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Summary of the doctoral dissertation  
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### **Modelling and analysis of linkages and transmission of shock phenomena in financial markets**

The main purpose of the dissertation was the analysis of linkages and shock phenomena transmission on financial markets in the years 2005 to 2018. Examined time bracket covered the period of global financial crisis, Eurozone crisis and China's stock market crisis. Contagion effect in international stock markets during the above-mentioned crises was the detailed subject of the analysis.

Steadily advancing process of globalization, integration and liberalization of financial markets as well as the technological and telecommunications development cause stronger and stronger links between global capital markets. Connections via financial markets start to play the significant role in crises and shock phenomena dissemination. On the one hand, markets integration creates new possibilities of investing and capital allocation but, on the other hand, also carry certain threats, such as increase in investment risk or substantial reduction of portfolio diversification possibilities. In the event that the change in the economy on a given market often has almost instantaneous reflection in significant rise or fall of assets quotations in markets not only in neighboring countries but also has influence on countries thousands of kilometers away from the market initiating crisis, then analysis of shock transmission phenomena and relationship between instruments quoted in different markets appears to be reasonable.

The events in the last thirty years have shown, that many times specific shock for a particular market can be spread to other markets throughout the world, also including markets significantly different in the size and structure compared to the market initiating shock. Negative shock transmission phenomenon also affects countries with no real trade and capital links with country initiating crisis. All the above facts demonstrate high significance of contagion effect analysis for global financial markets, which enable the recognition of shock transmission mechanisms between particular countries and the identification of countries most

susceptible to market turbulence in other countries. Such studies play important role not only for international investors seeking the best possibility for portfolio diversification, but also are crucial for financial supervisory institutions all over the world to take appropriate action in order to minimize the severity of contagion effect taking into account the situation in local markets as well as the global financial system.

The analysis of shock transmission phenomena, called the contagion effect, was the main subject of interest in the thesis. The term contagion effect was borrowed from medical language, because the speed, violence and range of contemporary crises appearing in different markets can be associated with spread of epidemic. In economics and financial sciences this term emerged in the 1990s in order to distinguish the classical crisis transmission in real economy from crisis transmission via financial markets. It should be emphasized, that crisis transmission via financial markets, called the contagion effect, takes place significantly quicker than crisis transmission in real economy. Moreover, the contagion effect is not exclusively result of financial linkages but often concerns markets with no significant connections of financial nature, because the spread of negative shocks on global markets takes place many times due to behaviour of international investors, which can be difficult to anticipate.

The main objectives of the dissertation include:

1. review of applied methods for analyzing linkages and shock transmission between markets, assessment of inference possibilities on the basis of reviewed methods,
2. systematizing definitions of contagion effect on financial markets appearing in the literature,
3. verification of appearance of contagion effect in international stock market,
4. comparison of influence and effects of subprime crisis in United States, which sparked the global financial crisis, with events on international stock markets during Eurozone crisis and China's stock market crisis in the years 2015 to 2016,
5. cognition of direction of mutual relations in financial markets.

Daily and weekly logarithmic rates of return estimated on the basis of stock market indices quotations from 26 countries from North, Middle and South America, Asia and Australia, Western, Middle and Eastern Europe were the subject of examination. Empirical analyses were conducted with application of diversified statistical and econometrical methods, and calculations were carried out in Excel and R programme.

Following research hypotheses were verified in the dissertation:

1. The strength of linkages between assets quoted on international stock markets increases during the crisis periods.
2. The increase in strength of linkages during the crisis periods between market initiating shock and remaining markets in greater degree concerns emerging markets.
3. During the crisis periods there is an increase in number of markets in which rates of return are characterized by leverage effect, that is higher volatility increase after negative return than after equal to the (absolute) value positive return.
4. Leverage effect in greater extent concerns assets returns quoted on developed markets.
5. Shifts of stock indices quotations in international financial markets are primarily determined by shifts of stock indices from developed markets.

The dissertation includes the introduction, four chapters (1 theoretical and 3 theoretical-empirical) and ending in the form of conclusions and summary.

In chapter one the basic notions connected with financial crisis and the most important crises in global economy in the 20th and 21st century were outlined. Furthermore, the review of definitions applied in economic literature was conducted and channels of crisis propagation were also described. In the last part of the chapter classification of methods applied in examination of links and contagion effect in financial market was outlined. Moreover, the review of selected studies devoted to contagion effect with particular reference to papers analyzing global financial crisis and Eurozone crisis was presented.

