Price Discovery in Emerging Index spot and Futures Markets: Evidence from Poland*

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This Draft: January 2, 2009

Abstract

We analyze price discovery in terms of lead-lag relationships and volatility spillovers between WIG20 stock index and index futures markets at the Warsaw Stock Exchange. This market has several interesting attributes, such as being the largest futures market in post-communist countries and dominated by individual investors. Using a VECM-GARCH-DCC modelling approach, we find that futures price movements predict changes in the stock index. However, there is no evidence of volatility spillovers. Conditional correlation between both markets increases over time, driven by changes in the institutional setting. In sum, our findings highlight the role of the futures market as a vehicle of price discovery improving the efficiency of an emerging stock market.

JEL Classification:

Keywords: Futures Markets, Individual Investors, Volatility Spillovers, Price Discovery, Dynamic Conditional Correlation VECM

* The authors thank Judith Lischewski for useful comments and suggestions. Bohl gratefully acknowledges financial support from the Alexander von Humboldt Foundation.

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1 Introduction

Since the introduction of stock index futures trading, a lot of research has been devoted to the relationship between spot and derivative markets, especially in terms of price discovery and volatility transmission. The question whether index futures trading induces additional volatility or rather contributes to the efficiency of equity markets is of great interest for both practitioners and regulators. These issues are particularly relevant in the case of emerging stock markets, where experience with innovative financial products is scarce. Nevertheless, existing research has mainly focused on mature countries while largely neglecting emerging markets. This paper aims at filling this void by analyzing price discovery in the Polish WIG20 index futures market. This market is particularly interesting for several reasons. Not only is Poland one of the largest financial markets in post-communist transition economies. The WIG20 future traded on the Warsaw stock exchange is also by far the most popular index futures contract in these countries. Moreover, the Polish futures market offers a unique investor structure dominated by domestic private individuals. This is especially interesting given popular concerns about emerging market investor sophistication, the presumably speculative character of futures trading and its impact on financial market stability.

Our empirical investigation uses a Vector Error Correction Model with a Multivariate DCC-GARCH extension. This setup allows us to jointly analyze long and short-run interactions as well as volatility transmission and correlation between the two markets. Even though private emerging market investors supposedly have little experience in derivatives trading, we find that price discovery occurs primarily in the futures market. As in most mature markets where institutional investors dominate futures trading, futures price movements predict index changes. However, there is no evidence of volatility spillovers. Our empirical analysis shows that the conditional correlation between futures and underlying increases as the investor structure changes.

There is a long-standing debate over positive or negative effects of futures trading on equity markets. Empirical research has mainly focused on (1) the potential impact on cash market volatility (e.g. Antoniou and Holmes (1995); Gulen and Mayhew (2000)), and (2) informational efficiency, i.e. the role of futures markets in price discovery. As is usually
argued, informed agents will use the futures market to trade on private information. This is because, besides lower transaction costs and higher leverage, futures contracts allow to bet on index changes without having to go long or short in all constituents. Such reasoning is in line with evidence from vector error correction models, showing that changes in futures prices predict changes in the underlying stock index (e.g. Stoll and Whaley (1990); Koutmos and Tucker (1996)). In addition, Multivariate GARCH models often find significant volatility transmission between both markets. Such higher order linkages can be interpreted either as an additional indicator of the direction of information flows (Chan et al. (1991); Tse (1999); Kavussanos and Visvikis (2004)) or - more in line with popular belief - as a source of spot market volatility (Zhong et al., 2004).¹

Despite the relevance of these empirical issues, little is known about spot-future linkages in emerging stock markets. The only exception is a paper by Zhong et al. (2004) who study daily data from Mexican stock index and futures markets between 1999 and 2002. Using a VECM-EGARCH framework, the authors find that the futures market performs a price discovery function. Their results also convey that volatility in both markets is affected by spillovers and deviations from the cost-of-carry relationship.

The plan of the paper is as follows. Sections 2 and 3 present institutional details of the WIG20 index futures markets and our dataset, respectively. Our empirical approach is described in Section 4, while estimation results are discussed in Section 5. Section 6 summarizes our findings and concludes.

