Integration of CEEC-3's financial markets: Evidence from both regional and international perspective

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杨　璐

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(CEEC-3 の金融市場の統合：地域および国際の視点からの実証分析)

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Doctor Dissertation

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Abstract

Financial market integration in Europe has evolved dramatically with the political, economic, and monetary developments in the European Union (EU). In 2004, 10 countries from Central and Eastern Europe and the Mediterranean region joined the EU, which was the largest ever enlargement of the EU and a historic step towards unifying the whole of Europe after several decades of division that resulted from the Cold War. In this paper, I want to focus on the financial integration, contagion effect and cause-effect relationship in the Eastern European. To do so, I choose Germany to represent the EU, since it is the largest economy in the eurozone and has the most liquid government securities market. Considering data availability, CEEC-3 countries (i.e., Poland, Czech Republic, and Hungary) are suitable representatives of new accession members because they have the longest available time series data that can match those of Germany.

Following the chapter 1, this paper is consistent of six chapters. In the second chapter, I try to investigate whether asymmetry is exist between the bond markets in CEEC-3 and Germany from 2000 to 2012. To do so, I employ the asymmetric dynamic conditional correlation model developed by Cappiello et al. (2006). Specifically, CEEC-3 comprise emerging transition economies that became European Union members in 2004, while Germany serves as a representative of the EU because it is the largest economy in the eurozone. Based on the presented analytical models, I make four important findings. First, I show that financial integration had already evolved before the EU accession in 2004 in Czech Republic, while the financial integration process continues in Poland but not in Hungary. Second, the bond markets in both Poland and Hungary decreased their dependence on that in Germany during the global financial crisis period. Third, financial contagion did not occur in the bond markets in CEEC-3 and Germany during the European sovereign debt crisis period. Finally, I can observe asymmetric effects on returns over time when markets fluctuate sharply.

Following the results in the second chapter, in the second chapter, I try to analyze the direction and the degree of this asymmetry. Therefore, I use copula models to investigate the structural dependence between CEEC-3 and German bond markets from 2000 to 2012. I evaluate the degree of financial integration and dependence structure changes in government securities markets following European monetary integration and, first, find that integration between CEEC-3 and Germany is greater for the long-term interest rate but decreased during the crisis period. Second, the dependence between the Czech Republic and Poland increased significantly since EU accession before the recent financial crises occurred. Finally, the structural dependence between CEEC-3 and German government securities markets is generally symmetric.

Since the above chapters only discussed the one-day dependence between the bond markets in CEEC-3 and Germany, I still do not know this kind of dependence at the different time

scales. To solve this problem, I employ the wavelet transform analysis to investigate interdependence among the bond markets in CEEC-3 and Germany at the different time scale. Firstly, I find that contagion occurred in these markets during the global financial crisis and the European debt crisis. Secondly, I show that the degree of bond market integration was relatively high before 2004 for both Poland and Hungary and very high for Czech Republic throughout the entire sample period. Finally, I find that the interest rate movements in both Poland and Czech Republic mirrored those in Germany for the entire sample period.

Finally, the above chapters only discussed the dependences of bond market between CEEC-3 and Germany. However, the dependences of financial markets among the CEEC-3 countries are still unknown. Therefore, I employ the DECO-MGARCH model (Engle and Kelly, 2012) to investigate the equicorrelation of financial markets in CEEC-3 countries with three or above variables. And I find that even though the degree integration of financial markets in CEEC-3 increase after 2004, the degree of integration with the world financial market is still low. Meanwhile, I demonstrate the benefit of diversifications among the different asset across countries. My results will provide lots of useful information for both policymakers and investors. Chapter 6 is the summarizations of my analysis.

Chapter 1

Developments of financial markets in CEEC-3 countries

In this thesis, I attempt to analyze the integration degree of financial markets between Eastern Europe and Central Europe. Specifically, I examine the integration of the government securities markets of three major accession countries, namely Poland, the Czech Republic, and Hungary (CEEC-3 hereafter), all emerging transition economies that became EU members in 2004 during the organization's largest-ever expansion. In addition, I choose Germany to represent the EU, since it is the largest economy in the Eurozone and has the most liquid government securities market. Considering data availability, CEEC-3 countries are suitable representatives of new accession members because they have the longest available time series data that can match those of Germany. Further, I divide securities returns into short- and long-term bond yields to examine specific issues related to the path of government securities integration from the pre-EU period to the EU period. The transformation of the economic structures of CEEC-3 countries may be more complex than that in other developed European countries because of the nature of their economies and their financial regulations. Therefore, the degree of integration is expected to differ for short- and long-term bond yield curves.

I examine short- and long-term bond yields for the following reasons. First, considering that short-term bond yields serve as an indicator of monetary policy, the coordination of monetary policies across countries would lead to a high degree of integration among short-term bond markets. Second, a gradual increase in integration levels during the process of monetary development in the EU is expected. Finally, short-term bond yields would expectedly be highly dependent on the synchronous business cycles in the EU. In our analysis, divergent economic conditions and financial regulations are also determining factors. In addition, long-term bond yields can be considered to be an indicator of future economic perspectives driven by investor preferences, risk attitudes, and expectations. The savings-investment balance also plays an important role in determining long-term bond yields and considerations of term structure (Greenspan, 2007). Therefore, divergent dependence patterns should be assumed between short- and long-term bond yields.

The financial market in Eastern European countries has experienced dramatic reform from a planned economy to a market economy since the 1990s, with private capital flows to the CEEC-3 increasing from $5.3 billion in 1990 to almost $8 billion in 1993. Inflows in 1995 are estimated to be $14 billion. With the ongoing privatization process, investors have more cash and confidence in investing in the domestic markets, which provides a good environment to establish financial intermediaries. During the 1990s, over 90% of all private capital flowing into the CEEC-3 was in the form of bonds. Since both public and private sectors can issue securities in the domestic or international market, investors must come from aboard due to the lack of capital in these countries. To develop the economy, financial markets must be built to provide external capital from aboard. Therefore, it is an important issue to analyze the development and integration of financial markets in these countries. And we illustrate the structure of financial system in Table1.1.

To understand the importance of financial development, the essentials of the Eastern European financial system will first be outlined, particularly the financial markets, which play an important role in diverting funding from sectors that have a surplus to those sectors that have a shortage of funds. Since most of the Eastern European countries are emerging economies that have experienced the process of transforming from planned economies to market economies, an efficient government securities market is essential for funding fiscal deficit and promoting economic development. This thesis focuses on the development and integration of the financial markets in CEEC-3 countries. The following will discuss the development of a financial market for these three countries.

Financial market integration must be considered as a dynamic process in which both macroeconomic and microeconomic sectors are essential to constructing an efficient market and establishing the credibility of the securities' issuers. The sound prerequisites for creating a highly integrated and efficient financial market include credible and stable issuers; sound fiscal and monetary policies; effective legal, tax, and regulatory infrastructure; smooth and secure settlement arrangement; and a liberalized financial system. Since CEEC-3 countries are transition economies, a stable and credible macroeconomic policy framework, reforming and liberalizing the financial sector, and ensuring the proper pace of liberalization will advance the European integration process.

To better understand the process of the liberalization of financial markets in CEEC-3, we illustrate the key events occurs since 1990s for each countries. And we summarize the key events that will affect the process of the liberalization of financial markets in Table 1.2.

In case of Czech Republic, we can see that the stock market reopened in 1993 combined with government securities market with Act No. 6/1993 Coll. on the Czech National Bank, which allow the Czech National Bank to keep a record of the securities maturing within one year and to operate a settlement system for these investment instruments. These activities are performed via the short-term bond system (SKD). Meanwhile, under Article 35 of Act No. 6/1993 Coll. on the Czech National Bank, the Czech National Bank declares the exchange rate of the Czech currency against foreign currencies in the form of central bank exchange rate fixing and in the form FX rates of other currencies, which is the start-up of foreign exchange market. In case of Hungary, we can see that the first stock and bond are traded in 1991 when Hungarian Stock Exchange reopened and it is the start-up of the liberalization of financial market. However, it takes 5 years to trade foreign exchange freely when the central bank reduces the regulations, which can also be considered to be the start-up of foreign exchange market. In case of Poland, similar to the Hungary, both bond market and stock market start in 1991 while the foreign exchange market start in1996 when Foreign Exchange Law established.

Since we have discussed the start-up of the financial market in CEEC-3 countries, in this paragraph, we will extend our topic to the development and liberalization of their financial market. In the following discussion, we will concentrate on three main parts. First, we give an overview of the banking system. Second, we discuss the legal and supervisory system. Finally, we give a description of the financial market. Since the financial markets in transition economies are relatively young, there is reasonable to believe that their market is far from efficiency beyond their specular development developments in the past two decades. Thus, an overview of banking system will provide more specific detail on the development of financial markets in CEEC-3. The most important step is recapitalization program launched from 1992 to 1996. And after 2000, all these countries own its modern banking system. Due to the recapitalization program, the bad debts from transformation disappear with a good healthy banking system.

Moreover, with the enlargement of bank sector, managers are provided with incentives for improving the performance of their bank. However, no one has noticed the increasing of risk in the banking sector until in 1997 the political and financial crisis occurred in Czech Republic. Since then, authorizes in CEEC-3 countries are more and more playing attentions on controlling the uncertain risk from banking sector. For example, Czech Republic turns to helps from foreign sector and active the Revitalization program in1999 to spur the sale of firms to foreign companies. Key priorities included accelerating legislative convergence with EU norms, restructuring enterprises, and privatizing banks and utilities. The failures of market in Czech Republic let the other countries realize the importance of controlling the risk in the banking sector. And in 1999, to obtain the US funds and avoid the political treat from Russia, CEEC-3 countries join the North Atlantic Treaty Organization (NATO). This action provides a official way to obtain the foreign finance and military protection from Russia. For example, the share of foreign ownership in the banking equity is over 50% in CEEC-3 countries in 2000, which provided numerous potential players for the financial markets. Therefore, the importance of central bank as creditor for the public sector was decreasing, especially for the government securities markets. Up to 2000, the private sectors have largest share in the financial markets in CEEC-3 countries.

Before 2004 when CEEC-3 joined EU, the countries in CEEC-3 must satisfy the requirements from EU. Therefore, the central banks in CEEC-3 passed variations Act to make the inflation under control and stabilize the financial market. Particularly, Narodowy Bank Polski changes exchange rate policy principles to a floating exchange rate on April 12, 2000 that is not subject to any restrictions. However, Czech Republic and Hungary keep their exchange rate system till they become EU members. Therefore, the foreign exchange market in Poland has attracted more investors since 2000 than other two countries. As we can see that the transaction volume is largest in the CEEC-3 countries in Table 1.5. Moreover, the new Act on foreign exchange implemented in 2002 in Poland allowed the flow of capital to countries within the foregoing areas will make it possible for residents to freely invest on capital markets of these countries. As a result of these changes, residents obtained the right to maintain accounts with foreign banks and to freely deposit funds on such accounts. This is a big step of liberalization of foreign exchange market since the trade in lending was also liberalized by abolishing the restrictions imposed on residents related to contracting and extending short-term loans.

To keep the development of economy and financial markets, the legal and supervision authorities must be established to maintain their financial system. However, supervisory authorities in CEEC-3 are different. For example, though the central banks in each country set rules and supervise the activity of financial market, in Poland, the Financial Supervision Authority (KNF) was formed on 19 September 2006 as a result of the legislation passed on 21 July 2006 on the supervisory of the financial markets. Based on this act, we could expect more independent central bank in Poland than that in other countries. Actually, the financial market in Poland recovered quickly from global financial crisis in 2008 with the high growth rate of economy. Moreover, the ability of implementing the independent policy from central bank encourages the investment on the government securities market in Poland, which in turn stimulates the growth of economy.

Finally, to interpret the integration progress in the European financial market, we consider the size of the financial market in the CEEC-3 countries. Tables 1.3, 1.4 and 1.5 summarize the development of each country's financial market during our sample periods. According to the tables, we can see that the size of the financial market in the CEEC-3 countries has increased dramatically since 2000. Even though the global financial crisis disrupted this trend temporally, the enlargement of financial markets in these countries is still in process. With the enlarged financial markets, the participants will make the markets more efficient. Further, an increase in foreign exchange reserves enhances the central banks' capability in both the Czech Republic and Poland to influence the foreign market. However, on the other side, foreign exchange reserves did not change much for Hungary. Considering the sharp increases in government debt, the fiscal crisis in Hungary is inevitable.

Further, since the two recent crises deeply influenced international financial markets, depression about the dangers of financial contagion and the prolonged depths of financial desperation spread quickly to some sectors of Europe's financial market. Understanding and assessing their effects on Eastern European financial markets has been recognized as an essential aspect of designing measures to analyze the integration and asset transmission channel. Since these two crises stem from two different sources, we treat these two crises separately. In this thesis, we consider the global financial crisis as the international shock and the European sovereign-debt crisis as the local shock to discuss the issues we want to solve.

Based on the above discussions, we can summarize the basic characteristics of developments of financial market in CEEC-3 countries. Though the financial markets in CEEC-3 still not well developed, the modern mechanisms of functioning market have already been set.

However, there are still several drawbacks needed to be fixed. First, the independent supervisory authorizes should be established for better supervision of financial market for both Czech Republic and Hungary. Second, to make financial market work efficient, the CEEC-3 countries need to provide a more integrated framework to deal with the foreign investors and private investors. Least but not last, the stock market should be developed for small enterprise since the debt market still do not finance the small enterprise.

Following the above discussions, I focus on the changes in correlation (Chapter 2), the changes in dependence structure (Chapter 3), and the changes in interdependence at different time scales before and after the EU accession (Chapter 4). In particular, in Chapter 2, I consider the linear correlation relationship in the government securities markets of CEEC-3 nd Germany by employing the Asymmetric Dynamic Conditional Correlation (ADCC)-GARCH model. Since the ADCC-GARCH model can provide us the dynamic conditional correlation series, I analyze the outside shocks to the correlation between CEEC-3 and Germany, using an AR model. Based on the presented analytical models, I report four important findings. First, I show that financial integration had already evolved before the EU accession in 2004 in the Czech Republic, and that while the financial integration process continues in Poland, it is not so in Hungary. Second, the bond markets in both Poland and Hungary reduced their dependence on Germany during the global financial crisis period. Third, the financial contagion did not occur in the bond markets in CEEC-3 and Germany during the European sovereign debt crisis period. Finally, we observe asymmetric effects on returns over time when markets fluctuate sharply.

