This is the most popular class of models used in modeling the financial time series of high frequency (e.g. Akgiray 1989, Schwert and Seguin 1990, Nelson 1991, Andersen et al. 1999, Osiewalski and Pipień 1999 and 2004, Bollerslev and Wright 2000, Fiszeder 2001 and 2003, Brzezyczyński and Kelm 2002, Doman M. and Doman R. 2003).

The GARCH model has been proposed independently by Bollerslev (1986) and Taylor (1986) as a generalization of ARCH model introduced by Engle (1982).

The main feature of ARCH model is to describe the conditional variance as an autoregression process. However, most empirical time series require using long-lag length ARCH models and a large number of parameters must be estimated. The solution of the problem was GARCH models which gave better results (cf. Engle and Bollerslev 1986; Nelson 1991).

The basic linear generalized autoregressive conditional heteroscedastic GARCH(p, q) model is given as follows (e.g. Bollerslev 1986):

$$(1) \quad y_t = \mathbf{x}_{(k)t} \boldsymbol{\alpha}_k + \varepsilon_t,$$

where:

$$(2) \quad \varepsilon_t = \vartheta_t \sqrt{h_t},$$

and h_t is a function of conditional variance represented as:

$$(3) \quad h_t = \gamma_0 + \sum_{i=1}^p \gamma_i \varepsilon_{t-i}^2 + \sum_{j=1}^q \varphi_j h_{t-j},$$

where: ϑ_t is i.i.d. with $E(\vartheta_t) = 0$ and $\text{var}(\vartheta_t) = 1$, $\gamma_0 > 0$, $\gamma_i \geq 0$, $\varphi_j \geq 0$. If $\sum_{i=1}^p \gamma_i + \sum_{j=1}^q \varphi_j < 1$, the process h_t is covariance stationary.

Engle and Bollerslev (1986) considered also GARCH processes with $\sum_{i=1}^p \gamma_i + \sum_{j=1}^q \varphi_j = 1$, which they denoted integrated GARCH (IGARCH).

In empirical research the most frequently used is GARCH(1, 1) model in which $h_t = \gamma_0 + \gamma_1 \varepsilon_{t-1}^2 + \varphi_1 h_{t-1}$ and $\gamma_0 > 0$, $\gamma_1 \geq 0$, $\varphi_1 \geq 0$. When $\gamma_1 + \varphi_1 < 1$, than unconditional variance of ε_t is given by $\text{var}(\varepsilon_t) = \frac{\gamma_0}{1 - \gamma_1 - \varphi_1}$.

The coefficients of the model are then easily interpreted, with the estimate of γ_1 showing the impact of current news on the conditional variance process and the estimate of φ_1 as the persistence of volatility to a shock or, alternatively, the impact of "old" news on volatility.

Recently a number of new formulations have been proposed, for example exponential GARCH(p, q) model (EGARCH, e.g. Nelson 1991), GJR-GARCH model (e.g. Glosten et al. 1993), GARCH in the mean (GARCH-M(p, q), e.g. Engle et al. 1987), power GARCH (PGARCH, e.g. Ding et al. 1993), and the fractionally integrated GARCH (FIGARCH, e.g. Baillie et al. 1996).

Such models are commonly applied in financial time series research. The estimation of GARCH models is both classic and non-classic, e.g. Bayesian approach (e.g. Osiewalski and Pipień 1999, 2004).

In Section 3 we test models for influence of foreign stock markets on the Polish market.

3. TESTING FOR INFLUENCE OF FOREIGN STOCK INDEXES ON WIG INDEX

In the paper we use a GARCH methodology with GARCH(1,1) models. We have found that both ARCH and GARCH effects appeared to be statistically significant in the dependence tested.

The focus of the paper is to find the influence of American and European stock market indexes on WIG index over the period 1.01.1995 to 29.12.2003 (2346 observations).

After introducing suggested foreign indexes to the GARCH(1, 1) equation describing WIG index, it was impossible to separate mutual relationships between index WIG and foreign indexes, mainly DAX and FTSE, because the estimates used to be statistically insignificant and had opposite signs which negated the assumptions of positive influence of the biggest stock markets on index WIG. Hence, we were unable to include both European indexes DAX and FTSE in one equation, and we decided to test for the influence of European markets by two equations accordingly.