2 Institutional Details

The Warsaw Stock Exchange (WSE) dates back to 1817 when a first exchange was founded.² Warsaw grew to become the most important stock market in Poland by the end of the 1930s, when it closed due to the beginning of WWII. Only after the demise of communism in 1989, economic transition lead to a reopening of the exchange on April 16, 1991. Since then, the WSE has emerged as the largest stock market in all Central and Eastern European

¹Another strand of the literature uses Multivariate GARCH models to explore the term-structure of second moments for hedging-purposes (e.g. Kroner and Sultan (1993); Lien and Tse (1998); Lien and Yang (2006)).

²Information on trading volume, contract specifications, investor structure, etc. can be found in various issues of the WSE Fact Book (e.g. Warsaw Stock Exchange (2008)).
Countries (CEECs). As of 2007, total market capitalization of the Warsaw Stock Exchange has reached USD 212 billion, which is far more than other Eastern European markets like Budapest (USD 46 billion) and Ljubljana (USD 29 billion). In fact, its size rivals that of smaller Western European exchanges such as Vienna (236 billion USD) or Luxembourg (166 billion USD).\(^3\)

On January 16, 1998, about seven years after the reopening of the WSE, the first futures contract on the the blue-chip index WIG20 was introduced. This contract is not only the oldest in the Polish futures market, it is also the most popular by far accounting for 94% of total trading volume in all derivatives in 2007 (Warsaw Stock Exchange, 2008). With an open interest of 50,533 contracts and a notional value of USD 122,191 million, total index futures trading on the WSE in 2007 is comparable in volume to larger emerging markets such as MexDer (48,731 contracts; USD 285,010 million). At the same time, the Polish stock index futures market is considerably larger compared to other CEECs, as for instance Budapest (33,810 contracts; USD 5,758 million), or even some Western European exchanges such as Athens (25,485 contracts; USD 52,096 million) or Vienna (21,643 contracts; USD 21,561 million).\(^4\)

All index futures contracts considered in this study, as well as all constituents of the underlying indices, are traded in a continuous trading system with only two auctions at opening and closing. The delivery months for the WIG20 futures contract are March, June, September, and December.

[Insert Figure 1 about here]

As can be seen from Figure 1, there is an astonishing difference in investor structure between spot and futures stock markets on the Warsaw Stock Exchange. During the last 10 years, the spot turnover shares of domestic private, domestic institutional and foreign investors have been relatively equal. The futures market, however, is clearly dominated by domestic individual traders. While foreigners account for about one third of trading volume in the spot market, their activity in futures trading has been negligible as measured by

\(^3\)See World Federation of Exchanges (2007a).

a share in annual turnover of merely 2-10%. The trading volume generated by domestic institutional investors has also been relatively low. This is because a large fraction of them, such as pension and mutual funds, are not permitted to invest in derivatives. Domestic individuals, by contrast, have accounted for 56-85% of annual turnover since the inception of futures trading in 1998. However, recent years have seen a slight change in the investor structure in the Polish futures market. Since 2004/2005, the share of foreign and domestic institutional investors has gradually risen, leading to a harmonization of investor shares across cash and futures markets.

Summing up, various aspects warrant a close examination of informational linkages between spot and futures markets on the Warsaw Stock Exchange. First, little is known about the price discovery function of futures markets in emerging capital markets, let alone Eastern European transition economies. The WSE as the largest stock market in Eastern Europe provides an interesting opportunity to fill this void. Second, the particular investor structure in the Polish futures market makes such an investigation at the WSE even more interesting. Private investors in transition economies or emerging markets are often perceived as less sophisticated than investors in developed financial markets. Given the dominance of this group in futures trading, we will explore how their trading contributes to the incorporation of news into prices and may induce volatility in the spot market.

3 Data

Our dataset consists of daily close prices for the WIG20 index and daily settlement prices for the WIG20 futures contract. Both time series are taken from Thomson Financial Data.

The index futures contract of the most immediate maturity is generally the most heavily traded until the beginning of the delivery month when the market interest shifts over to the contract with the next most immediate maturity.