In Chapter 3, instead of analyzing the linear correlation relationship, I focus on the dependence structure by including tail dependence. For simplicity, I consider tail dependence to be the correlation under extreme values. Therefore, I employ the copula functions to investigate the non-linear correlation relationship between CEEC-3 and Germany. I evaluate the degree of financial integration and dependence structure changes in government securities markets following European monetary integration. We find that (1) integration between CEEC-3 and Germany is greater for the long-term interest rate, but decreased during the crisis period; (2) the dependence between the Czech Republic and Poland increased significantly since the EU accession before the recent financial crises occurred; and (3) the structural dependence between CEEC-3 and German government securities markets is generally symmetric.

In Chapter 4, I investigate the non-linear correlation relationship between CEEC-3 and Germany at different time scales by employing wavelet coherence analysis. By investigating the interdependence structure, I analyze the dependence structure at the time scale. It is important to understand the interdependence structure since it can provide useful information for duration management. I find that (1) contagion occurred in these markets during the global financial crisis and the European debt crisis; (2) I show that the degree of bond market integration was relatively high before 2004 for both Poland and Hungary and very high for Czech Republic throughout the entire sample period; and (3) I find that the interest rate movements in both Poland and Czech Republic mirrored those in Germany for the entire sample period. Implications for investors and policymakers are also suggested.

In Chapter 5, instead of focusing on the dependence between CEEC-3 and Germany, I investigate the linear correlation relationships in financial markets, such as stock market, foreign exchange market, and stock market, among the CEEC-3 countries. In contrast to Chapter 2, I employ the evolution version of ADDC-GARCH model, the Dynamic Equicorrelation (DECO)-GARCH model, to examine the linear correlation among the CEEC-3 financial markets. I find that even though the degree of integration of financial markets in CEEC-3 increased after 2004, the degree of integration with the world financial market is still low. Meanwhile, I demonstrate the benefit of diversification among different assets across countries. Our results will provide useful information for both policymakers and investors. Chapter 6 concludes and provides some implications. Figure 1.1 illustrates the structure of this thesis.

Table1.1 Structure of financial system[1].

	Financial system	
Financial institutions	Legal structure	Financial market
Banks	**Legal acts**	**Debt**
Non-bank financial Institutions	**Internal regulations**	**Stock**
Undertaking for collective Investment	Customs	**Foreign exchange**
Insurance companies	**Regulatory and supervisory institutions**	Money
Brokerage houses	Payment systems	
Pension fund	Securities settlement systems	
	Financials market intermediaries	
	Other institutions and systems	

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[1] The bold one is the one that I mentioned in the thesis.

Table 1.2 Key events since 1990

	Czech Republic	Hungary	Poland
1990		State Privatization Agency	
1991		Reopen of Hungarian Stock Exchange	Reopen of Warsaw Stock Exchange The first issue of the Treasury bills
1992	voucher privatization system Recapitalization program		
1993	Reopen of Prague Stock Exchange Act No. 6/1993 Coll.	Recapitalization program	Reconstructing program
1995		Bokros Package	
1996	Managed floating	Pension reform Foreign exchange market start-up	
1997	Political and financial crises		
1998			Foreign Exchange Law
1999	Revitalization program NATO	NATO	NATO
2000			Floating exchange
2002			New Act on foreign exchange
2004	EU member	EU member	EU member
2006			Polish Financial Supervision Authority
2008	Global financial crisis	Global financial crisis	Global financial crisis
2011	EU sovereign-debt crisis	EU sovereign-debt crisis	EU sovereign-debt crisis
2012	European Stability Mechanism	"junk status" for bond European Stability Mechanism	Pension reform European Stability Mechanism

Source: IMF

Table 1.3 Financial market development in Czech Republic

Year	Government Debt (USD)	Stock (CZK)	Foreign Exchange Reserve (USD)
2000	21608.3	591.1	50621.2
2001	22374	411.7	51788.4
2002	26983.4	473.5	78111.2
2003	34892.8	536.1	99883.3
2004	45240.7	772.5	105625.7
2005	46542.2	1127.9	114643.4
2006	57309	1532.9	120317.4
2007	76192.7	1831.6	128507.4
2008	84231.8	1636.8	144794.1
2009	89244.5	982.7	146890.1
2010	94217.3	1146.6	148387.1
2011	94155.2	1266.1	148207.1
2012	102465.5	893.1	139542.9

Notes: We use government debt to represent the total value of the government securities market. The total value of the stock market is based on market value, and foreign exchange reserve is selected to denote the ability of the central bank to influence the foreign exchange market. All the figures are measured in millions.

Source: DataStream.

Table 1.4 Financial market development in Hungary

Year	Government Debt (USD)	Stock (HUF)	Foreign Exchange Reserve (USD)
2000	32571.5	9193.71	284.73
2001	37387	6877.7	279.03
2002	38559.3	8885.35	225.16
2003	46041.1	8112.2	207.92
2004	59785.1	10729.78	180.29
2005	71769.7	16481.05	213.58
2006	86681.3	25302.38	191.62
2007	103988.3	25842.87	172.61
2008	123454.3	23119.46	187.91
2009	137119.5	14358.08	188.07
2010	138343.2	21423.66	208.65
2011	133259.1	23614.21	240.68
2012	124837.4	17223.53	220.93

Notes: We use government debt to represent the total value of the government securities market. The total value of the stock market is based on market value, and foreign exchange reserve is selected to denote the ability of the central bank to influence the foreign exchange market. All the figures are measured in millions.

Source: DataStream.

Table 1.5 Financial market development in Poland

Year	Government Debt (USD)	Stock (PLN)	Foreign Exchange Reserve (USD)
2000	69463	19093.7	27214.5
2001	71970.5	14639	26747.2
2002	84875	14936.17	25504.1
2003	107274	14675.9	25310.3
2004	129943	23651.06	25321.3
2005	132869	26000.59	32805.2
2006	169765	44939.95	34250.4
2007	233343	60121.37	37141.1
2008	244751	47598.66	40637
2009	280187	29698.36	48386.8
2010	317132	39923.58	60947.4
2011	323289	48904.49	67161.5
2012	365744	39175.83	72870.8

Notes: We use government debt to represent the total size of the government securities market. The total value of the stock market is based on market value, and foreign exchange reserve is selected to denote the ability of the central bank to influence the foreign exchange market. All the figures are measured in millions.

Source: DataStream.

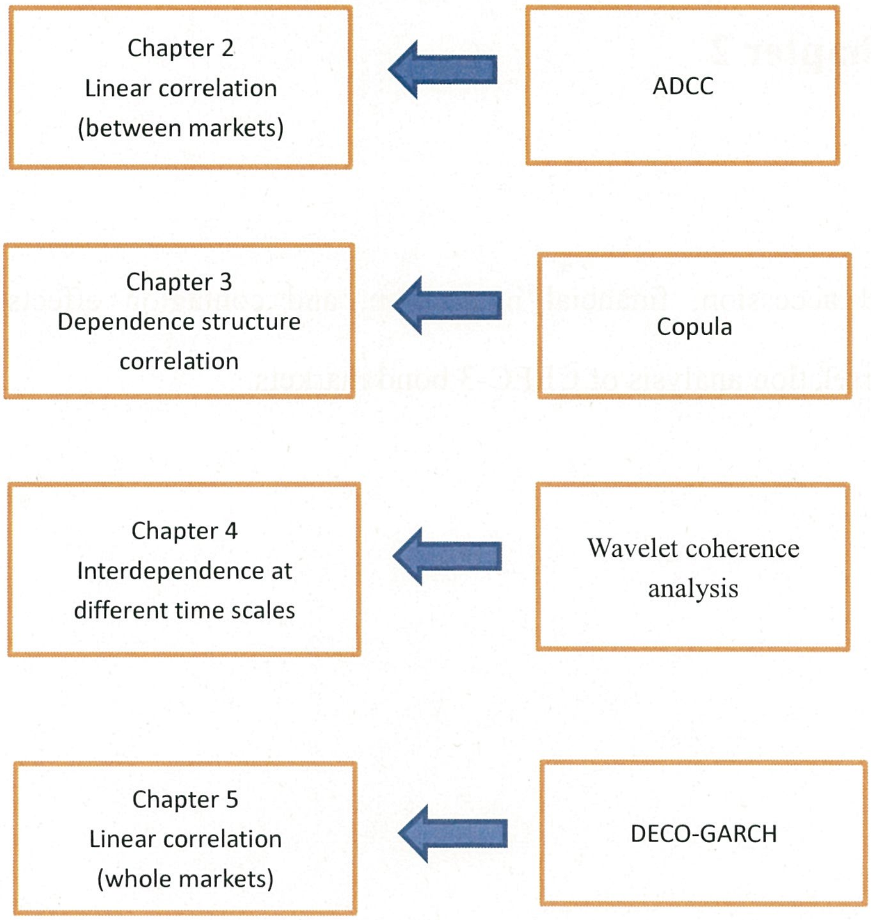

Figure 1.1 Structure of thesis.

Chapter 2

EU accession, financial integration, and contagion effects: Dynamic correlation analysis of CEEC-3 bond markets.

2.1 Introduction

Financial market integration in Europe has evolved dramatically with the political, economic, and monetary developments in the European Union (EU). In 2004, 10 countries from Central and Eastern Europe and the Mediterranean region joined the EU, which was the largest ever enlargement of the EU and a historic step towards unifying the whole of Europe after several decades of division that resulted from the Cold War.

This study examines the integration of government bond markets for three major accession countries, namely Poland, Czech Republic, and Hungary (CEEC-3 hereafter), which are all emerging transition economies and which became EU members in 2004. In addition, I choose Germany as a representative of the EU, since it is the largest economy in the eurozone and has the most liquid government bond market. Considering data availability, CEEC-3 are suitable representatives of new accession members because they have the longest available time series data that can match with those of Germany.

Financial market integration occurs when economies become more and more dependent on each other. Specifically, an increase in trade and FDI connects countries more closely both in the real economy and in financial markets. As the integration process proceeds, markets become vulnerable to outside macroeconomic news (i.e., shocks) because investors must consider the return and risk payoff both at the domestic level and at the regional level. Further, the correlations among these markets ascend sharply during periods of economic crisis as financial contagion occurs (Yiu et al. 2010).

Most previous studies apply a multivariate extension of Engle's (1982) ARCH model in order to investigate regional financial integration and contagion. For example, Galati and Tsatsaronis (2003) analyzed how the introduction of the euro influenced Europe's financial structure and provided evidence of convergence in EU bond markets. Barr and Priestley (2004) applied time-varying expected returns to evaluate international bond market integration based on an asset pricing model. Christiansen (2003) provided evidence that regional effects have come to dominate both domestic and global effects in European Monetary Union (EMU) bond markets following the introduction of the euro based on the AR-GARCH model of Bekaert et al. (2002). Finally, Kim et al. (2006) found evidence of strong contemporaneous and dynamic linkages between eurozone bond markets with that of Germany using Haldane and Hall's (1991) Kalman filtering method and bivariate EGARCH modeling perspectives (Nelson 1991).

However, few studies have examined the dynamic changes in financial integration between accession and established members in the EU. Although it is clear that market correlations increase through economic integration, especially monetary integration as in the case of the EU, the most recent research focuses on the dynamic correlations of asset returns. For example, Engle (2002) introduced a new class of dynamic conditional correlation (DCC) model that permits time-varying correlations and estimated such correlations based on a series of univariate GARCH models (Bollerslev 1987). Moreover, Cappiello et al. (2006) incorporated asymmetry into the GARCH model (i.e., the A-DCC model) in order to show that the conditional correlations of stock or bond returns are more significantly influenced by negative shocks than they are by positive shocks[2].

By extending the dynamic correlation analysis to the market level, I thus investigate the major economic events that influenced the CEEC-3 bond market during the 2000s. Specifically, I measure how and to what extent the conditional correlations between the bond markets in CEEC-3 and Germany were affected by the EMU, world shocks (using the global financial crisis as a proxy), and regional shocks (using the European sovereign debt crisis as a proxy)[3]. The existence of contagion among interdependent financial markets is a crucial issue when we diversify our portfolios, because such diversification becomes ineffective in the case of financial crises or other economic shocks. Moreover, whether the bond markets in CEEC-3 and Germany become more interdependent when these countries join the EU is another research question. Methodologically, in contrast to previous studies of the financial integration of European government bond markets, I also incorporate asymmetry into the DCC analysis of bond markets by adopting the AR-EGARCH model.

The remainder of this paper is organized as follows. Section 2 discusses the theoretical framework in order to examine regional market integration. Section 3 describes the data and statistical issues. Section 4 provides the empirical results and Section 5 concludes.

2.2 Econometric methods

This paper examines the asymmetric DCCs (Cappiello et al. 2006) between the bond markets in CEEC-3 and Germany across several key periods by adopting the following three-step approach. In the first step, I estimate the conditional variance of bond yields in each country based on an autoregressive (AR) model for the conditional mean and an EGARCH model. The AR (*k*)-EGARCH (*p*, *q*) specification is expressed as follows:

$$x_t = a_0 + \sum_{i=1}^{k} a_i x_{t-i} + \varepsilon_t,\ E_{t-1}(\varepsilon_t) = 0,\ E_{t-1}(\varepsilon t^2) = \sigma^2 \tag{2.1}$$

and

$$\ln(\sigma_t^2) = \omega + \sum_{i=1}^{p}(\alpha_i |\varepsilon_{t-1}/\sigma_{t-i}| + \gamma_i \varepsilon_{t-i}/\sigma_{t-i}) + \sum_{i=1}^{q} \beta_i \ln(\sigma_{t-i}^2) \tag{2.2}$$

where E_{t-1} is the conditional information operator based on the information at time *t*-1.

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[2] For the application of the A-DCC method, refer to, for example, Toyoshima et al. (2012) and Toyoshima and Hamori (2013).

[3] For the analysis of contagion effects, refer to, for example, Chiang et al. (2007), Yiu et al. (2010), and Syllignakis and Kouretas (2011).

Eq. (2.1), the AR(*k*) model, indicates that the current movement of a variable x_t can be explained by its own past movement $(x_{t-1}, x_{t-2}, \ldots)$. In this paper, the variable x_t is represented by bond yield. Eq. (2.2), the EGARCH (*p, q*) model, describes the asymmetry of markets, and the sign of past shocks (good news or bad news) has different effects on volatility is represented by including the term z_{t-i}. If $\gamma_t > 0$, $z_{t-i} = \varepsilon_{t-i} - \sigma_{t-i}$ is positive. The persistence of shocks to the conditional variance is given by $\sum_{i=1}^{q} \beta_i$.

Since the residuals ε_t express skewed and heavy tailed, I assume the density function of ε_t follow Student's t-distribution[4] given by:

$$f(t) = \frac{\Gamma\left(\dfrac{\nu+1}{2}\right)}{\sqrt{\nu\pi}\,\Gamma\left(\dfrac{\nu}{2}\right)} \left(1 + \frac{t^2}{\nu}\right)^{-\dfrac{\nu+1}{2}} \tag{2.3}$$

where ν is the number of degrees of freedom and Γ is the gamma function.