In turn, we analyze the following models:

- for American market:

$$(4) \quad \dot{wig}_t = \alpha_0 + \alpha_1 \dot{djia}_{t-1} + \alpha_2 \dot{nasdaq}_{t-1} + \varepsilon_t,$$

- for European market:

$$(5) \quad \dot{wig}_t = \alpha_0 + \alpha_1 \dot{dax}_{t-1} + \varepsilon_t,$$

or

$$(6) \quad \dot{wig}_t = \alpha_0 + \alpha_1 \dot{ftse}_{t-1} + \varepsilon_t,$$

where the variables are first differences of natural logarithms, so they are the close-to-close returns on corresponding indexes.

The estimation was made by maximum likelihood method¹ for daily data from 1.01.1995 to 29.12.2003.

The equations (4), (5) and (6) were recursively estimated and helped to obtain a series of 250 one-period-ahead *quasi ex-ante* forecasts. The estimates

¹ We used Econometric Views package.

of individual equations were generally statistically significant. The sum $\hat{\gamma}_1 + \hat{\phi}_1$ in the equation of conditional variance was around 0.92, while the estimates $\hat{\gamma}_1$ were about 0.12 and $\hat{\phi}_1$ about 0.80. Hence, we can conclude that the impact of current news on volatility in the conditional variance process is smaller than the impact of "old" news.

The coefficient of determination *R*-squared for corresponding equations (4), (5) and (6) was about 12%, 3% and 3% respectively.

In Table 1 we give measurement of *ex-post errors*² for forecasts obtained from respective equations of index WIG.

Table 1. *Ex-post errors* of index WIG forecasts

Specification	DJIA-NASDAQ	DAX	FTSE
MAE	0.00922	0.00926	0.00929
RMSE	0.01193	0.01197	0.01213
THEIL	0.75195	0.82760	0.84897
I_1^2	0.005	0.004	0.005
I_2^2	0.411	0.575	0.582
I_3^2	0.588	0.425	0.417
TP1 (%)	19.69	13.39	15.75
TP2 (%)	50.21	43.57	47.72

In the analysis of *ex-post errors* we used turning points test statistic – TP1 – represented as:

$$(7) \quad TP1 = \frac{N(r_t r_t^* > 0 \wedge r_{t-1} r_{t-1}^* > 0 | r_t r_{t-1} < 0)}{N(r_t r_{t-1} < 0)},$$

where:

$N(r_t r_{t-1} < 0)$ – a number of turning points in empirical series;

$N(r_t r_t^* > 0 \wedge r_{t-1} r_{t-1}^* > 0 | r_t r_{t-1} < 0)$ – a number of points, in which changes to direction in empirical and forecasting series are the same in the period t and $t-1$ under the condition that the points are turning points in empirical series.

We also used the following direction quality measure (e.g. Welfe and Brzeszczyński 2000):

² We used the following *ex-post errors*: MAE – mean absolute error, RMSE – root mean square error, THEIL – Theil's inequality coefficient, I_1 , I_2 , I_3 – decomposition of Theil's inequality coefficient, TP1 and TP2 – turning points test statistics.

$$(8) \quad TP2 = \frac{N(r_t r_t^* > 0)}{N(r_t r_t^* \neq 0)},$$

where:

$N(r_t r_t^* > 0)$ – a number of points in which direction changes in empirical and forecasting series are the same.

The most accurate forecasts we obtained from the equation with American indexes. Forecasts basing on European indexes, however, were close to each other as far as errors are concerned.

In Section 4 we apply a methodology of combined forecasting. We test for relative importance of foreign stock markets in explaining WIG index.

4. COMBINED FORECASTS OF WIG INDEX

In order to assess the power of influence of foreign markets on the Polish market we estimated the following Fair and Shiller (1990) equation (e.g. Wdowiński 2004):

$$(9) \quad y_t - y_{t-1} = \alpha_0 + \alpha_1({}_{t-1}\hat{y}_{1t} - y_{t-1}) + \alpha_2({}_{t-1}\hat{y}_{2t} - y_{t-1}) + \varepsilon_t$$

where ${}_{t-1}\hat{y}_{1t}$ – denotes one-period-ahead forecasts of y_t generated by the model 1, i.e. the model with American indexes based on information available up to the moment $t-1$ with the use of recursive estimation for each period t . The predictor ${}_{t-1}\hat{y}_{2t}$ – denotes one-period-ahead forecasts generated accordingly by the model 2, i.e. the model with European indexes, while ε is an error term, $\varepsilon \sim IN(0, \sigma_\varepsilon^2)$. If neither model 1, nor model 2 contain any relevant information in terms of forecasts quality for variable y in period t , the estimates of α_1 and α_2 will be statistically insignificant. If both models generate forecasts that contain independent information, the estimates of α_1 and α_2 should both be statistically significant. If both models contain information but information contained in forecasts generated by model 2 is completely contained in forecasts generated by model 1 and furthermore model 1 contains additional relevant information, the estimate of α_1 will be statistically significant while the estimate of α_2 statistically insignificant. If both forecasts contain the same information, they are perfectly correlated and the estimation of parameters of (9) is not possible.