A continuous time series for the futures prices is created by considering data of the most immediate contract apart from the delivery month where the next most immediate contract is used instead. This eliminates abnormal price volatility that may occur during the delivery month. The WIG20 index and the corresponding futures price are expressed in natural logarithms by \( s_t = \log(S_t) \) and \( f_t = \log(F_t) \), respectively. Continuously com-
pounded daily returns are calculated as

\[ \Delta s_t = (s_t - s_{t-1}) \]  \hspace{1cm} (1a)  
\[ \Delta f_t = (f_t - f_{t-1}) \]  \hspace{1cm} (1b)

Table 1 presents descriptive statistics of prices and returns series for the WIG20 index and the corresponding futures time series. Panel A of Table 1 exhibits details regarding the distributional characteristics whereas Panel B concerns time dependency as well as dependence across the spot and the futures market.

The means, standard deviations as well as minimums and maximums of both prices and returns show clear similarity in the two markets. Excess kurtosis and the Jarque-Bera test statistics indicate that neither log futures nor log spot index returns are normally distributed.

The Ljung-Box statistic is applied to the returns and the squared returns. The Ljung-Box statistics for 5 and 20 lags are significant for returns and squared returns, suggesting the presence of linear and nonlinear intertemporal dependencies. Moreover, the nonlinear dependencies seem to be far more prevalent judging from the size of the test statistic. The Engle (1982) test of an autoregressive conditional heteroskedasticity (ARCH) effect clearly rejects the null of no ARCH effect in both index and index futures returns.

Finally, we also examine the stationarity of the time series data using the Augmented Dickey-Fuller (ADF), the Phillips-Perron (PP) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test. The results are reported in Panel A of Table 2. Not surprisingly, all individual index spot and futures prices are first difference stationary.
4 Model and Empirical Approach

Simple arbitrage arguments such as the cost-of-carry model imply that the logarithms of futures and spot prices are cointegrated with a common stochastic trend\(^5\)

\[
f_t = \alpha_0 + \alpha_1 s_t
\]  

(1)

Intuitively, market frictions will cause temporal deviations from this equilibrium relationship. An extant literature has used vector error correction models (VECM) to study lead-lag relationships between the prices of futures and their underlying (e.g. Wahab and Lashgari (1993); Pizzi et al. (1998)). More precisely, consider a bivariate error-correction model of the following form

\[
\Delta s_t = \beta_{s,0} + \gamma_s ec_{t-1} + \sum_{i=1}^p \beta_{ss,i} \Delta s_{t-i} + \sum_{i=1}^q \beta_{sf,i} \Delta f_{t-i} + \varepsilon_{s,t}
\]  

(2)

\[
\Delta f_t = \beta_{f,0} + \gamma_f ec_{t-1} + \sum_{i=1}^p \beta_{fs,i} \Delta s_{t-i} + \sum_{i=1}^q \beta_{ff,i} \Delta f_{t-i} + \varepsilon_{f,t}
\]  

(3)

where \( ec_t = f_t - \alpha_0 - \alpha_1 s_t \) is the cointegration residual. This framework accounts for different aspects of the short and long-term relationship between the two variables. So-called "speed of adjustment" coefficients \((\gamma_s, \gamma_f)\) measure the adjustment of both variable to deviations from their common trend. Moreover, the predictive power of one variable for the other is captured by coefficients \(\beta_{sf,i}\) and \(\beta_{fs,i}\). If price changes in one market predict changes in the other, we can conclude that price discovery occurs in the former. Finally, the coefficients measuring the reaction of spot and futures returns to their own lagged values \((\beta_{ss,i}, \beta_{ff,i})\) indicate the degree of mean-reverting behavior of both time-series.

Chan et al. (1991) first highlighted the role of spillover effects between conditional volatilities as an indicator of price discovery. Accounting for such potential linkages requires a Multivariate Generalized Autoregressive Heteroskedasticity (MV-GARCH) modelling framework. Define the variance-covariance matrix of spot and futures residuals con-

\(^5\)In what follows, we abstract from time-varying interest rates and dividends as well as the time to maturity of the respective futures contract.
ditional on the information set at point in time $t$ (denoted $I_t$) as

\[
\text{var}(\epsilon_{s,t}, \epsilon_{f,t}|I_{t-1}) \equiv H_t = \begin{bmatrix}
h_{ss,t} & h_{sf,t} \\
h_{sf,t} & h_{ff,t}
\end{bmatrix}
\] (4)