The maximum likelihood method was used to estimate each model. The Schwarz Bayesian information criterion (SBIC) was used to evaluate the AR terms by choosing smallest values of its. The Ljung-Box Q test was applied to examine the residuals of the AR term. According to the SBIC and residual diagnostics, the values of *k*, *p*, and *q* range from *k*=1, 2…, 5; *p*=1,2; and *q*=1,2, respectively.

In the second step, based the conditional volatilities from Eq. (2.2), we calculate the conditional correlations from the conditional covariance matrix:

$$H_t = E[\varepsilon_t \varepsilon_t'] = D_t R_t D_t \tag{2.4}$$

where the diagonal matrix D_t is the conditional volatilities from Eq. (2.2).

Third, the trend of the asymmetric generalized DCC (AG-DCC) model (Cappiello et al. 2006) can then be specified:

$$Q_t = (\overline{Q} - A'\overline{Q}A - B'\overline{Q}B - G'\overline{N}G) + A'z_{t-1}z_{t-1}'A + B'Q_{t-1}B + G'\eta_{t-1}\eta_{t-1}'G \tag{2.5}$$

where $\overline{Q}$ and $\overline{N}$ are the unconditional correlation matrices of z_t and η_t, $\eta_t = I[z_t < 0] \mathrm{o} z_t$ ($I(\cdot)$ is a $k \times 1$ indicator function that takes a value of 1 if the argument is true and 0 otherwise, while "o" indicates the Hadamard product), and $\overline{N} = E[\eta_t \eta_t']$.

In particular, A-DCC (1, 1) is a special case of the AG-DCC (1, 1) model if the matrices *A*, *B*, *C* are replaced by scalars (a_t, b_t, and g_t). According to the analysis from Cappiello et al. (2006), Q_t is positive definite with probability 1 if the term $(\overline{Q} - A'\overline{Q}A - B'\overline{Q}B - G'\overline{N}G)$ is positive definite. Therefore, Eq. (2.5) can be rewritten as:

$$q_{ij,t} = (\overline{q} - a^2\overline{q} - b^2\overline{q} - g^2\overline{n}) + a^2 z_{ij,t-1} + b^2 q_{ij,t-1} + g^2 \eta_{ij,t-1} \tag{2.6}$$

where the restriction condition is $a^2 + b^2 + \gamma g^2 < 1$, $\gamma =$ maximum eigenvalue $[\overline{q}^{-1/2}\overline{n}\ \overline{q}^{-1/2}]$. The Conditional correlation matrix R_t is derived as:

$$R_t = Q_t^{*-1} Q_t Q_t^{*-1} \tag{2.7}$$

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[4] The generalized error distribution does not provide robust results according to the properties of data nor does it generalize to a multivariate process.

where the diagonal matrix $Q_t^* = \sqrt{q_{ii,t}}$ contain the square roots of the diagonal elements of Q_t.

Finally, I consider the several key events that can affect the conditional correlation derived from the second step. Specifically, the dummy variables Di triggered by the EMU on May 1, 2004, the global financial crisis on August 7, 2007, and the European sovereign-debt crisis on November 5, 2010 are applied to test whether the events significantly altered the dynamics of the estimated conditional correlation of bond markets between the CCEC3 and Germany; that is:

$$D\hat{C}C_t = \delta_0 + \delta_1 D\hat{C}C_{t-1} + \delta_2 D_1 + \delta_3 D_2 + \delta_4 D_3 + v_t \tag{2.8}$$

where $D\hat{C}C_t$ is the conditional correlation estimated from Eq. (2.6) and v_t is the white noise.

2.3 **Data and descriptive statistic**

In this paper, I use 10-year government bond yields from the bond markets in CEEC-3 and Germany in order to analyze the conditional correlation changes among these markets based on a daily frequency from April 10, 2000 to January 1, 2013 (Fig. 2.1). The sample period is constrained by data availability and comparability between the sample countries. Instead of using returns from changes of yields, I apply the data of yields directly since the yields will converge among the countries in the long term when they are became monetary union according to the interest rate parity theorem. All data are from DataStream.

The first sample period runs from April 10, 2000 to May 1, 2004, namely before the EU accession in CEEC-3. The second period runs from May 1, 2004 to August 6, 2007, before the start of the global financial crisis. The third period runs from August 7, 2007, to November 4, 2009, before the European sovereign debt crisis. The final period runs from November 5, 2009 to January 1, 2013. Table 2.1 summarizes the statistical properties of the data, while Table 2.2 presents the unconditional correlation matrixes. The results of the Jarque–Bera (1987) test show that the null hypothesis of the normal distribution is rejected in all cases. The results of the Ljung–Box Q statistics also demonstrate the ARCH effects in the time series for all variables.

2.4 Empirical results

2.4.1 AR-EGARCH specifications

The first step is designed to estimate the univariate AR(k)-EGARCH(p, q) models for each series of bond yields. These transformations generate the conditional variance from the series. Unlike the other models, I incorporate asymmetry into our model.

Table 2.3 summarizes the estimation results for the AR(k)-EGARCH(p, q) model. As indicated in this table, the AR(3)-EGARCH(1, 1) specifications are suitable for all sample countries. Second, all coefficients of the GARCH term (β) that have values less than one are statistically significant at the 1% level. The coefficients of the asymmetric effect (γ) are also significant at the 1% level with positive values for Poland and Hungary; however, an asymmetric effect was not detected for Czech Republic and Germany. Finally, the t distribution is justified at the 1% significance level, suggesting that the tails of the error terms are heavier compared with the normal distribution and that ARCH effects exist.

Table 2.3 also presents the $Q(s)$ and $Q^2(s)$ statistics, which aim to justify the empirical results of the AR-EGARCH models. Its null hypothesis assumes that there is no autocorrelation up to lag s for standardized residuals. The $Q^2(s)$ statistic at lag s proposes a null hypothesis of no autocorrelation up to order s for standardized squared residuals. According to Table 1.3, the null hypothesis of no autocorrelation up to order 25 for standardized residuals and standardized squared residuals is accepted for all countries, supporting our model specifications.

2.4.2 A-DCC model

The second step is to estimate the A-DCC model based on the conditional variance from step one. Fig. 2.2 illustrates the DCCs between CEEC-3 and Germany, while Table 2.4 shows the results of the A-DCC model for the entire sample period. The estimates of the parameter of standardized residuals (a) and innovation in the DCC matrix (b) are both statistically significant at the 1% level for all sample countries. The parameters of the asymmetric term (g) for Poland and Czech Republic are also significant at the 1% level, but that for Hungary is not. Therefore, the conditional correlations of bond yields show asymmetry in the Poland and Czech Republic bond markets only. Specifically, a negative shock increases the conditional correlation of bond yields between Czech Republic and Germany but decreases that between Poland and Germany.

Table 2.5 summarizes the estimation results of the A-DCC model for the subsample periods. In the case of Poland, the parameter of the asymmetric term (g) becomes statistically significant at conventional levels after the EU accession. However, a significant result for the asymmetric term is not detected for Czech Republic after the same event. Fig. 2.2 also illustrates that the conditional correlation between Czech Republic and Germany stabilized after 2002 when the EMU agreement was signed, especially so after the EU accession. However, during the two crisis periods, even though the asymmetric term (g) was statistically significant at conventional levels for Czech Republic and Poland, their values were positive, suggesting that financial contagion did not occur in these countries. Moreover, the asymmetric effects for Hungary were not detected for all subsample periods.

2.4.3 AR model for the estimated dynamic conditional correlation

The final step is to use the AR(1) models to describe the trend in estimated DCCs by taking account of the dummy variables. Table 2.6 presents the results of these estimations. Both the constant term (δ_0) and the AR term (δ_1) are shown to be significant at the 1% level for all sample countries. The dummy variable for the EMU (δ_2) is significant at the 5% level only for Poland, while that for the global financial crisis (δ_3) is significant at the 1% level with a negative value for both Poland and Hungary, but not for Czech Republic. The negative value for δ_3 indicates that the bond markets in both Poland and Hungary decreased their dependence on that in Germany. Moreover, the European sovereign debt crisis (δ_4) had no impact on the conditional correlations. The results also indicate that financial contagion did not occur across EU bond markets during this crisis period.

2.5 Conclusion

In this paper, I investigated the conditional correlations between CEEC-3 and Germany by applying the A-DCC model developed by Cappiello et al. (2006) and the AR model developed by Yiu et al. (2010). Based on an examination of these correlations over three key events during the 2000s, I were able to make three principal findings. First, financial integration had already begun to evolve before the EU accession in 2004 in Czech Republic, while the financial integration process continues to advance in Poland but not in Hungary. Second, the bond markets in both Poland and Hungary decreased their dependence on that in Germany during the global financial crisis period. Finally, financial contagion did not occur across bond markets in CEEC-3 and Germany during the European sovereign debt crisis period.

By separating the whole sample into four subsamples, I then compared the asymmetric effect of volatility on the correlations by period. First, in Poland, which is the largest economy in CEEC-3, even though the asymmetric effect exists throughout the whole sample period, the real asymmetric effect was felt from the beginning of the EMU period to the beginning of the global financial crisis. Second, the bond market in Hungary had no asymmetry effect in the whole sample period or in any of the subsample periods. Finally, the asymmetric effect existed only in the calm period before joining the EU for Czech Republic. In summary, the presented evidence confirms the fact that I observe the asymmetric effect when bond markets are calm. Further explanations and rationalizations for these results is a challenging issue, however, and remains the subject of ongoing research.

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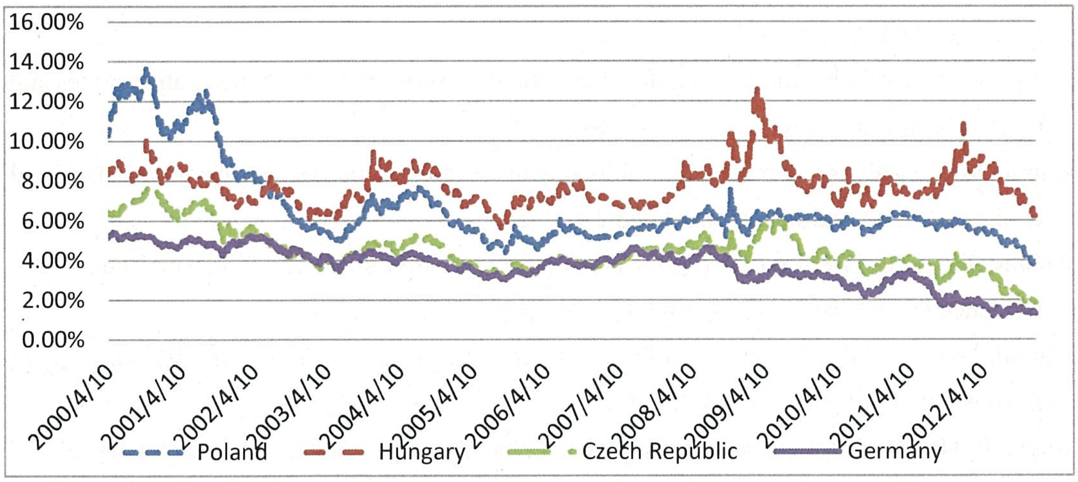

Fig.2.1 The 10-year bond yields for CEEC-3 and Germany.

Table 2.1

Descriptive statistics for bond yields.

	Poland	Hungary	Czech republic	Germany
Mean	6.666467	7.760990	4.486419	3.708543
Std. Dev.	2.083804	1.002061	1.115789	0.994435
Skewness	1.773093	1.147343	0.699980	−0.618510
Kurtosis	5.164789	5.445521	3.460922	2.872000
Jarque-Bera	2389.314**	1556.656**	300.6874**	214.0758**
Q(25)	81791.15**	70018.34**	80434.63**	81335.58**

Notes: *Q*(25) is the Ljung–Box *Q* statistic for the null hypothesis that there is no autocorrelation up to order 25 for the standardized residuals. * means statistical significance at the 5% level, while ** means statistical significance at the 1% level.

Table 2.2

Unconditional correlation matrix for bond yields.

	Poland	Hungary	Czech republic	Germany
Poland	1.000000	0.346595	0.897676	0.646973
Hungary.		1.000000	0.454656	−0.012496
Czech Republic			1.000000	0.768589
Germany				1.000000

Table 2.3

Empirical results of the AR(3)-EGARCH(1, 1) model.

	Poland	Hungary	Czech republic	Germany
Mean Equation				
θ_0	0.00181(0.00180)	0.02683(0.01055)*	−0.00114(0.00116)	0.00110(0.00280)
θ_1	0.96365(0.00032)**	1.03229(0.00641)**	1.01098(0.00028)**	1.08522(0.00495)**
θ_2	0.04686(0.00000)**	−0.06354(0.00201)**	0.01145 (0.01179)	−0.10483(0.00226)**
θ_3	−0.01107(0.00000)**	0.02741(0.00762)**	−0.02245(0.01198)**	0.01904 (0.00639)*
Variance Equation				
ω	−0.17002(0.03533)**	0.17998(0.02083)**	−1.01723(0.14419)**	−0.29406(0.04025)**
α	0.22478(0.02177)**	0.15593(0.01764)**	0.35502(0.04441)**	0.15509(0.01725)**
γ	0.28829(0.14382)**	0.05146(0.00840)**	0.03105 (0.02051)	−0.00699 (0.01302)
β	0.98544(0.00530)**	0.98775(0.00349)**	0.86411(0.02217)**	0.97311(0.00546)**
T DOF	2.00944(0.00334)**	6.10022(0.25107)**	2.99579(0.19995)**	10.7417(1.99470)**
Log likelihood	4763.17275	3524.97134	5664.750597	5977.87574
Diagnostic				
$Q(25)$	29.094 [0.14221]	29.287 [0.13684]	29.757 [0.12448]	22.098 [0.45403]
$Q^2(25)$	25.029 [0.17352]	27.077 [0.20831]	0.363 [1.00000]	23.237 [0.38846]

Notes: The numbers in parentheses are standard errors. The numbers in square brackets are p-values. $Q(25)$ ($Q^2(25)$) is the Ljung–Box Q statistic for the null hypothesis that there is no autocorrelation up to order 25 for standardized residuals (standardized squared residuals). * and ** represent significance at the 5% and 1% levels.

Table 2.4

Empirical results of the asymmetric conditional correlation estimates (whole sample analysis)

	Poland	Hungary	Czech Republic
a	0.33131 (0.05399)	0.15052 (0.02842)	0.18152 (0.01542)
b	0.87659 (0.03936)	0.96199 (0.01932)	0.97838 (0.00482)
g	0.33186 (0.10076)	−0.00002 (0.00006)*	−0.12915 (0.04394)
Log likelihood	8379.04660	9016.17607	11189.69572

Notes: The numbers given in parentheses are standard errors.* means statistical insignificance at the 5% level. The restriction condition is $a^2 + b^2 + \gamma g^2 < 1$.