Because the influence of European markets was described by two equations, we estimated model (9) for two cases:

- for empirical WIG index and forecasts generated by (4) and (5).
- for empirical WIG index and forecasts generated by (4) and (6).

Below in Table 2 we present estimation results of equation (9).

Table 2. Estimation results of Fair and Shiller equation

Intercept	DJIA-NASDAQ	DAX	FTSE	S_e	J-B	D-W	ARCH	WHITE	Wald (USA)	Wald (EUR)	R^2 (adj.)	Obs.
0.0007 1.0018	0.5495 2.105	0.3989 1.4923	x x	0.0119	0.6407 (0.7258)	2.0719	0.2211 (0.6382)	0.3888 (0.4214)	4.4313 (0.0353)	2.227 (0.1356)	0.4429	250
0.0007 1.0226	0.6523 3.1112	x x	0.2915 1.3777	0.0119	0.8254 (0.6618)	2.0818	0.3223 (0.5702)	4.073 (0.3961)	9.6799 (0.0019)	1.8982 (0.1683)	0.4422	250

With *italics* we have denoted *t*-statistics with regard to estimates. Respective test probabilities with regard to test statistics are given in brackets. We applied the following tests: Jarque-Bera normality of residuals test (J-B), conditional heteroscedasticity test (ARCH), White's test for heteroscedasticity (White), Wald coefficient restrictions test (Wald). The D-W stands for Durbin-Watson test statistic.

The test statistics and their probabilities in case of J-B, D-W, ARCH and White's tests denote that errors in both models are normal, with no autocorrelation, no ARCH effects and no heteroskedasticity. Thus we can test the power of influence of foreign indexes on WIG index using *t*-statistic.

It can be easily seen that the influence of American market indexes DJIA and NASDAQ turned out to be more relevant for WIG index than European indexes DAX and FTSE. It is supported by the significance of estimates and their size. We can conclude, that information contained in forecasts generated by models (5) or (6) is fully contained in forecasts by model (4). Therefore, American indexes DJIA and NASDAQ were more influential than European indexes (DAX or FTSE) as regards WIG index. This conclusion is also confirmed by Wald coefficient restrictions test, i.e. we should reject the null that the respective coefficient equals zero in case of model (4) and should not reject the null in case of models (5) or (6).

Similar conclusions about the co-dependence of markets in case of Poland were drawn by e.g. Fiszeder (2003).

Since the parameters in equation (9) do not sum up to one, we should not treat them as weights in calculating combined forecasts.

Therefore, to calculate the weights, we used the nonlinear programming problem (NLP):

$$\min f(\omega) = \omega^T V \omega,$$

$$(10) \quad \omega^T \mathbf{1} = 1,$$

$$\omega \geq 0,$$

where:

$\omega = \begin{bmatrix} \omega_1 \\ \omega_2 \end{bmatrix}$ – is the vector of weights;

V – the variance-covariance matrix of forecast errors.

In Table 3 we present covariances and correlations of forecasts errors.

Table 3. Covariance and correlation coefficients matrix of forecast errors

Specification	Covariance		
	DJIA-NASDAQ	DAX	FTSE
DJIA-NASDAQ	0.0001417		
DAX	0.0001380	0.0001427	
FTSE	0.0001375	0.0001427	0.0001427
Correlation			
DJIA-NASDAQ	1		
DAX	0.9708	1	
FTSE	0.9546	0.9875	1

After solving the problem of nonlinear programming (10) we obtained the following weights which are given in Table 4.

Table 4. The weights in a NLP problem

DJIA-NASDAQ	DAX	FTSE
0.5664	0.4336	x
0.6734	x	0.3266

As we can notice the weights are close to estimated parameters in equation (9). Thus we confirmed earlier conclusions about the strong influence of American market on the Polish stock market. As shown in Table 5, we could not substantially reduce the variance of combined forecast errors, because of the high and positive correlation between forecast errors from individual models (4), (5) and (6).