We assume that conditional variances follow an autoregressive processes of the following form

\[
h_{ss,t} = \omega_s + \delta_{s,1} h_{ss,t-1} + \delta_{s,2} \epsilon_{s,t-1}^2 + \delta_{s,3} \epsilon_{s,t-1} I_{s,t} + \delta_{s,f} \epsilon_{f,t-1}^2 + \delta_{s,ec} \epsilon_{t-1}^2
\] (5)

\[
h_{ff,t} = \omega_f + \delta_{f,1} h_{ff,t-1} + \delta_{f,2} \epsilon_{f,t-1}^2 + \delta_{f,3} \epsilon_{f,t-1} I_{f,t} + \delta_{f,s} \epsilon_{s,t-1}^2 + \delta_{f,ec} \epsilon_{t-1}^2
\] (6)

Notice that this specification accounts for various effects on conditional volatility. First, we allow for asymmetric reactions to positive and negative return innovations by including a multiplicative dummy term where the indicator variable $I_{i,t}$ takes on the value of 1 if $\epsilon_{i,t-1} < 0$. Second, cross-spillover effects between the two markets are captured by coefficients $\delta_{s,f}$ and $\delta_{f,s}$, respectively. Third, we are interested in whether deviations from the equilibrium relationship of futures and cash prices have an effect on the variance of either of the two series. Therefore, the error correction term is included in Equations 5 and 6.

Various approaches to modelling conditional covariances have been proposed in the literature.\(^6\) We follow Engle (2002) in allowing conditional correlation to vary over time. His Dynamic Conditional Correlation (DCC) model ensures the positive definiteness of $H_t$ under simple conditions on the parameters, while not restricting correlations to be time-invariant as in the Constant Conditional Correlation approach of Bollerslev (1990). Thus it provides us with a direct measure of time-varying correlation between futures and cash market. Let $\rho_{ij,t}$ denote the correlation coefficient between spot index and futures prices. The variance-covariance matrix of residuals can then be rewritten as

\[
H_t = \begin{bmatrix}
h_{ss,t} & \rho_{sf,t} \sqrt{h_{ss,t} h_{ff,t}} \\
\rho_{sf,t} \sqrt{h_{ss,t} h_{ff,t}} & h_{ff,t}
\end{bmatrix} = D_t R_t D_t^{-1}
\] (7)

\(^6\)See Bauwens et al. (2006) for a survey.
where \( D_t = \text{diag}(h_{11,t}^{1/2}, \ldots, h_{22,t}^{1/2}) \) is the diagonal matrix of conditional standard deviations. The matrix of conditional correlations \( (R_t) \) is given as:

\[
R_t = \text{diag}(q_{11,t}^{1/2}, \ldots, q_{22,t}^{1/2}) \ Q_t \ \text{diag}(q_{11,t}^{1/2}, \ldots, q_{22,t}^{1/2})
\]

In the DCC model of Engle (2002), the matrix \( Q_t \) depends on squared standardized residuals \( (u_{i,t} = \varepsilon_{i,t}/\sqrt{h_{ii,t}}) \), their unconditional variance-covariance matrix \( (\bar{Q}) \) and its own lagged value:

\[
Q_t = (1 - \kappa_1 - \kappa_2)\bar{Q} + \kappa_1 u_{t-1} u_{t-1}' + \kappa_2 Q_{t-1}
\]

with \( \kappa_1, \kappa_2 > 0 \) and \( \kappa_1 + \kappa_2 < 1. \)

5 Empirical Results

5.1 Price Discovery

We choose to limit the lag-length for past changes of futures and spot index in the VECM to one. Comparisons with higher order models based on Schwarz’s Bayesian Information Criterion suggest this parsimoneous specification. Tests for autocorrelation of standardized residuals confirm adequacy of our model. Our main estimation results are summarized in Table 3.

[Insert Table 3 about here]

As shown in Panel A of Table 3, past changes in the log index do not affect changes in log futures prices \( (\beta_fs) \). Conversely, futures price movements do predict spot prices, as evinced by a strongly significant estimate for \( \beta_sf \). This finding is common in the literature (e.g. Brooks et al. (2001); Lien and Yang (2006)). As is usually argued, futures adjust more immediately to new information because (1) index constituents are less frequently traded and (2) traders who possess information affecting the stock market as a whole find it less costly to trade in futures as opposed to buying/selling individual stocks. The coefficient

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7 The diagonal matrices in Equation 8 ensure that \( Q_t \) is a well-defined correlation matrix.