Table 2.5

Empirical results of the asymmetric conditional correlation estimates (subsample analysis)

	Poland	Hungary	Czech Republic
April 10, 2000 to April 30, 2004			
a	0.24957 (0.02273)	0.05138 (0.0127)	0.08554 (0.00000)
b	0.92295 (0.01377)	0.99872 (0.0008)	0.96534 (0.00000)
g	−0.00003 (0.00014)*	−0.00004 (0.00041)*	−0.00003 (0.00000)
Log likelihood	2787.23077	2189.37348	3514.45244
May 3, 2004 to August 6, 2007			
a	0.21637 (0.00000)	0.35257 (0.10887)	0.23803 (0.06744)
b	0.97273 (0.00000)	0.89156 (0.23787)	0.80136 (0.12358)
g	−0.00128 (0.00000)	−0.00000 (0.00005)*	−0.00001 (0.00012)*
Log likelihood	874.19688	2767.42648	3672.02687
August 7, 2007 to November 4, 2010			
a	0.54581 (0.00002)	0.28641 (0.03376)	0.35461 (0.00000)
b	0.83049 (0.00001)	0.95986 (0.01081)	0.92559 (0.00089)
g	0.17627 (0.00000)	−0.00002 (0.13641)*	0.25301 (0.00049)
Log likelihood	583.38167	1830.42957	1309.35007
November 5, 2010 to January 1, 2013			
a	0.61897 (0.00000)	0.24929 (0.05278)	0.43240 (0.00095)
b	0.77105 (0.00001)	0.89046 (0.04995)	0.87863 (0.00035)
g	0.24917 (0.00000)	−0.00001 (0.00009)*	0.21652 (0.00000)
Log likelihood	−787.57596	1898.37832	−496.52574

Notes: The numbers given in parentheses are standard errors.* means statistical insignificance at the 5% level. The restriction condition is $a^2 + b^2 + \gamma g^2 < 1$

Table 2.6

Regression of the correlation evolution between CEEC-3 and Germany

	Poland	Hungary	Czech Republic
δ_0	0.01784 (0.00372)**	−0.00177 (0.00067)**	0.00686 (0.00159)**
δ_1	0.84766 (0.00922)**	0.94402 (0.00593)**	0.99102 (0.00344)**
δ_2	0.01000 (0.00432) *	−0.00035 (0.00097)	0.00267 (0.00168)
δ_3	−0.02333 (0.00641)**	−0.00424 (0.00121)**	−0.00305 (0.00191)
δ_4	−0.00017 (0.00628)	0.00066 (0.00113)	−0.00295 (0.00194)
Adj R^2	0.71890	0.91093	0.97392

Notes: The numbers given in parentheses are standard errors.* means statistical significance at the 5% level. ** means statistical significance at the 1% level.

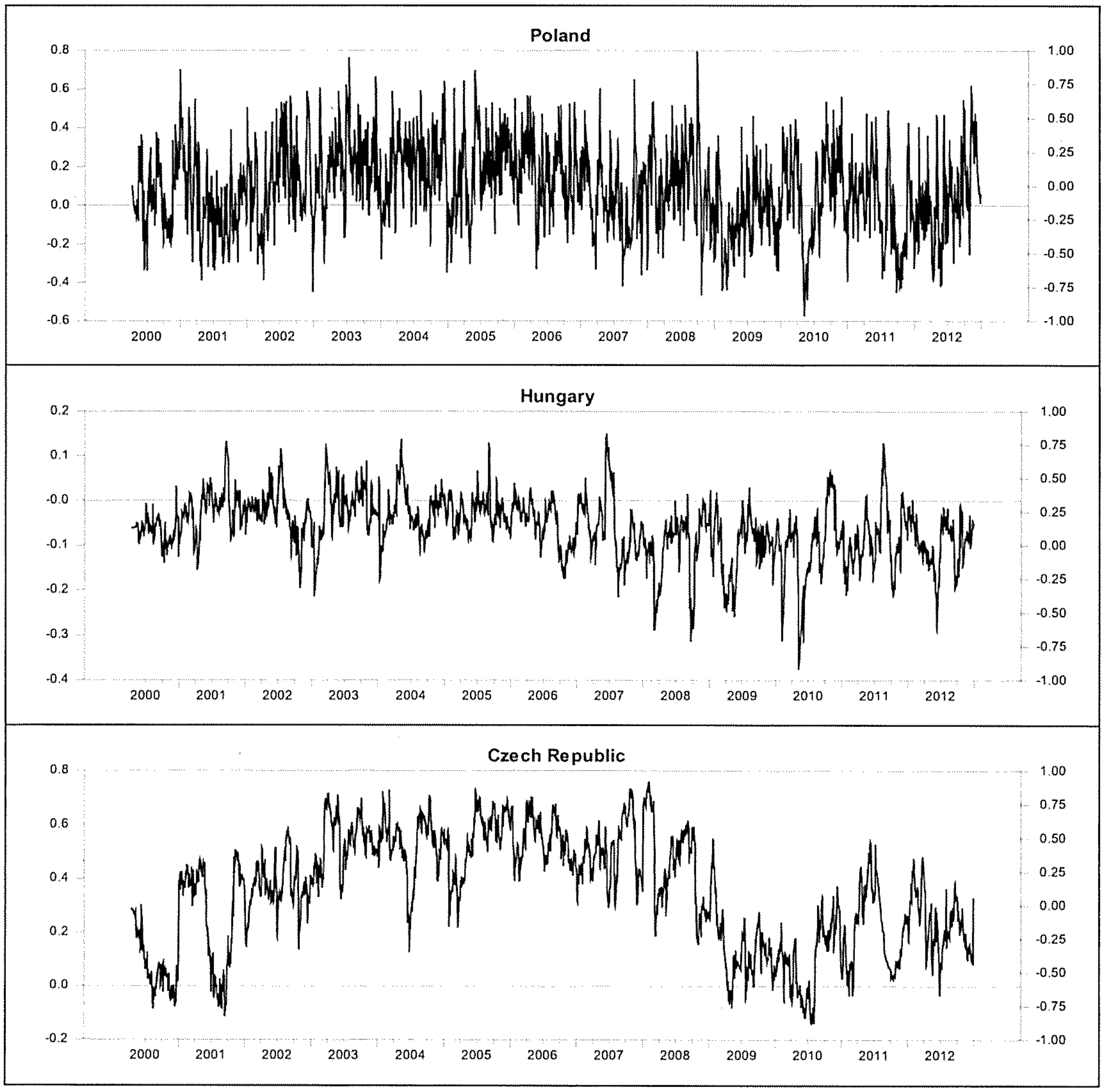

Fig.2.2. Conditional correlations of 10-year bond yields in CEEC-3 and Germany.

Chapter 3

Dependence structure between CEEC-3's and German government securities' markets

3.1 Introduction

In Europe, financial market integration, which occurs when economies become increasingly interdependent, has evolved noticeably through the political, economic, and monetary development driven by the European Union (EU).

This study examines the integration of the government securities markets of three major accession countries, namely Poland, the Czech Republic, and Hungary (CEEC-3 hereafter), all emerging transition economies that became EU members in 2004 during the organization's largest ever expansion. In addition, I choose Germany to represent the EU, since it is the largest economy in the eurozone and has the most liquid government securities market. Considering data availability, CEEC-3 countries are suitable representatives of new accession members because they have the longest available time series data that can match those of Germany.

In this paper, I divide securities returns into short- and long-term bond yields in order to examine specific issues related to the path of government securities integration from the pre-EU period to the EU period. The transformation of the economic structures of CEEC-3 countries may be more complex than that in other developed European countries because of the nature of their economies and their financial regulations. Therefore, the degree of integration is expected to differ for short- and long-term bond yield curves. Indeed, as shown in Figures 1 and 2 in the present paper, based on the sample period studied herein, short-term bond yields fluctuate more than long-term yields do. Moreover, both the mean and the volatility of bond yields decrease gradually after EU accession.

I examine short- and long-term bond yields for the following reasons. First, considering that short-term bond yields serve as an indicator of monetary policy, the coordination of monetary policies across countries would lead to a high degree of integration among short-term bond markets. Second, a gradual increase in integration levels during the process of monetary development in the EU is expected. Finally, short-term bond yields would expectedly be highly dependent on the synchronous business cycles in the EU. In our analysis, divergent economic conditions and financial regulations are also determining factors.

Further, long-term bond yields can be considered to be an indicator of future economic perspectives driven by investor preferences, risk attitudes, and expectations. As well as considerations of term structure, the savings–investment balance also plays an important role in determining long-term bond yields (Greenspan, 2007). Therefore, divergent dependence patterns should be assumed between short- and long-term bond yields.

This paper uses a copula model in order to examine the changes in the dependence structures of the government securities markets of CEEC-3 countries and Germany after EU accession. In addition, since the two recent economic crises (i.e., the global financial crisis and European sovereign-debt crisis) are included in our sample period of 2000 to 2012, I also consider dependence structure changes during the crisis period. Specifically, this paper addresses the following questions: (1) has CEEC-3's sovereign bond market integrated with the EU significantly since EU accession; (2) to what degree does the level of integration differ between short- and long-term yields; and (3) are the government securities markets of CEEC-3 and Germany asymmetrically interdependent?

The remainder of this paper is organized as follows. Section 2 provides an overview of the related literature. Section 3 discusses various copulas to verify dependence structures. Section 4 describes the data and reports on statistical issues. Section 5 provides the empirical results, and Section 6 concludes.

3.2 Literature review

The integration of government securities markets in the eurozone is attracting considerable research interest. Most previous studies apply a multivariate extension of Engle's (1982) ARCH model in order to investigate regional financial integration and contagion. For example, by analyzing how the development of the EU has influenced Europe's financial structure, Galati and Tsatsaronis (2003) demonstrate convergence in EU government securities markets. In the same vein, Barr and Priestley (2004), by applying time-varying expected returns, evaluate international bond market integration based on an asset-pricing model, while Christiansen (2007) uses Bekaert et al.'s (2002) AR-GARCH model in order to show that regional effects have dominated both domestic and global effects in European Monetary Union (EMU) bond markets following the introduction of the euro. Finally, Kim et al. (2006) find evidence of strong contemporaneous and dynamic linkages between eurozone and German bond markets by using Haldane and Hall's (1991) Kalman filtering method and bivariate EGARCH modeling perspectives (Nelson, 1991). Their broad conclusion is that EU bond markets have become increasingly integrated in recent years.

However, for several reasons, few studies have examined dependence structure changes in the financial integration between accession and established EU members. In particular, the ongoing structural changes in the EU economy, including its underlying economic and financial market conditions, make the process of integration complex to analyze. Although it is clear that market correlations increase through economic integration, especially monetary integration as in the case of the EU, correlation is only a linear measure of dependence and as such, it cannot capture non-linear changes. In contrast to previous studies, this paper therefore applies a copula-GARCH model in order to investigate the dependence structures of CEEC-3 and German government securities markets. Since copulas can describe non-linear dependence, I can explain the joint behavior of these markets. Moreover, copulas also present rich patterns of tail dependence, which allow us to examine dependence structure changes after EU accession.

Kumar and Okimoto (2011) use a set of rigorous smooth-transition copula-GARCH models[5] in order to demonstrate international integration in government securities markets.[6] Samitas and Tsakalos (2013) also examined the contagion effect from Greek's debt crisis on the other European Union (EU) member states' stock markets during the recent debt crisis based on both A-DCC and copula analysis. They found that the existence of a contagion effect during crash periods but not during the Greek debt crisis. However, these papers contributes to the body of knowledge on this topic by providing more copula functions and using Genest et al.'s (2009) goodness-of-fit (GOF) test to validate our empirical results and improve the reliability of the copula models estimated in this paper. Moreover, since the term structure of the yield curve may vary from country to country, I employ both short- and long-term yields in line with the approach taken by Kumar and Okimoto (2011), and consider both the global financial crisis and the EU sovereign-debt crisis to investigate their potential effects and obtain relatively accurate empirical results.

3.3 Empirical methodology

In this section, I first briefly describe the copula functions, and then, I introduce the margins of the return distributions based on our empirical model and the alternative copula models of the conditional dependence structure, and finally present the estimation procedure.

3.3.1 Copula functions

Copulas are being increasingly used to model multivariate distributions with continuous margins in many research fields, particularly, finance (McNeil et al., 2005; Chollete et al., 2011; Aloui et al., 2013). The recent rise in the popularity of this model in finance studies originates from the contribution of Sklar (1959). Indeed, Sklar's theorem remains very much the cornerstone of the theory of copulas. Without his contribution, the concept of copulas would comprise a rich set of joint distribution functions. Assume $X = (X_1, \dots, X_d)$ is a random vector with continuous marginal cumulative distribution functions (CDFs) $F_1, \dots, F_d$ and joint distribution H. Sklar (1959) showed that the joint distribution H of X can be represented as

$$H(X) = C(F_1(x_1), \dots, F_d(x_d)) \tag{3.1}$$

in terms of a unique function C: $[0, 1]^d \to [0, 1]$ called a copula.

Copula functions can conveniently construct a multivariate joint distribution by first specifying the marginal univariate distributions and then investigating the dependence structure between the variables according to different copula functions. In addition, tail dependence can be well described by copulas. Usually, two measurements are applied to

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[5] For the application of the copula-GARCH method, refer to, for example, Aloui et al. (2013), Bhatti and Nguyen (2012), and Yang and Hamori (2013b).

[6] For the recent analysis of the EU's financial market and dependence changes, refer to, for example, Duygun et al. (2013), Dimitriou and Kenourgios, Trapp and Wewel, and Yang and Hamori (2013a).

evaluate tail dependence, namely, the upper and lower tail dependence coefficients, which function well regardless of whether the markets are crashing or booming.

By assuming that *X* and *Y* are random variables with marginal distribution functions *F* and *G*, I can compute the coefficient of lower tail dependence λ_L according to

$$\lambda_L = \lim_{t \to 0+} Pr\left[Y \le G^{-1}(t) \,|X \le F^{-1}(t)\right] \tag{3.2}$$

which measures the probability of observing a lower *Y* if the condition of X is itself lower. On the contrary, the coefficient of upper tail dependence λ_U can be estimated by

$$\lambda_U = \lim_{t \to 1-} Pr\left[Y > G^{-1}(t) \,|X > F^{-1}(t)\right] \tag{3.3}$$

When the value of lower tail dependence is the same as the value of upper tail dependence, I state that there is "symmetric tail dependence" between the two variables. In other cases, dependence is asymmetric. This approach is thus an efficient way to order copulas. Moreover, if λ_U of C_2 is greater than λ_U of C_1, I state that copula C_2 is more concordant than copula C_1.