In the theoretical part of chapter two the fundamentals of vector autoregressive models, principles of Granger causality analysis, forecast error variance decomposition, impulse response function and spillover index introduced by Diebold and Yilmaz were described. Then the research material including daily closing quotations of 26 stock indices representing situation on financial markets from North, Middle and South America, Asia and Australia, Western, Middle and Eastern Europe from the period between January 3, 2005 to November 30, 2018 was presented. In the empirical part of the chapter linkages between stock indices during global financial crisis, Eurozone crisis and China's stock market crisis were examined with the use of Granger causality analysis, generalized forecast error variance decomposition and static spillover index. Based on data from the whole period (03.01.2005-30.11.2018) dynamic analysis of the links between particular stock indices were conducted. For this purpose Diebold and Yilmaz spillover index was estimated using rolling windows including 150 observation (for daily returns) and 100 observation (for weekly returns).

In the third chapter the principles of selected models using asset correlation for contagion analysis on financial markets were presented, according to methodology of Forbes

and Rigobon, Collins and Biekpe, Dungey et al. as well as Corsetti, Pericoli and Sbracia. In the empirical part of the chapter these models were utilized to contagion effect analysis during global financial crisis, Eurozone crisis and international stock market turbulence in the years 2015 to 2016 initiated by China's stock market crash.

In the theoretical part of the fourth chapter the basic principles of generalized autoregressive conditional heteroskedasticity model GARCH and its extensions as well as selected multivariate GARCH models were presented. In the empirical part the dynamic conditional correlation model was used to examine the connections between stock indices during examined crisis periods in international stock markets. Moreover, volatility asymmetric effects in financial markets were also analyzed.

Based on results of Diebold and Yilmaz spillover index for daily and weekly data the increase in spillover index was observed:

- in the year 2007, that is in the period of disclosure of HSBC and BNP Paribas problems,
- in the second half of 2008, which was accompanied by bankruptcy of Lehman Brothers in September 2008,
- in the second half of 2011, which was connected with surprising downgrade of U.S. rating, market uncertainty related to prolonged Eurozone crisis, which in turn led to events of Black Monday on August 8, 2011, that is sudden fall of quotations in international stock markets,
- in the second half of 2015 and at the beginning of 2016, which was related to crisis on stock market in China and decrease of indices quotations on global markets.

The results confirmed that during crisis periods the strength of linkages between assets quoted on international stock markets increases, which was the main research hypothesis verified in the dissertation.

According to results of Diebold and Yilmaz spillover index based on daily and weekly data net spillovers (describing the difference between spillovers initiated and spillovers received by particular index) in international stock markets were transferred to the greatest extent by indices CAC40, AEX, DAX, BEL20, FTSE100, S&P500 and FTSE MIB. Amongst them, there are indices belonging to Euronext group (that is Amsterdam, Parisian and Brussels Stock Exchange, excluding Lisbon Stock Exchange index, which represents the least developed market) and exclusively indices from developed markets.

Furthermore, results of dynamic spillover index based on weekly returns and describing linkages between WIG index and particular stock indices revealed that Polish stock index in the years 2005 to 2018 was receiver of spillovers transmitted primarily by CAC40, AEX, DAX, BEL20 i FTSE MIB and S&P500 stock index. In turn, WIG index was the

source of spillovers mainly for stock indices from Middle and Eastern Europe countries: BET (Romania), BUX (Hungary), ATH (Greece), RTSI (Russia) and Asian countries: SHC (China) and PSEI (Philippines). Results estimated on the basis of daily returns were similar to a great extent with the difference that in the group (ranking) of WIG spillovers receiver, indices from Asian markets: NKX (Japan) and S&P/ASX200 (Australia) were also highly ranked. In addition, according to results based on daily and weekly returns from the years 2005 to 2018 Polish stock market index WIG was included in the group of indices receiving spillovers.

Results based on correlation coefficient models pointed out that during global financial crisis, Eurozone crisis and China's stock market crisis contagion effect occurred in international stock markets. During the examined periods the most frequent infected indices were indices from developing markets: BET, BVP and WIG.

Analysis concerning occurrence of volatility asymmetric effects in international stock markets revealed during the global financial crisis and Eurozone crises the increase in number of markets, in which rates of return were characterized by leverage effect, that is higher volatility increase after negative return than after equal to the (absolute) value positive return. Such effect was not found during turbulence on financial markets in the years 2015 to 2016. However, for that period the inverted leverage effect was observed, that is higher volatility increase after positive return than after equal to the value negative return. It should be also noticed, that during each of analyzed periods there was an increase in number of markets, where asset volatility was characterized by asymmetric effects and such effects were related to greater extent to developed markets.

The analysis conducted in the dissertation pointed out that during global financial crisis, Eurozone crisis and China's stock market crisis the strength of linkages increased in international stock markets. Moreover, it was found that emerging markets indices responded most heavily to global turbulence.

Knowledge on linkages and contagion effect in financial market extended with the empirical study results may be useful for individual investor as well as international financial institutions for making optimal investment decisions and minimising severity of contagion effect during crisis events.