8 Note that in empirical applications, the \( \bar{Q} \) is replaced by its sample analogue.
on lagged spot index changes in the spot equation is significant at the one percent level and has a negative sign. We conclude that, in contrast to futures prices, the index exhibits mean reversion. The respective coefficient in the futures equation ($\beta_{ff}$) is also negative but not statistically different from zero at conventional levels of significance.

The point estimate measuring the speed of adjustment of futures prices to equilibrium errors ($\gamma_f$) is negative. Intuitively, if the futures price is higher than implied by the cointegration relationship ($ec_t > 0$), rational arbitrageurs will go short in the future. This will drive prices back to their equilibrium levels. As highlighted by Zhong et al. (2004), two opposing effects determine the sign of this coefficient in the spot equation ($\gamma_s$). Suppose the spot index is below its equilibrium value ($ec_t > 0$). This may induce arbitrageurs to buy the constituting stocks of the index, leading to a price increase. Equilibrium would be restored due to the arbitrage effect, implying a positive sign on the error correction term. However, unlike the futures contract, the index is not a traded asset itself but rather a weighted average of individual assets. In fact, some constituting stocks may depreciate even more due to short-term momentum. In this case, the index may deviate even further from equilibrium. Thus the momentum effect implies that the sign on the error correction term in the spot equation can be negative. Our estimation results show that the latter effects seem to dominate. The point estimate for $\gamma_s$ is significantly negative, which implies that momentum dominates the arbitrage effect or, conversely, arbitrageurs prefer the futures market when trading against deviations from long-run equilibrium.

Most importantly, we find $\gamma_f$ to be larger than $\gamma_s$ in absolute terms. Futures returns exhibit a stronger reaction to departures from long-run equilibrium than does the spot index. Thus the futures price seems to lead the spot value of the WIG20 index. This finding is in line with longstanding evidence of a future-lead and consistent with various arguments why informed traders may choose to trade in futures rather than index constituents.

As can be seen from significant point estimates of $\delta_{s,1}$ and $\delta_{f,1}$, there is volatility clustering in both spot index and future returns. Squared past return innovations also have a significant effect, which is stronger if the surprise in returns was negative. The coefficient measuring such asymmetries in spot (futures) volatility, $\delta_{s,3}$ ($\delta_{f,3}$), is statistically different from zero at the 1 percent (5 percent) level of significance. Such asymmetric reactions of the conditional variance of stock returns is usually interpreted as evidence for the leverage
effect of Black (1976). Note that these asymmetries are less significant for the futures contract. Koutmos and Tucker (1996) argue that there is no theoretical explanation as to why future volatility should rise in response to market declines.

Our empirical model also allows us to study the effect of squared spot (futures) innovations on the conditional futures (spot) variance. Even though there is strong evidence for a lead-lag relationship between WIG20 futures and the spot index, we do not find volatility spillover effects between the two markets. Neither of the two coefficients $\delta_{sf}$ and $\delta_{fs}$ in the variance equations is significant. This result is surprising since many other studies (Tse, 1999; Zhong et al., 2004; So and Tse, 2004) find interactions between the conditional volatilities of index values and index futures prices.

We also investigate the volatility effects of the cointegrating relationship. Our results indicate that the conditional variances of both variables tend to be higher, the more futures and spot prices deviate from their long-run equilibrium relationship. Moreover, cointegration residuals have a more significant and greater impact (in magnitude) on spot than on futures volatility. This finding is in line with empirical results reported by Zhong et al. (2004) for Mexico. Even though this result may imply that futures trading has an impact on the volatility of the underlying (via the cointegrating relationship), the effect is small in magnitude.

The introduction of the computerized trading system WARSET on November 17, 2000 has led to a remarkable increase in the volume of trading in WIG20 index futures. We investigate whether our empirical findings on price discovery and volatility transmission are affected by the lower level of liquidity before the start of WARSET. Results from additional estimations for a shorter 2000 - 2008 sample period (not shown) confirm our main conclusions on price discovery. If anything, the evidence for a future-lead appears even stronger. First, the error-correction coefficient in the spot equation is indistinguishable from zero at conventional levels of significance. Second, the marginal effect of lagged cash market returns on futures prices is even less significant.