3.3.2 Marginal specifications

Interdependences in international stock markets can be examined by combining the copula functions above with a GARCH-type model (Engle, 1982; Bollerslev, 1987) of conditional heteroscedasticity, since this model not only successfully describes the characteristics of volatility clustering in stock returns, but also eliminates serial dependence from the component time series.

By incorporating asymmetry into the model, I estimate the conditional variance of stock returns in each country on the basis of an autoregressive (AR) model for the conditional mean and an GARCH model. The AR (*k*)-GARCH (*p*, *q*) specification is expressed as follows:

$$x_t = a_0 + \sum_{i=1}^{k} a_i x_{t-i} + \varepsilon_t,\ E_{t-1}(\varepsilon_t) = 0,\ E_{t-1}\left(\varepsilon_t^2\right) = \sigma^2 \tag{3.4}$$

and

$$h_{i,t} = \omega_i + \sum_{i=1}^{p} \alpha_i \varepsilon_{i,t-1}^2 + \sum_{i=1}^{q} \beta_i h_{i,t-1} \tag{3.5}$$

where E_{t-1} is the conditional information operator based on the information at time *t*-1. Eq. (3.1), the AR(*k*) model, indicates that the current movement of a variable x_t can be explained by its own past movement $(x_{t-1}, x_{t-2}, \ldots)$. In this paper, the variable x_t is represented by bond yields. The persistence of shocks to conditional variance is given by $\sum_{i=1}^{q} \beta_i$. In this study, I assume that the error term ε_t follows the Student's *t* distribution.

The maximum likelihood method was used to estimate each model, while the Schwarz Bayesian information criterion (SBIC) was used to evaluate AR terms by choosing their smallest values. The Ljung-Box Q test was then applied to examine the residuals of AR terms. According to the SBIC and residual diagnostics, the values of *k*, *p*, and *q* range from *k*=1, 2…, 6; *p*=1,2; and *q*=1,2, respectively.

3.3.3 Conditional dependence structure specifications

In this part, I consider both the symmetric and the asymmetric structure dependence structures between the variables since portfolio diversification depends on both dependence and marginal properties. For a given set of marginals above, I adopt the copula model in order to investigate the conditional dependence structure among stock markets. In this paper, I focus on two types of copulas: elliptical copulas (i.e., Normal and Student's-*t*), and Archimedean copulas (i.e., Gumbel, Frank, and Clayton).

For all *u*, *v* in [0, 1], the bivariate Normal copula is defined by

$$C(u,v) = \int_{-\infty}^{\phi^{-1}(u)} \int_{-\infty}^{\phi^{-1}(v)} \frac{1}{2\pi\sqrt{1-\theta^2}} exp\left(-\frac{s^2 - 2\theta st + t^2}{2\left(1-\theta^2\right)}\right) dsdt \qquad (3.6)$$

where ϕ represents the univariate standard normal distribution function and θ is the linear correlation coefficient restricted in the interval (-1,1).

The bivariate Student's-*t* copula is defined by

$$C(u,v) = \int_{-\infty}^{t_v^{-1}(u)} \int_{-\infty}^{t_v^{-1}(v)} \frac{1}{2\pi\sqrt{1-\theta^2}} exp\left(1 + \frac{s^2 - 2\theta st + t^2}{v\left(1-\theta^2\right)}\right)^{-(v+2)/2} dsdt \qquad (3.7)$$

where $t_v^{-1}(u)$ denotes the inverse of the CDF of the standard univariate Student's-*t* distribution with *v* degrees of freedom.

The Gumbel copula (1960) is an asymmetric copula with higher probability concentrated in the right tail. It can be expressed by

$$C(u,v) = exp\left\{-\left[(-\ln u)^{\theta} + (lnv)^{\theta}\right]^{1/\theta}\right\}, \theta \in (1, +\infty) \qquad (3.8)$$

The Frank copula (1979) is defined as

$$C(u,v) = -\frac{1}{\theta} ln\left(1 + \frac{(exp(-\theta u) - 1)(exp(-\theta v) - 1)}{exp(-\theta) - 1}\right), \theta \in (-\infty, +\infty) \qquad (3.9)$$

The Clayton copula (1978) is defined as

$$C(u,v) = \left(u^{-\theta} + v^{-\theta} - 1\right)^{-1/\theta}, \theta \in (0, +\infty) \qquad (3.10)$$

In the finance literature, elliptical copulas are most frequently applied because they have been shown to offer straightforward implications. The Normal and Student's-*t* copulas can be classified into this family because they are based on an elliptically contoured distribution. Gaussian copulas are symmetric and show no tail dependence, while Student's-*t* copulas can exhibit extreme dependence between variables.

Meanwhile, Archimedean copulas such as the Frank copula tend to be symmetric and able to provide the full range of dependence estimation for marginals exposed to weak tail dependence. However, the Gumbel and Clayton copulas are asymmetric and not derived from multivariate distributions. Therefore, they are typically used to capture asymmetry between lower and upper tail dependences. For example, Clayton copulas show greater dependence in the negative tail than in the positive, while Gumbel copulas exhibit the reverse properties.

Nevertheless, for both the Clayton and the Gumbel copulas, the greater the value of θ, the greater is the dependence between the variables (see Aloui, Aïssa and Nguyen, 2013).

3.3.4 Estimation method

In the second step, I estimate the parameters of the copulas on the basis of the quasi-maximum likelihood (QML) or pseudo-maximum likelihood (PML) method based on filtered returns. Following Aloui et al. (2013), I estimate the marginals F_x and G_y nonparametrically via their empirical CDFs (ECDFs) $\hat{F}_x$ and $\hat{G}_y$, which are defined as

$$\hat{F}_x = \frac{1}{n} \sum_{j=1}^{n} 1\{X_i < x\} \text{ and } \hat{G}_y = \frac{1}{n} \sum_{j=1}^{n} 1\{Y_i < y\} \quad (3.11)$$

In the implementation, $n/(n+1)$ is substituted for $\hat{F}_x$ and $\hat{G}_y$ into uniform variates using the ECDFs of each marginal distribution in order to ensure that the first-order condition of the log-likelihood function for the joint distribution is well defined for all finite n. X_i and Y_i are the standardized residuals estimated from step one. Then, I transform the observations into uniform variates using the ECDF of each marginal distribution and estimate the unknown parameter θ of the copula as

$$\widehat{\theta}_m = argmax \sum_{i=1}^{n} \ln c\left(\widehat{F}_x(x_i), \widehat{G}_y(y_i), \theta\right) \quad (3.12)$$

The idea of the PML or QML method is that a family of densities exists whose first-order conditions with respect to the mean parameters are the same. This assumption implies that even if the chosen density is wrong but it belongs to this family, the mean parameters are consistently estimated. Further details in this regard can be found in Wedderburn (1974).

3.4.Data

In this paper, I examine not only dependence structure changes in government securities markets after the CEEC-3 joined the EU in 2004 but also the effect of the two recent financial crises. Specifically, I use two-year government treasury yields as the short-term (mid-term) interest rate and 10-year government bond yields as the long-term interest rate (the only exception is the Hungarian short-term interest rate, which is proxied by the three-year interest rate since the two-year rate is unavailable). Daily data are derived from DataStream based on a sample period that runs from April 10, 2000, to December 31, 2012.All the data are plotted in Figures 3.1 and 3.2. Since the global financial crisis started on August 7, 2007 and European sovereign-debt crisis occurred on November 5, 2011, I treat the sample period from August 7, 2007 to December 31, 2012 as the crisis period. Because the sample period is constrained by issues of data availability and comparability between sample countries, I apply the yield data directly rather than using returns from changes in yields. According to the interest rate parity theorem, yields converge in the long-term among countries when they form a monetary union.

Tables 3.1 and 3.2 summarize the statistical properties of the data for both the pre-EU period and the EU period, while Table 3.3 presents the statistical properties of the data for the crisis period. The results of the Jarque–Bera (J-B) test show that the null hypothesis of the normal distribution is rejected in all cases, which indirectly supports the existence of ARCH effects. The results of the Ljung–Box Q statistics demonstrate the existence of serial correlation for each series.

3.5. Empirical results

The analysis of the estimation results in this section not only provides an overview of the correlations in government securities markets but also offers accurate estimations of the degree of tail dependence. In particular, changes in dependence during the EU period have a huge influence on the dependence structure in government securities markets, which is the major concern in this paper.

3.5.1 Marginal distribution

In the first step, I choose the most appropriate specifications for modeling conditional heteroscedasticity according to the usual information criteria, such as the AIC, SBIC, and logLik statistics, by employing univariate GARCH models (Verbeek, 2004). Tables 3.5–3.10 report our estimation results. As indicated in this table, all coefficients of the GARCH term (β) with values less than one are statistically significant at the 1% level. Moreover, the t distribution is justified at the 1% significance level, suggesting that the tails of the error terms are heavy compared with the normal distribution and that ARCH effects exist.

Tables 3.5–3.10 also show the $Q(s)$ and $Q^2(s)$ statistics to validate the empirical results of the AR-GARCH models. The $Q(s)$ statistic at lag s is a test statistic that follows an asymptotical distribution with degrees of freedom equal to the number of autocorrelations less the number of parameters. Its null hypothesis assumes that there is no autocorrelation up to lag s for standardized residuals. The $Q^2(s)$ statistic at lag s proposes a null hypothesis of no autocorrelation up to order s for standardized squared residuals. According to Tables IV–VII, the null hypothesis of no autocorrelation up to order 20 for standardized residuals and standardized squared residuals is accepted for all countries, supporting our model specifications. Overall, the results are acceptable and sufficient to describe the marginal behavior of short- and long-term government bond yields.

In the second step, I transform the standardized residuals obtained from the GARCH model into uniform variates based on the ECDFs. By applying this step, I obtain the vector of filtered yields to estimate the copula functions for government securities markets. Moreover, I check the rank correlation coefficients for international stock market dependence. Table 3.4 summarizes the Kendall's tau and Spearman's rho statistics between CEEC-3 and German government securities markets. Generally, the degree of correlation is higher for the long-term than it is the short-term interest rate before the crises. Moreover, the degree of correlation for the long-term interest rate increases after Poland and the Czech Republic joined the EU, but not for Hungary. However, the correlation for the short-term interest rate does not change appreciably. More importantly, the degree of correlation decreases for both the long-term and the short-term interest rate during the crisis period, indicating that CEEC-3 countries employ more independent economic policies during this period.

3.5.2 Copula estimations

By applying the vector of filtered yields, I incorporate five copula functions (normal, Student's *t*, Frank, Gumbel, and Clayton) to estimate the dependence parameters θ for the pre-EU and EU periods. The results are reported in Table 3.11. During the pre-EU period, the dependence parameters for the short-term interest rate are significant at the 10% level for most pairs, indicating that CEEC-3 and German treasury markets are highly interdependent, especially for the Czech Republic. Moreover, the dependence parameters show higher dependence for the long-term than they do for the short-term interest rate, as expected. These results imply that the monetary policies and business cycles of CEEC-3 countries and Germany can hardly be described as convergent. The pre-EU period also shows a potential benefit from diversification.

However, during the EU period, only the bond market in the Czech Republic shows strong dependence on the German government securities market. As shown in Table 3.11, the dependence parameters of the Czech Republic–Germany pair are significant at the 1% level. In contrast to the Czech Republic, Poland does not exhibit strong dependence on Germany for the short-term interest rate partly because Poland has an independent monetary policy. Moreover, Hungary shows little dependence on Germany for the long-term interest rate because of its large financial deficit. In summary, even though CEEC-3 government securities markets show unique properties in relation to Germany, I find that the dependence parameters increase significantly for the long-term interest rate in the Czech Republic and Poland after EU accession, indicating progress in EU bond market integration.

Further, the degree of dependence between these three countries and Germany decreases sharply during the crisis period. In particular, Hungary shows significant negative dependence on Germany for both the short-term and the long-term interest rates, indicating that its financial deficit deteriorates throughout the crisis period. However, while Poland also shows negative dependence on Germany for both sets of interest rates, the results are not significant, partly because of the quick recovery of the economy during the crisis period.

3.5.3 Goodness-of-fit test

To verify which copula offers the best results, I employ Genest et al.'s (2009) goodness-of-fit test, which compares the distance between the estimated and empirical copulas:

$$\mathbb{C}_{n_1} = \sqrt{n}\left(C_n - C_{\theta_n}\right) \qquad (3.13)$$

The test statistics are based on the Cramér–Von Mises distances, defined as

$$S_n = \int \mathbb{C}_n\left(u\right)^2 dC_n\left(u\right) \qquad (3.14)$$

The larger the values of the statistic S_n, the higher is the rejection probability of the null hypothesis that copula C belongs to class C_0. Kojadinovic and Yan (2011) propose a multiplier approach to find the p-values related to test statistics, which overcome the problem of dependence on the unknown parameter value θ when the limiting distribution of S_n is estimated. On the basis of the findings of Kojadinovic and Yan (2011), the highest p-values indicate that the distance between the estimated and empirical copulas is the lowest, which in turn suggests that the copula used best fits the data.

The goodness-of-fit test and tail dependence results are presented in Table 3.12. I see that the dependence structure between the government securities markets of CEEC-3 and Germany is the most symmetric because the normal copula and Frank copula, which show the highest p-values, fit best. For both the pre-EU period and the EU period, government securities markets show weak tail dependence between CEEC-3 and Germany, and only for the bond markets at that. For instance, the Czech Republic–Germany pair shows right-side dependence (Gumbel copula) in the pre-EU period, while the Hungary–Germany pair demonstrates left-side dependence (Clayton copula) in the EU period. These findings indicate that after EU accession, the long-term interest rates of the Czech Republic and Hungary were most likely to have been influenced by positive and negative news from Germany, respectively. In particular, the treasury markets of the Hungary–Germany pair do not fit the listed copulas well during the EU period. Overall, the bond markets of Hungary and Germany exhibit asymmetry in the EU period, indicating a saving-investment imbalance (Greenspan, 2007) between the two countries. This imbalance mainly occurs because the central bank of Hungary does not want to finance the huge financial deficit of the country's government.

Further, I examine the low level of weak left tail dependence (Clayton copula) between Poland and Germany in the treasury market during the crisis period. However, the dependence structure between CEEC-3 and Germany in the bond market seems to be symmetric. The presented results imply that the diversification benefits derived from the CEEC-3 government securities market decrease after EU accession and increase during the crisis period. However, CEEC-3 countries would still need a long time to integrate their economies into the eurozone (Kim et al., 2006).