Table 5. Variance of forecast errors

Individual forecast	
DJIA-NASDAQ	0.0001417
DAX	0.0001427
FTSE	0.0001427
Combined forecast	
DJIA-NASDAQ-DAX	0.0001406
DJIA-NASDAQ-FTSE	0.0001409

After calculating optimal weights, we calculated combined forecasts and assessed their accuracy. The results are given in Table 6.

Table 6. *Ex-post* errors of combined forecasts of WIG index

Specification	DJIA-NASDAQ	DJIA-NASDAQ-FTSE
MAE	0.00918	0.00916
RMSE	0.01186	0.01188
THEIL	0.78937	0.79123
I_1^2	0.005	0.005
I_2^2	0.514	0.515
I_3^2	0.537	0.534
TP1 (%)	15	17
TP2 (%)	48.55	48.96

It is clearly shown that combined forecasts are not superior to forecasts obtained from each model separately.

Finally, we tested the forecasting quality of the equations including indexes of both foreign markets at the same time. We estimated the following equations:

$$(11) \quad \dot{wig}_t = \alpha_0 + \alpha_1 \dot{djia}_{t-1} + \alpha_2 \dot{nasdaq}_{t-1} + \alpha_3 \dot{dax}_{t-1} + \varepsilon_t$$

$$(12) \quad \dot{wig}_t = \beta_0 + \beta_1 \dot{djia}_{t-1} + \beta_2 \dot{nasdaq}_{t-1} + \beta_3 \dot{ftse}_{t-1} + \xi_t$$

The estimates of α_3 and β_3 describing the influence of European market were usually insignificant. Also, as before, we obtained opposite signs of estimates which does not comply with the postulate of positive influence of the biggest stock markets on WIG index.

By applying the all-index approach itself we were not able to determine the power of influence of individual markets on the Polish market due to high correlation coefficients between indexes and difficulties in estimating the parameters. Therefore, the combined forecasts approach suggested in the paper can be considered correct.

Despite questionable statistics in results of regressions (11) and (12) and their weak economic properties we used them to forecast WIG index. The errors of these forecasts are shown in Table 7.

Table 7. *Ex-post* errors of forecasts obtained in all-index equations

Specification	DJIA-NASDAQ-DAX	DJIA-NASDAQ-FITSE
MAE	0.00918	0.00932
RMSE	0.01191	0.0123
THEIL	0.75361	0.7531
I_1^2	0.005	0.005
I_2^2	0.42	0.394
I_3^2	0.579	0.606
TP1 (%)	21.26	19.69
TP2 (%)	51.04	50.21

As in the case of combined forecasts they are not of better quality than forecasts obtained from individual models separately.

5. CONCLUSIONS

In this paper we attempted to assess the influence of American and European stock markets on the Polish stock market. In our analysis we used the GARCH methodology which is popular to describe the financial phenomena of high frequency. We have found that the situation on American market had more influence on the Polish market than the situation on European markets in the analysed period during 1.01.1995 – 29.12.2003. We based these conclusions on the analysis of forecasting equations for WIG index and on the analysis of combined forecasting. Our results are consistent with those obtained by other authors for the Polish stock market (e.g. Fiszeder 2001 and 2003; Brzeszczyński and Kelm 2002).

We should notice, however, a few aspects which can affect conclusions drawn from this kind of research.

Firstly, it must be remembered that there is a strong co-dependence among the biggest stock markets so it is difficult to show the impact of one individual market on another one in a simple approach.

Secondly, it is very important to choose the proper indexes as determinants of market development. It is necessary, then, to test also the influence of other indexes and stock markets – including emerging markets – on the Polish market.

Thirdly, the Polish stock market may be treated by foreign investors as one of secondary importance, and consequently domestic investment funds may influence the variability of returns more than situation on foreign markets.

In the paper we have used only series of 250 one-period-ahead forecasts. In future research we will attempt to show how the parameters reflecting the influence of American stock market and other markets on the Polish market change over time.

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MODELOWANIE I PROGNOZOWANIE INDEKSU WIG

(Streszczenie)

W artykule podjęliśmy próbę oceny wpływu indeksów rynku amerykańskiego DJIA i NASDAQ oraz indeksów rynku europejskiego DAX i FTSE na indeks WIG z giełdy w Warszawie. Do modelowania tego wpływu wykorzystaliśmy metodologię GARCH. Stosując metodologię łączenia prognoz oraz metodologię oceny jakości progностycznej modeli ekonometrycznych, zaproponowane w pracy Fair i Shiller (1990), pokazaliśmy, że rynek NYSE ma względną przewagę nad rynkiem europejskim w wyjaśnieniu zmian indeksu WIG.