5.2 Correlation and Changes in Institutional Regimes

As discussed in Section 4, we allow for dynamic conditional correlation between both markets within the modelling framework of Engle (2002). Panel C of Table 3 reports the
corresponding coefficients, which are different from zero at the five and one percent level of significance, respectively. We plot conditional correlations for our 10-year sample period in Figure 2. Visual inspection reveals that the correlation between futures prices and the underlying appears to gradually increase over time. Additional estimations of our VECM-GARCH-DCC model for mature stock market index futures such as the French CAC40 or the Dow Jones Industrial Average show that the overall level of conditional correlation for the WIG20 is relatively low, especially during earlier years.9

We are also interested in how changes in the institutional setup and the investor structure of the two markets have affected their comovement over time. There are three main regime shifts during the 1998 - 2008 sample period. As already mentioned, the introduction of WARSET has led to an increase in index futures trading volume. Moreover, as shown in Figure 1 and discussed in Section 2, the share of foreign and domestic institutional investors in futures trading has increased considerably since 2004 and 2005, respectively. The resulting investor structure, while still dominated by domestic individuals, has become more similar to both the stock market and more mature markets where institutional investors play a prominent role. In order to investigate the effect of these changes, we regress the conditional correlation coefficient for log futures and spot index changes on three corresponding dummies. Table 4 reports coefficient estimates. Evidently, the introduction of the computerized trading system as well as the subsequent changes in the investor structure have led to an increase in conditional correlation between futures and cash markets. Ten years after the introduction of WIG20 futures trading, both the investor structure and the level of conditional correlation with the underlying are now more similar to mature markets.

[Insert Figure 2 about here]

[Insert Table 4 about here]

9Estimation results for mature stock market index futures are available from the authors on request.
6 Conclusion

We study the cointegration relationship between the Polish blue-chip index WIG20 and its futures contract traded at the Warsaw stock exchange. Our empirical approach allows us to study three related questions, i.e. lead-lag relationships between futures and the spot index, volatility transmission and the term-structure of conditional correlation. In contrast to other studies (e.g. Tse (1999); Zhong et al. (2004)), we do not find evidence of volatility spillovers between the two markets. Deviations from equilibrium prices (cointegration residuals) have a significant but small effect on the volatility of the WIG20. At the same time, there is strong evidence that futures prices lead the spot market, which is consistent with various arguments why informed agents trade in the derivative rather than the underlying constituents.

Our empirical results highlight the role of the WIG20 futures market as a vehicle of price discovery. In fact, the information transmission function of the futures market does not seem to be impaired by the dominance of presumably unexperienced domestic individuals. This result is interesting given popular concerns about private investor sophistication, particularly in emerging markets.

In the light of this evidence, we conclude that introducing stock index futures trading does not seem to destabilize an emerging stock market such as Poland. Futures markets rather play an important role in the process of price discovery and thus contribute to market efficiency.
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Table 1: Descriptive Statistics of WIG20 Index and Futures Prices and Returns.

Panel A: Distribution

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Median</th>
<th>Maximum</th>
<th>Minimum</th>
<th>Std. Dev.</th>
<th>Skewness</th>
<th>Kurtosis</th>
<th>Jarque-Bera</th>
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</thead>
<tbody>
<tr>
<td>Index prices</td>
<td>1994.89</td>
<td>1747.80</td>
<td>3917.87</td>
<td>971.30</td>
<td>773.76</td>
<td>0.83</td>
<td>2.53</td>
<td>337.856***</td>
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<tr>
<td>Futures prices</td>
<td>1992.62</td>
<td>1749.00</td>
<td>3953.00</td>
<td>892.00</td>
<td>778.80</td>
<td>0.83</td>
<td>2.53</td>
<td>332.624***</td>
</tr>
<tr>
<td>Index returns</td>
<td>0.0093</td>
<td>0.0177</td>
<td>9.0006</td>
<td>-10.4491</td>
<td>1.8131</td>
<td>-0.22</td>
<td>5.71</td>
<td>849.369***</td>
</tr>
<tr>
<td>Futures returns</td>
<td>0.0102</td>
<td>0.0000</td>
<td>8.7298</td>
<td>-9.5089</td>
<td>1.8674</td>
<td>-0.03</td>
<td>5.48</td>
<td>692.492***</td>
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Panel B: Autocorrelations and cross-correlations