3.6 Conclusion

In this paper, I investigate the structural dependence between the government securities markets of CEEC-3 and Germany with due consideration to EMU effects. By analyzing the pre-EU and EU periods based on the estimation of a copula model, I find that the dependence between CEEC-3 and Germany is greater in bond markets than it is in treasury markets, indicating that integration is greater for the long-term rather than the short-term interest rate. In particular, the degree of dependence increases significantly after EU accession for the long-term interest rate in the Czech Republic and Poland, indicating that the integration of the EU bond market is at an advanced stage (Kim et al., 2006). However, I also find that the degree of dependence of the bond markets between CEEC-3 and Germany decreases during the crisis period, which indicates that the bond markets in this area are only partially integrated (Abad et al., 2010).

By applying Genest et al.'s (2009) GOF test, I find that the structural dependence between the treasury markets of CEEC-3 and Germany as well as between the bond markets of Poland and Germany is symmetric in both the pre-EU and the EU periods. However, right-side dependence is observed only between the bond markets of the Czech Republic and Germany in the pre-EU period, while left-side dependence is witnessed only between the bond markets of Hungary and Germany in the EU period. Further, I also examine the low level of weak left tail dependence (Clayton copula) between Poland and Germany in the treasury market during the crisis period, however, the dependence structure between CEEC-3 and Germany in the bond market seems to be symmetric.

In summary, the status of CEEC-3 countries as emerging market economies in the EU has two important implications: (1) financial integration with the EU has reduced investors' diversification benefits (Kim et al., 2006; Lamedica and Reno, 2007) but these gains still existed during the crisis period and (2) monetary and fiscal policy coordination is still required to relieve the saving-investment imbalance between CEEC-3 countries and Germany, especially for Hungary.

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Table 3.1

Descriptive statistics of the pre-EU yield series (April 10, 2000 to April 30, 2004)

	Short-term				Long-term			
	PO	CZ	HU	GM	PO	CZ	HU	GM
Mean	10.49	4.198	8.986	3.571	8.662	5.431	7.720	4.643
Median	9.231	4.401	9.110	3.636	8.144	5.317	7.830	4.723
S.D.	4.808	1.457	1.257	0.971	2.627	1.163	0.823	0.463
Skew	0.384	0.076	−0.150	0.016	0.280	0.224	−0.032	−0.265
Kurtosis	1.579	1.396	2.755	1.669	1.612	1.729	2.160	1.934
J-B	115.3^{***}	114.6^{***}	6.627^{**}	78.20^{***}	98.90^{***}	80.10^{***}	31.31^{***}	62.59^{***}
$Q(10)$	10638^{***}	10602^{***}	9871^{***}	10518^{***}	10577^{***}	10543^{***}	9955^{***}	10219^{***}
Obs	1060	1060	1060	1060	1060	1060	1060	1060

Notes: PO, CZ, HU, and GM represent Poland, the Czech Republic, Hungary, and Germany, respectively. ** and *** indicate significance at the 5% and 1% levels, respectively. $Q(10)$ is the Ljung–Box Q statistic for the null hypothesis of no autocorrelation up to order 10 for standardized residuals.

Source: DataStream.

Table 3.2

Descriptive statistics of the EU period yield series (May 1, 2004 to August 6, 2007)

	Short term				Long term			
	PO	CZ	HU	GM	PO	CZ	HU	GM
Mean	5.303	2.849	7.916	3.051	5.616	3.989	7.244	3.794
Median	4.823	2.955	7.530	2.792	5.384	3.852	7.090	3.809
S.D.	1.108	0.467	1.267	0.711	0.788	0.534	0.711	0.382
Skew	1.136	−0.470	0.829	0.445	1.175	0.859	0.516	0.051
Kurtosis	2.862	2.365	2.949	1.867	3.381	2.708	3.097	2.290
J-B	183.7^{***}	45.70^{***}	97.61^{***}	73.61^{***}	201.2^{***}	107.8^{***}	38.09^{***}	18.22^{***}
$Q(10)$	8439^{***}	8145^{***}	8354^{***}	8495^{***}	8366^{***}	8360^{***}	8129^{***}	8262^{***}
Obs	851	851	851	851	851	851	851	851

Notes: **, and *** represent significance at the 5% and 1% levels, respectively. $Q(10)$ is the Ljung–Box Q statistic for the null hypothesis that there is no autocorrelation up to order 10 for standardized residuals.

Table 3.3

Descriptive statistics of the crisis period yield series (August 7, 2000 to December 31, 2012)

	Short-term				Long-term			
	PO	CZ	HU	GM	PO	CZ	HU	GM
Mean	5.127	2.355	8.091	1.569	5.802	4.078	8.105	2.956
Median	4.994	1.843	7.510	1.253	5.874	4.121	7.875	3.122
S.D.	0.718	1.206	1.666	1.366	0.504	0.867	1.127	0.9211
Skew	0.382	0.344	1.287	0.851	−1.505	−0.364	1.325	-0.197
Kurtosis	3.276	1.893	4.603	2.461	6.251	3.072	4.895	2.054
J-B	38.77^{***}	99.94^{***}	540.2^{***}	187.2^{***}	1153^{***}	31.55^{***}	623.4^{***}	61.56^{***}
$Q(10)$	15363^{***}	16782^{***}	12211^{***}	13814^{***}	14657^{***}	17763^{***}	12536^{***}	17245^{***}
Obs	1410	1410	1410	1410	1410	1410	1410	1410

Notes: PO, CZ, HU, and GM represent Poland, the Czech Republic, Hungary, and Germany, respectively. ** and *** indicate significance at the 5% and 1% levels, respectively. $Q(10)$ is the Ljung–Box Q statistic for the null hypothesis of no autocorrelation up to order 10 for standardized residuals.

Source: DataStream.

Table 3.4

Correlation estimates of government securities' markets dependence

	Short-term			Long-term		
	PO	CZ	HU	PO	CZ	HU
Spearman						
Pre-EU period	0.07677	0.16283	0.09071	0.12810	0.36707	0.09486
EU period	0.06484	0.24183	0.00128	0.25397	0.53485	0.02600
Crisis period	−0.01678	0.11212	−0.10855	−0.01129	0.07568	−0.07275
Kendall						
Pre-EU period	0.05123	0.11003	0.06088	0.08602	0.25383	0.06505
EU period	0.04258	0.16426	0.00038	0.17128	0.37837	0.01714
Crisis period	−0.03634	0.25608	−0.15531	−0.02435	0.17426	−0.10491

Notes: PO, CZ, HU, and GM represent Poland, the Czech Republic, Hungary, and Germany, respectively.

Table 3.5

Marginal specifications of short-term yield series for Pre-Euro period.

	PO	CZ	HU	GM
Mean Equation				
μ	−0.001 (0.005)	−0.005 (0.004)	0.005 (0.014)	−0.005 (0.005)
AR_1	0.924 (0.029)***	0.755 (0.031)***	1.037 (0.029)***	1.000 (0.001)***
AR_2	0.036 (0.040)	0.245 (0.031)***	−0.038 (0.029)	
AR_3	0.086 (0.041)**			
AR_4	−0.057 (0.039)			
AR_5	0.030 (0.038)			
AR_6	−0.019 (0.028)			
Variance Equation				
$\omega \times 10^{-4}$	0.174 (0.274)	3.641 (4.452)	138.9 (44.83)	2.134 (15.08)**
α_1	0.182 (0.049)***	0.311 (0.097)***	3.555 (11.52)	0.063 (0.025)**
α_2		−0.255 (0.103)**	−0.343 (1.452)	
β_1	0.877 (0.017)***	0.864 (0.157)***	0.616 (0.071)***	0.858 (0.056)***
T DOF	3.139 (0.436)***	3.393 (0.422)***	2.054 (0.181)***	4.793 (0.809)***
Diagnostic				
$Q(20)$	28.149 [0.106]	21.506 [0.368]	20.767 [0.411]	17.269 [0.635]
$Q^2(20)$	13.481 [0.856]	13.769 [0.842]	4.9935 [1.000]	21.607 [0.362]

Notes: The numbers in parentheses are standard errors. The numbers in square brackets are *p*-values. $Q(20)$ (Q^2 (20)) is the Ljung–Box Q statistic for the null hypothesis that there is no autocorrelation up to order 20 for standardized residuals (standardized squared residuals). *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

Table 3.6

Marginal specifications of short-term yield series for Euro period.

	PO	CZ	HU	GM
Mean Equation				
μ	0.012 (0.011)	−0.007 (0.009)	0.010 (0.013)	−0.001 (0.004)
AR_1	0.779 (0.032)***	0.742 (0.038)***	1.088 (0.032)***	1.001 (0.001)***
AR_2	0.217 (0.032)	0.231 (0.044)***	−0.090 (0.032)***	
AR_3		0.005 (0.042)		
AR_4		0.054 (0.037)		
AR_5		−0.031 (0.029)		
Variance Equation				
$\omega \times 10^{-4}$	1.577 (0.775)***	12.70 (3.331)***	4.262 (1.966)***	0.154 (0.110)
α_1	0.105 (0.031)***	0.372 (0.106)***	0.204 (0.073)***	0.017 (0.011)
β_1	0.888 (0.027)***	0.319 (0.115)***	0.806 (0.044)***	0.966 (0.019)***
T DOF	3.479 (0.550)***	3.699 (0.586)***	2.994 (0.445)***	10.34 (3.483)***
Diagnostic				
$Q(20)$	28.767 [0.109]	27.326 [0.126]	20.549 [0.424]	10.046 [0.967]
$Q^2(20)$	14.486 [0.805]	29.151 [0.185]	13.707 [0.845]	11.615 [0.929]

Notes: The numbers in parentheses are standard errors. The numbers in square brackets are p-values. $Q(20)$ (Q^2 (20)) is the Ljung–Box Q statistic for the null hypothesis that there is no autocorrelation up to order 20 for standardized residuals (standardized squared residuals). *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

Table 3.7

Marginal specifications of long-term yield series for Pre-Euro period.

	PO	CZ	HU	GM
Mean Equation				
μ	0.001 (0.007)	−0.008 (0.006)	0.019 (0.016)	0.003 (0.012)
AR_1	0.933 (0.029)***	1.001 (0.001)***	0.997 (0.002)***	0.999 (0.003)***
AR_2	0.077 (0.040)***			
AR_3	−0.044 (0.041)			
AR_4	0.077 (0.043)**			
AR_5	−0.043 (0.029)			
Variance Equation				
$\omega \times 10^{-4}$	1.062 (0.528)**	4.711 (1.453)***	30.26 (25.37)	0.265 (0.148)**
α_1	0.104 (0.027)***	0.286 (0.074)***	0.798 (0.679)	0.043 (0.014)***
β_1	0.903 (0.017)***	0.646 (0.061)***	0.612 (0.060)***	0.944 (0.017)***
T DOF	3.573 (0.501)***	3.432 (0.496)***	2.247 (0.243)***	7.479 (1.807)***
Diagnostic				
$Q(20)$	21.747 [0.354]	23.169 [0.281]	22.913 [0.293]	28.366 [0.101]
$Q^2(20)$	14.203 [0.820]	9.3147 [0.979]	6.8024 [0.997]	15.553 [0.744]

Notes: The numbers in parentheses are standard errors. The numbers in square brackets are p-values. $Q(20)$ (Q^2 (20)) is the Ljung–Box Q statistic for the null hypothesis that there is no autocorrelation up to order 20 for standardized residuals (standardized squared residuals). *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

Table 3.8

Marginal specifications of long-term yield series for Euro period.

	PO	CZ	HU	GM
Mean Equation				
μ	0.014 (0.012)	0.008 (0.008)	0.016 (0.019)	0.009 (0.009)
AR_1	0.997 (0.002)***	1.082 (0.000)***	1.065 (0.028)***	1.141 (0.036)***
AR_2		−0.056 (0.025)***	−0.152 (0.044)***	−0.142 (0.035)***
AR_3		−0.029 (0.025)	0.084 (0.029)***	
Variance Equation				
$\omega \times 10^{-4}$	0.028 (0.140)	0.002 (0.021)	0.175 (0.285)	0.137 (0.086)*
α_1	0.109 (0.028)***	−0.010 (0.005)**	0.053 (0.021)***	0.011 (0.009)
β_1	0.080 (0.078)	0.997 (0.005)***	0.947 (0.013)***	0.971 (0.014)***
β_2	0.820 (0.079)***			
T DOF	4.148 (0.755)***	4.075 (0.575)***	2.975 (0.398)***	28.560 (16.442)**
Diagnostic				
$Q(20)$	13.915 [0.835]	28.271 [0.103]	14.462 [0.806]	16.442 [0.732]
$Q^2(20)$	27.139 [0.131]	28.185 [0.105]	7.2509 [0.996]	18.957 [0.525]

Notes: The numbers in parentheses are standard errors. The numbers in square brackets are p-values. $Q(20)$ (Q^2 (20)) is the Ljung–Box Q statistic for the null hypothesis that there is no autocorrelation up to order 20 for standardized residuals (standardized squared residuals). *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

Table 3.9

Marginal specifications of the crisis period short-term yield series

	PO	CZ	HU	GM
Mean Equation				
μ	−0.007 (0.009)	−0.003 (0.003)	−0.004 (0.012)	−0.005 (0.012)
AR_1	0.880 (0.026)***	0.716 (0.024)***	1.000 (0.016)***	0.998 (0.001)***
AR_2	0.121 (0.026)***	0.284 (0.024)***		
Variance Equation				
$\omega \times 10^{-4}$	2.375 (0.664)***	0.105 (0.201)	33.36 (29.42)	0.044 (0.045)
α_1	0.197 (0.040)***	0.019 (0.005)***	0.192 (0.882)	0.050 (0.011)***
β_1	0.784 (0.033)***	0.963 (0.007)***	0.684 (0.042)	0.949 (0.009)***
T DOF	3.525 (0.371)***	2.412 (0.139)***	2.180 (0.174)***	5.474 (0.916)***
Diagnostic				
$Q(20)$	33.100 [0.335]	22.392 [0.320]	15.755 [0.732]	15.137 [0.769]
$Q^2(20)$	1.478 [1.000]	3.972 [1.000]	0.093 [1.000]	16.764 [0.668]

Notes: PO, CZ, HU, and GM represent Poland, the Czech Republic, Hungary, and Germany, respectively. The numbers in parentheses are standard errors. The numbers in square brackets are p-values. $Q(20)$ and Q^2 (20) are the Ljung–Box Q statistics for the null hypothesis of no autocorrelation up to order 20 for standardized residuals and standardized squared residuals, respectively. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Table 3.10

Marginal specifications of the crisis period long-term yield series

	PO	CZ	HU	GM
Mean Equation				
μ	−0.012 (0.012)	0.001 (0.005)	0.022 (0.018)	0.001 (0.004)
AR_1	1.002 (0.002)***	0.999 (0.001)***	0.997 (0.002)***	1.141 (0.026)***
AR_2		−0.056 (0.025)***		−0.142 (0.026)***
Variance Equation				
$\omega \times 10^{-4}$	2.768 (0.714)***	4.950 (0.021)	28.87 (42.77)	0.351 (0.165)**
α_1	0.225 (0.051)***	0.245 (0.064)***	0.071 (0.574)***	0.063 (0.013)***
β_1	0.728 (0.039)***	0.711 (0.044)***	0.790 (0.027)***	0.923 (0.016)***
T DOF	3.347 (0.324)***	2.893 (0.575)***	2.114 (0.180)***	21.103 (10.741)**
Diagnostic				
$Q(20)$	21.834 [0.350]	19.508 [0.489]	21.550 [0.365]	17.256 [0.636]
$Q^2(20)$	20.561 [0.196]	0.819 [1.000]	3.899 [1.000]	18.870 [0.530]

Notes: PO, CZ, HU, and GM represent Poland, the Czech Republic, Hungary, and Germany, respectively. The numbers in parentheses are standard errors. The numbers in square brackets are p-values. $Q(20)$ and Q^2 (20) are the Ljung–Box Q statistics for the null hypothesis of no autocorrelation up to order 20 for standardized residuals and standardized squared residuals, respectively. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Table 3.11

Estimates of the dependence parameters of different copula models.

	Normal	Student's *t*	Frank	Gumbel	Clayton
Short-term					
Pre-EU					
PO–GM	0.078 (0.031)**	0.078 (0.050)	0.459 (0.186)**	1.028 (0.020)***	0.070 (0.037)*
CZ–GM	0.153 (0.028)***	0.157 (0.048)***	0.977 (0.183)***	1.089 (0.021)***	0.175 (0.040)***
HU–GM	0.094 (0.029)***	0.094 (0.048)*	0.556 (0.181)***	1.053 (0.020)***	0.093 (0.038)**
EU					
PO–GM	0.069 (0.035)**	0.069 (0.058)	0.402 (0.210)**	1.011 (0.023)***	0.071 (0.044)*
CZ–GM	0.224 (0.029)***	0.234 (0.052)***	1.512 (0.210)***	1.150 (0.025)***	0.247 (0.043)***
HU–GM	−0.004 (0.038)	0.003 (0.056)	0.028 (0.207)	1.042 (2.145)	−0.014 (0.034)
Crisis					
PO–GM	0.001 (0.027)	0.001 (0.044)	−0.051 (0.158)	1.237 (0.152)***	0.033 (0.029)
CZ–GM	0.092 (0.032)***	0.092 (0.047)**	0.495 (0.158)***	1.057 (0.087)***	0.055 (0.032)*
HU–GM	-0.106(0.025)***	-0.107(0.041)***	-0.652(0.156)***	1.031 (0.132)***	-0.062(0.021)***
Long-term					
Pre-EU					
PO–GM	0.140 (0.030)***	0.140 (0.049)***	0.772 (0.187)***	1.076 (0.021)***	0.115 (0.041)***
CZ–GM	0.373 (0.022)***	0.022 (0.040)***	2.444 (0.190)***	1.302 (0.028)***	0.437 (0.045)***
HU–GM	0.089 (0.030)***	0.089 (0.053)*	0.581 (0.184)***	1.045 (0.020)***	0.068 (0.038)*
EU					
PO–GM	0.272 (0.031)***	0.272 (0.049)***	1.613 (0.212)***	1.176 (0.028)***	0.314 (0.048)***
CZ–GM	0.542 (0.019)***	0.552 (0.033)***	3.903 (0.246)***	1.531 (0.038)***	0.791 (0.049)***
HU–GM	0.041 (0.036)	0.041 (0.059)	0.151 (0.213)	1.013 (0.017)***	0.038 (0.040)
Crisis					
PO–GM	−0.034 (0.283)	−0.032 (0.284)	−0.202 (0.156)	1.082 (0.023)***	−0.007 (0.019)
CZ–GM	0.235 (0.125)*	0.243 (0.041)***	1.549 (0.160)***	1.163 (0.583)**	0.254 (0.035)***
HU–GM	−0.182(0.072)**	−0.178(0.052)***	−1.039(0.157)***	1.542 (0.174)***	-0.109(0.015)***

Notes: The numbers in parentheses are standard errors. *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

Table 3.12

Results for the goodness-of-fit tests and tail dependence coefficients of the best copulas

	Normal	Student's *t*	Frank	Gumbel	Clayton	λ_L	λ_U
Short-term							
Pre-EU							
PO–GM	0.845	0.056	**0.869**	4.995e-4	0.188	0.000	0.000
CZ–GM	0.203	0.047	**0.446**	0.005	0.023	0.000	0.000
HU–GM	**0.524**	0.288	0.458	4.995e-4	0.159	0.000	0.000
EU							
PO–GM	**0.454**	0.017	0.318	4.995e-4	0.349	0.000	0.000
CZ–GM	0.029	0.010	**0.317**	4.995e-4	4.995e-4	0.000	0.000
HU–GM	0.054	0.009	0.035	4.995e-4	**0.108**	–	–
Crisis							
PO–GM	0.662	0.088	0.689	4.995e-4	**0.698**	7.54e-10	0.000
CZ–GM	**0.037**	0.011	0.016	4.995e-4	0.007	0.000	0.000
HU–GM	**0.209**	0.149	0.007	4.995e-4	4.995e-4	0.000	0.000
Long-term							
Pre-EU							
PO–GM	**0.766**	0.043	0.555	0.644	0.010	0.000	0.000
CZ–GM	0.018	0.006	0.016	**0.059**	4.995e-4	0.000	0.297
HU–GM	0.020	0.002	**0.026**	4.995e-4	0.002	0.000	0.000
EU							
PO–GM	**0.757**	0.309	0.139	0.035	0.006	0.000	0.000
CZ–GM	**0.115**	0.090	0.001	0.002	4.995e-4	0.000	0.000
HU–GM	0.233	4.995e-4	0.178	4.995e-4	**0.397**	1.336e-8	0.000
Crisis							
PO–GM	**0.664**	0.236	0.560	4.995e-4	0.523	0.000	0.000
CZ–GM	0.026	0.010	**0.051**	0.011	4.995e-4	0.000	0.000
HU–GM	0.339	**0.385**	0.175	4.995e-4	4.995e-4	0.000	0.000

Notes: The table presents the *p*-values of the goodness-of-fit tests. Large *p*-values (bold face numbers) indicate that the copula provides the best fit to the data. λ_L and λ_U represent the lower and upper tail dependence coefficients estimated from the best-fitted copulas.

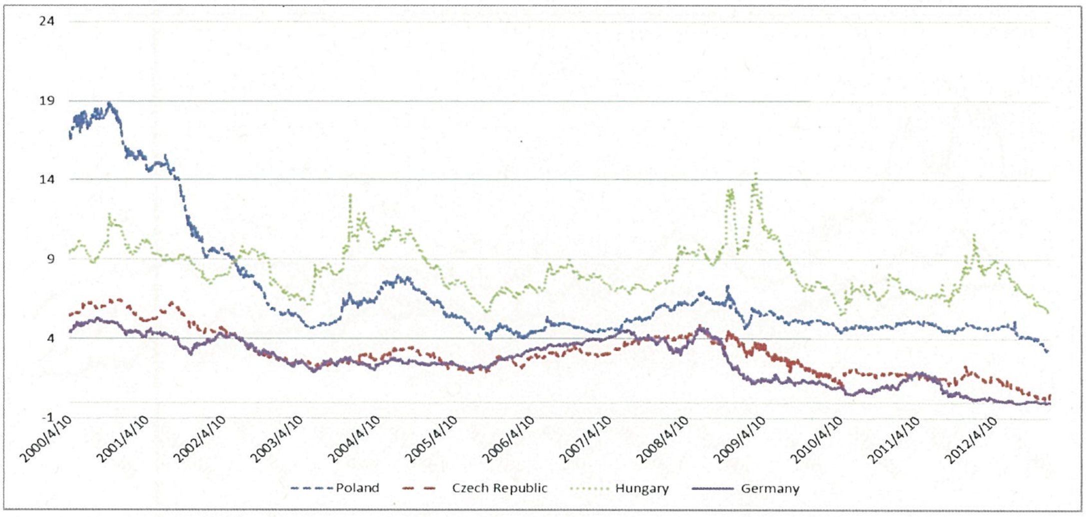

Fig 3.1. Time series for short-term bond yields (percentage, left scale).

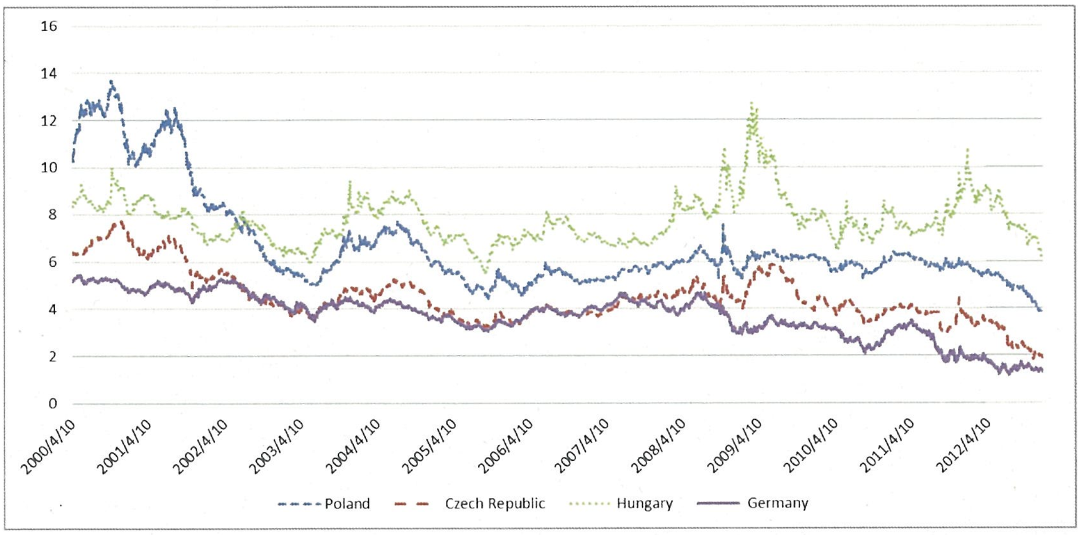

Fig 3.2. Time series for the long-term bond yields (percentage, left scale).

Chapter 4

Interdependence of bond markets between CEEC-3 and Germany: A wavelet coherence analysis

4.1 Introduction

Research on the integration of government securities markets in the Eurozone is attracting increasing academic attention as the number of European Union (EU) member states grows. The largest ever EU expansion in 2004 heralded the entrance of 10 new members, most emerging transition economies. Since becoming an EU member is a great event for these countries, wide-scale changes to the structure of their economies and their degree of financial market integration follow accordingly.

In this paper, I investigate the degree of the integration of the government bond markets in Poland, Czech Republic, and Hungary (CEEC-3 hereafter). In addition, Germany is used to represent the EU, since it is the largest economy in the Eurozone and has the most liquid government securities market. CEEC-3 countries serve as the most suitable representatives of new EU accession members because they have the longest available time series data that match those of Germany.

Further, I choose short- and long-term bond yields in order to examine the process of integration at different timescales. Since CEEC-3 countries have undertaken huge structural changes in their economic systems, the integration patterns for short- and long-term bond yields should differ significantly. Indeed, as shown in Figures 1 and 2, short-term bond yields show a higher level of volatility than long-term bond yields. The discrete wavelet transform (DWT) provides further evidence to support this fact.

Since short-term bond yields are usually considered to serve as a reference for the policy rate, a highly integrated short-term bond market indicates that monetary policies are well coordinated across countries. Further, long-term bond yields can be considered to indicate future economic perspectives driven by investor preferences, risk attitudes, and expectations. The common feature for both short- and long-term bond yields is that the degree of integration with Germany increases if monetary policies are well coordinated and economic policies suitably implemented. However, short-term bond yields are more sensitive to the business cycle or to other shocks than long-term bond yields. Therefore, divergent dependence patterns should be assumed for both these yields.

This paper uses wavelet transform analysis in order to investigate interdependence among the bond markets of CEEC-3 and Germany at different timescales. In particular, I aim to answer the following three research questions. First, does EU accession increase the degree of integration with Germany's bond market? Second, how did the recent financial crisis affect this relationship? Finally, are there any differences between the short- and long-term effects of this interdependence?

Our threefold contribution to the body of knowledge on this topic can be summarized as follows. First, employing wavelet analysis in bond markets is novel in the financial literature. Second, investigating correlations at different timescales provides information on investor preferences, risk attitudes, and expectations. Finally, illustrating the phase pattern explains the cause–effect relationship between CEEC-3 and Germany.

The remainder of this paper is organized as follows. Section 2 provides an overview of the related literature. Section 3 discusses various copulas to verify dependence structures. Section 4 describes the data and reports on statistical issues. Section 5 presents the empirical results, and Section 6 concludes.

4.2 Literature reviews

Three types of econometric models are used to analyze interdependence among the financial markets in the EU. The first type is ordinary least squares, which is mainly employed to analyze the European Monetary Union (EMU) effect on bond spreads, such as credit risk and liquidity risk. For example, Abad et al. (2010) found that Eurozone markets are less vulnerable to the influence of global risk factors and more vulnerable to EMU risk factors. The second type of model is the causality test, which is employed to investigate the cause–effect relationship. Gómez-Puig and Sosvilla-Rivero (2013) and Yunus and Swanson (2012) found that Granger causality significantly increases during certain key periods such as the launch of the EMU in 1999, the circulation of the euro in 2002, and the global financial crisis in 2008. The third type is a volatility-based (GARCH) model for investigating interdependence among markets. Christiansen (2007) showed that regional effects have dominated both domestic and global effects in EMU bond markets since the introduction of the euro. In addition, Yang and Hamori (2013a,b) provided evidence on the evolution of structural dependence between the CEEC-3 and German bond markets since 2000.

Despite this volume of research, however, few studies have explored the independence structure or integration of EU bond markets at different timescales. In this paper, I bridge this gap in the literature by introducing a new econometric method (wavelet analysis) to investigate the changes in the independence structures of the CEEC-3 and German bond markets. By computing the wavelet coherence, I can also obtain the cause–effect relationship between the CEEC-3 and German bond markets. Since the investment horizon for bonds is usually more than one year, this analysis is also important for duration management. Hence, our research contributes to the current literature in two directions. First, I provide the independence structure of EU bond markets at different timescales, which is a crucial determinant of the degree of integration as well as beneficial for managing durations. Second, I provide the cause–effect relationship between the CEEC-3 and German bond markets at different timescales, which is also critical for analyzing the transmission of asset prices.