<table>
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<tr>
<th></th>
<th>Lag 1 - 5 autocorrelations</th>
<th>Q(5)</th>
<th>Q(20)</th>
<th>ARCH(20)</th>
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<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Index returns</td>
<td>0.008</td>
<td>0.042</td>
<td>-0.029</td>
<td>0.035</td>
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<tr>
<td>Squared index returns</td>
<td>0.172</td>
<td>0.173</td>
<td>0.256</td>
<td>0.238</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>48.248***</td>
</tr>
<tr>
<td>Future returns</td>
<td>0.003</td>
<td>0.036</td>
<td>0.002</td>
<td>0.018</td>
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<tr>
<td>Squared future returns</td>
<td>0.171</td>
<td>0.137</td>
<td>0.201</td>
<td>0.190</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>1243.700***</td>
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<tr>
<td>Lag 0 - 5 cross-correlations</td>
<td>Qz(5)</td>
<td>Qz(20)</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Returns</td>
<td>0.920</td>
<td>0.037</td>
<td>0.038</td>
<td>-0.017</td>
</tr>
<tr>
<td>Squared returns</td>
<td>0.850</td>
<td>0.166</td>
<td>0.139</td>
<td>0.218</td>
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</tbody>
</table>

Note: All prices are in natural logarithms and returns are their first differences in logs multiplied by 100. The Q(20) is the Ljung-Box Q test of serial correlation of up to 20 lags. The Qz(20) is the multivariate Ljung-Box Q test of serial correlation of up to 20 lags. The ARCH is the F-test of autoregressive conditional heteroskedasticity effect with 20 lags proposed by Engle(1982). The sample period is January 16, 1998 to October 31, 2008. *, **, *** denote statistical significance at the 10%, 5% and 1% level, respectively.
Table 2: Unit Root Tests and Cointegration Analysis of WIG20 Index and Futures Returns.

<table>
<thead>
<tr>
<th>Panel A: Unit root tests</th>
<th>ADF test</th>
<th>PP test</th>
<th>KPSS test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Intercept</td>
<td>Intercept and Trend</td>
<td>Intercept</td>
</tr>
<tr>
<td>Index prices</td>
<td>-1.389</td>
<td>-1.439</td>
<td>-1.389</td>
</tr>
<tr>
<td>Futures prices</td>
<td>-1.421</td>
<td>-1.503</td>
<td>-1.497</td>
</tr>
<tr>
<td>Index returns</td>
<td>None</td>
<td>Intercept</td>
<td>None</td>
</tr>
<tr>
<td>Futures returns</td>
<td>-51.565***</td>
<td>-51.561***</td>
<td>-51.584***</td>
</tr>
<tr>
<td></td>
<td>-51.844***</td>
<td>-51.840***</td>
<td>-51.943***</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Panel B: Cointegration analysis</th>
<th>Johansen cointegration tests</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Null hypothesis</td>
</tr>
<tr>
<td></td>
<td>None (r = 0)</td>
</tr>
<tr>
<td></td>
<td>At most one (r = 1)</td>
</tr>
<tr>
<td>Estimated cointegration vector</td>
<td></td>
</tr>
<tr>
<td>$f_t = \alpha_0 + \alpha_1 s_t + ec_t$</td>
<td>Restriction tests</td>
</tr>
<tr>
<td>$\alpha_0 = 0$</td>
<td>$\alpha_1 = 1$</td>
</tr>
<tr>
<td>0.0756*</td>
<td>-1.0097***</td>
</tr>
</tbody>
</table>

Note: All prices are in natural logarithms and returns are their first differences in logs multiplied by 100. The ADF test refers to the Augmented-Dickey-Fuller test, the PP test to the Phillips-Perron test, and the KPSS test to the Kwiatkowski-Phillips-Schmidt-Shin test. Lag length selection in all tests is based on Schwarz's Information Criterion (SBIC). We use a first-order vector autoregressive model for the Johansen (1991) cointegration test and restriction tests. Critical values (CV) of the Johansen cointegration tests come from Osterwald-Lenum (1992). The sample period is January 16, 1998 to October 31, 2008. *, **, *** denote statistical significance at the 10%, 5% and 1% level, respectively.
Table 3: Estimation Results for the DCC-Model of WIG20 Index and Index Futures, 1998-2008.

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Parameter Estimates</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Panel A: VECM</strong></td>
<td>$\Delta i_t = \beta_{i,0} + \gamma e_{t-1} + \sum_{i=1}^{p} \beta_{i,j} \Delta i_{t-i} + \sum_{j=1}^{q} \beta_{i,i} \Delta j_{t-i} + \epsilon_{i,t}$</td>
</tr>
<tr>
<td>$\Delta s_t$</td>
<td>0.316 $-$0.033 $-$0.157 0.190 (0.220) (0.049)** (0.001)** (0.000)**</td>
</tr>
<tr>
<td>$\Delta f_t$</td>
<td>0.444 $-$0.096 $-$0.020 0.025 (0.107) (0.000)** (0.662) (0.607)</td>
</tr>
<tr>
<td><strong>Panel B: Conditional Variance / Covariance</strong></td>
<td>$h_{i,t} = \omega_i + \delta_{i,1} \epsilon_{i,t-1} + \delta_{i,2} \epsilon_{i,t-1}^2 + \delta_{i,3} \epsilon_{i,t-1}^2 I_i + \delta_{i,j} \epsilon_{j,t-1}^2 \delta_{i,ec} \epsilon_{i,t-1}^2$</td>
</tr>
<tr>
<td>$h_{ss,t}$</td>
<td>0.005 0.897 0.045 0.041 0.012 0.005 (0.002)** (0.000)***** (0.000)***** (0.000)***** (0.195) (0.014)**</td>
</tr>
<tr>
<td>$h_{ff,t}$</td>
<td>0.004 0.913 0.051 0.021 0.011 0.002 (0.002)***** (0.000)***** (0.000)***** (0.040)** (0.312) (0.164)</td>
</tr>
<tr>
<td><strong>Panel C: Dynamic Conditional Correlation</strong></td>
<td>$Q_t = (1 - \kappa_1 - \kappa_2)Q + \kappa_1 \epsilon_{t-1} \epsilon'<em>{t-1} + \kappa_2 Q</em>{t-1}$</td>
</tr>
<tr>
<td>$Q_t$</td>
<td>0.024 0.974 (0.036)** (0.000)*****</td>
</tr>
</tbody>
</table>

Note: Intercepts in the mean ($\beta_{s,0}, \beta_{f,0}$) and conditional volatility equations ($\omega, \omega_f$) are multiplied by $10^4$. The sample period is January 16, 1998 - September 30, 2008. P-values are in parentheses.
Table 4: Dynamic Conditional Correlation and Changes in the Institutional Setting.

<table>
<thead>
<tr>
<th>$\zeta_0$</th>
<th>$\zeta_1$</th>
<th>$\zeta_2$</th>
<th>$\zeta_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.899</td>
<td>0.027</td>
<td>0.009</td>
<td>0.010</td>
</tr>
<tr>
<td>(0.000)***</td>
<td>(0.000)***</td>
<td>(0.000)***</td>
<td>(0.000)***</td>
</tr>
</tbody>
</table>

Note: The estimated regression is

$$\rho_{sf} = \zeta_0 + \zeta_1 D_1^t + \zeta_2 D_2^t + \zeta_3 D_3^t + e_t$$

where the dummy variables $D_1^t / D_2^t / D_3^t$ are zero until November 17, 2000 / January 2, 2004 / January 3, 2005, and take on a value of one afterwards. The sample period is January 16, 1998 - September 30, 2008. P-values are in parentheses.
Figure 1: Shares in Trading Turnover of Different Investor Groups for WSE Spot and Futures markets.

Note: The figure graphs annual percentage shares in trading turnover of different investor groups for trading in the WSE spot and futures markets, respectively. Source: Warsaw Stock Exchange (2008).
Figure 2: Conditional Correlation Between Futures and Spot Market.

Note: The figure shows conditional correlation coefficients estimated from the VECM-GARCH-DCC model described in Section 4. The sample period is January 16, 1998 - December 28, 2008.