Recent financial papers that have used wavelet transform analysis have typically focused on the co-movements of stock markets. For instance, Kiviaho et al. (2012) found that co-movement is stronger at lower frequencies and increased during the turbulent period of the global financial crisis based on wavelet coherence analysis[7]. In contrast to the findings of

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[7] For the application of wavelet analysis in finance, see Rua and Nunes (2009), Huang (2011), and Aloui and Hkiri (2014).

Kiviaho et al. (2012), this paper provides the phase pattern, which is a measurement of the cause–effect relationship at different timescales. Moreover, examining the interdependence between the studied bond markets offers information on the ongoing structural changes in the EU economy, including its underlying economic and financial market conditions, and the process of integration.

4.3 Wavelet analysis

4.3.1 The wavelet

In time series analysis, wavelet theory is a comparatively new and powerful tool to generate a data structure that contains segments of various lengths. One advantage of wavelet analysis is that it can decompose a time series into more elementary functions that contain information on a series. Based on the different scales of time series, I can then draw useful information on the signal (raw data). Kim and In (2013), for example, provided an overview of how wavelets can be applied in economics and finance research. In this paper, I thus investigate the correlations of the bond markets of CEEC-3 and Germany based on different timescales in order to analyze the degree of integration and the effect of recent crises.

Firstly, I identify the two types of wavelets based on different normalization rules, which can be named as father wavelets ϕ and mother wavelets ψ. Specifically, the father wavelet integrates to 1 and the mother wavelet integrates to 0

$$\int \phi(t) = 1, \tag{4.1}$$

$$\int \psi(t) = 0, \tag{4.2}$$

The father wavelet denotes the smooth and low-frequency parts of a signal while mother wavelet denotes the detail and high-frequency components.

Since wavelet analysis is capability of transforming any function $y(t)$ in $L^2(\mathbb{R})$ (space for square summable functions) into different frequency components with a resolution matched to its scale. And it can be built up as a sequence of projections onto father and mother wavelets generated from ϕ and ψ through scaling and translation as follows:

$$\phi_{j,k}(t) = 2^{-j/2}\phi(2^{-j}t - k) \tag{4.3}$$

$$\psi_{j,k}(t) = 2^{-j/2}\psi(2^{-j}t - k) \tag{4.4}$$

where$j = 1, \ldots, J$ is the scaling parameter in a J-level decomposition and k is a translation parameter. Thus, the wavelet representation of the signal $y(t)$ in $L^2(\mathbb{R})$ can be written as:

$$y(t) = \sum_k s_{J,k}\phi_{J,k}(t) + \sum_k d_{J,k}(t)\psi_{J,k}(t) + \sum_k d_{J-1,k}\psi_{J-1,k}(t) + \ldots + \sum_k d_{1,k}\psi_{1,k}(t) \tag{4.5}$$

In the representation J is the number of multi-resolution components, and $s_{J,k}$ are the smooth coefficients, and $d_{j,k}$ are the detail coefficients. They are defined by

$$s_{J,k} = \int y(t)\phi_{J,k}(t)dt \tag{4.6}$$

$$d_{j,k} = \int y(t)\psi_{j,k}(t)dt \tag{4.7}$$

the contribution of corresponding wavelet function to the total signal can be measured by the magnitude of these coefficients. The dilation factor is identified as the scale factor 2^j, the lactation is referred as the translation parameter $2^j k$. The larger index *j*, the wider value of the scale factor 2^j. Their translation parameter $2^j k$ gets larger coming by the functions $\phi_{J,k}(t)$ and $\psi_{j,k}(t)$ being wider.

As to multi-resolution decomposition, the decomposed signals are defined as follows:

$$S_J(t) = \sum_k s_{J,k}\phi_{J,k}(t) \tag{4.8}$$

$$D_j(t) = \sum_k s_{j,k}\phi_{j,k}(t) \tag{4.9}$$

The smooth signals and detail signals are expressed as the function $S_J(t)$ and $D_j(t)$, respectively.

They constitute a decomposition of a signal into orthogonal components at different scales. A signal $y(t)$ can be rewritten as:

$$y(t) = S_J(t) + D_J(t) + D_{j-1}(t) + \ldots + D_1(t) \tag{4.10}$$

The highest level approximation $S_j(t)$ is the smooth while the details $D_1(t)$, $D_2(t)$,..., $D_j(t)$ are associated with oscillations of length 2-4, 4-8,..., $2^J - 2^{J+1}$.

The discrete wavelet transform (DWT) of a real-valued function y(t) is defined as follow:

$$\omega = Wy \tag{4.11}$$

where the coefficients are ordered from coarse scales to fine scales in the vector ω. In the case where n is divisible by 2^J

$$\omega = \begin{pmatrix} s_J \\ d_J \\ d_{J-1} \\ \vdots \\ d_1 \end{pmatrix} \tag{4.12}$$

where $s_J = (s_{J,1}, s_{J,2}, \ldots, s_{J,n/2^J})'$, $d_J = (d_{J,1}, d_{J,2}, \ldots, d_{J,n/2^J})'$, $d_{J-1} = (d_{J-1,1}, d_{J-1,2}, \ldots, d_{J-1,n/2^J})'$, and $d_1 = (d_{1,1}, d_{1,2}, \ldots, d_{1,n/2^J})'$, respectively. Each set of coefficients $s_J, d_J, d_{J-1}, \ldots, d_1$ is called a crystal. The term crystal is used because the wavelet coefficients in a crystal correspond to a set of translated wavelet functions arranged on a regular lattice.

4.3.2 The continuous wavelet

I employ the wavelet coherence under Morlet's specification to analyze the joint behavior of both frequency and time space. The wavelet is defined as follows:

$$\varphi_{u,s}(t) = \frac{1}{\sqrt{s}}\varphi\left(\frac{t-u}{s}\right),\ \varphi(.) \subset L^2(\mathbb{R}) \tag{4.13}$$

where, $\frac{1}{\sqrt{s}}$ is the normalization factor to ensure the unit variance of wavelet $\left\|\varphi_{u,s}\right\|^2 = 1$.

The lactation parameter is defined as u to provide the exact position of the wavelet while the scale dilatation parameter of the wavelet is referred as s. Based on the previous studies, I employ the Morlet's wavelet with the specifications as follows:

$$\varphi^{M}(t) = \frac{1}{\pi^{1/4}} e^{i\omega_0 t} e^{-t^2/2} \quad (4.14)$$

where ω_0 is the central frequency of the wavelet. Contributed by Grinstedet al (2004), Rua and Nunes (2009), and Vacha and Barunik(2012), ω_0 is usually set to be 6. Moreover, the continuous wavelet transform is given by (Rua and Nunes, 2009; Vacha and Barunik, 2012):

$$W_x(u,s) = \int x(t) \frac{1}{\sqrt{s}} \varphi\left(\frac{t-u}{s}\right) dt \quad (4.15)$$

Specifically, the specific wavelet $\varphi(.)$ is used to generate the $W_x(u,s)$ based on the selected time series. The aptitude to decompose and then consequently reconstruct the function $x(t) \subset L^2(\mathbb{R})$ is usually considered to be the great merit of the continues wavelet transform:

$$x(t) = \frac{1}{C_\varphi} \int_0^\infty \left[\int_0^\infty W_x(u,s) \varphi_{u,s}(t) du\right] \frac{ds}{s^2},\ s > 0 \quad (4.16)$$

Correspondently, to identif the variance for the power spectrum analysis, I have:

$$\|x\|^2 = \frac{1}{C_\varphi} \int_0^\infty \left[\int |W_x(u,s)|^2 du\right] \frac{ds}{s^2},\ s > 0 \quad (4.17)$$

4.3.3 Wavelet squared coherence

To investigate the joint behavior of both time and frequency for the bond market, I employ the wavelet squared coherence analysis based on the cross-wavelet transform. Based on the study of Torrence and Compo (1998), the two signals *x*(*t*) and *y*(*t*) can be transformed by the cross-wavelet transform as follows:

$$W_{x,y}(u,s) = W_x(u,s) W_y^{*}(u,s) \quad (4.18)$$

where *u* denotes the position and *s* is the scale. The * denotes the complex conjugate. The timescale space is expressed as the area where the time series is identified as the common power in the cross-wavelet transform, which is the local covariance between the two signals at each scale.

Following Torrence and Webster (1999), the squared absolute value of the smoothed cross-wavelet power spectra of each selected time series is considered to be the wavelet coherence:

$$R^2(u,s) = \frac{\left|S(s^{-1} W_{xy}(u,s))\right|^2}{S(s^{-1}|W_x(u,s)|^2) S(s^{-1}|W_y(u,s)|^2)} \quad (4.19)$$

where s is the smoothing parameter. The squared wavelet coherence $R^2(u,s)$ ranges from 0 to 1. The strong correlation denotes the large value of $R^2(u,s)$ and vice versa.

Based on the above discussion, I analyze the degree of bond market integration between CEEC-3 and Germany by comparing correlations across timescales. If low-frequency correlations increase over time, I can state that the degree of integration increases. Moreover, I also investigate the contagion effect by comparing high-frequency with low-frequency correlations. If the former increase sharply in a certain period, while the latter do not, I can state that contagion occurs. Based on the logic above, I use bond yield data to answer the three research questions posed in the Introduction.

4.4 Data

In this paper, I use the two-year government treasury yield as the short-term (mid-term) interest rate and the 10-year government bond yield as the long-term interest rate , which are based on a daily frequency from April 10, 2000, to April 1, 2013. In addition, the sample period is constrained by issues of data availability and comparability between the sample countries. Instead of using returns from changes of yields, I thus apply the yield data directly since, according to the interest rate parity theorem, yields will converge among countries in the long-term when they form a monetary union. All data are obtained from DataStream.

Table 4.1 summarizes the statistical properties of the raw data for each country and Table 4.2 provides the correlation matrix for the raw data. The results of the Jarque–Bera test show that the null hypothesis of the normal distribution is rejected in all cases. As shown in Table 4.2, Czech Republic shows the highest degree of correlation with Germany, while Hungary shows the lowest. Meanwhile, the short-term interest rate shows a higher degree of correlation than the long-term interest rate. These results indicate that the coordination of the monetary policies of CEEC-3 and Germany is superior compared with that of their economic policies.

4.5 Empirical Results

4.5.1 Discrete wavelet transform

In this subsection, I report the results of the DWT of bond yields for both CEEC-3 and Germany. In order to analyze the degree of bond market integration between CEEC-3 and Germany, I must investigate these correlations at different timescales. Therefore, I decompose the raw data into four timescale components, namely $D1$, $D2$, $D3$, and $D4$. The finest scale component $D1$ represents short-term or high-frequency variations due to shocks that occur at a timescale of 2 days, while $D2$ accounts for variation at a timescale of 4 days (corresponding to the working days of a week). Similarly, the $D3$ and $D4$ components represent the mid-term (half-month) variations at timescales of 8 and 16 days (see Huang, 2011).

Variations in bond yields most often occur in the short-term (i.e., reflected by $D1$ and $D2$). Figures 4.1 and 4.2 illustrate the raw data and DWT of the raw data for two-year and 10-year bond yields, respectively. Tables 3 and 4 provide the correlation matrixes for the DWT of the raw data for two-year and 10-year bond yields, respectively. Tables 4.3 and 4.4 show that the degree of correlation between the bond markets of CEEC-3 and Germany increases as the timescale rises. This trend is consistent with our expectations that the short-term interest rate is hard to predict compared with the mid-term or long-term interest rates, thereby causing a high degree of correlation at the largest timescale since market participants have similar expectations about the Eurozone's economy.

4.5.2 Continuous wavelet transform

Figure 3 illustrates the raw data variations based on the CWT. The red area at the bottom (top) of the CWT represents the strong variation at low (high) frequencies, while the presence of the red area on the left-hand (right-hand) side means the existence of significant variation at the beginning (end) of the sample period (see Aloui and Hkiri, 2014). As before, the frequency is based on daily data.

According to Figure 4.3, both the short-term and the long-term interest rates in Poland show high variation at *D*4 before 2004, whereas such high variation is only observed for the long-term interest rate in Czech Republic. In the case of Hungary, the high variation in *D*4 for the short-term interest rate starts in 2002, while the long-term interest rate shows high variation from 2005 to 2011. One reason for this discrepancy is the huge financial deficit of the Hungarian government from 2002. As for Germany, the variation in both the short-term and the long-term interest rates peaks around 2008 at the one-year scale, indicating that the global financial crisis had a huge impact on the bond market in Germany.

Further, the cross-wavelet transforms for the pairs are summarized in Figure 4.4. The interpretation of Figure 4.4 is similar to that of Figure 4.3; however, Figure 4.4 also provides the relative phasing of two time series by using phase arrows, which indicate the cause–effect relationships among the bond markets of CEEC-3 and Germany. If the arrow points right, it means that the pair is in-phase. If the arrow points left, it is anti-phase. If the arrow points straight down, it means Germany leads CEEC-3. If the arrow points straight up, it means CEEC-3 leads Germany.

This figure shows that the Poland–Germany pair is in-phase in the significant area, indicating that the interest rate movements (both short-term and long-term) in Poland largely mirror those (both short-term and long-term) in Germany before 2004 (and again from 2013). In the Czech Republic–Germany pair, a straight up pattern is briefly observed for the short-term interest rate during 2001 in the significant zone. This finding means that the movements of the short-term interest rate in Germany briefly mimic those of the short-term interest rate in Czech Republic. However, after 2011, the in-phase pattern is observed for both interest rates, indicating that the interest rate movements in Czech Republic follow those in Germany. Moreover, a straight down pattern is observed around 2008, indicating that the contagion (leading) effect occurs in the long-term bond market from Germany to Czech Republic.

In the Hungary–Germany pair for the short-term interest rate, I observe an in-phase pattern before 2004 at the two-year scale, while a straight down pattern is observed around 2008 at the two-year scale and a straight up pattern around 2011 at the three-year scale. Meanwhile, a straight down pattern is observed around 2008 for the long-term interest rate. These results indicate that the contagion (leading) effect occurs around 2008 from Germany to Hungary, while the contagion (lagged) effect occurs around 2011 from Hungary to Germany.

4.5.3 The wavelet coherence

To investigate bond market interdependence among CEEC-3 and Germany, I plot the results of the wavelet coherence for each pair in Figure 4.5. Similar to Figures 4.3 and 4.4, the red area at the bottom (top) of the wavelet coherence represents a strong correlation at low (high) frequencies, while the presence of the red area on the left-hand (right-hand) side means the existence of significant correlation at the beginning (end) of the sample period.

Figure 4.5 illustrates that the significant areas for both the short-term and the long-term interest rates are similar for the correlation between Poland and Germany, specifically the period before 2005, the period around 2008, and the period after 2011. These results indicate that the degree of bond market integration before EU accession is higher than that after EU accession. Meanwhile, the contagion effect is also observed for both the global financial crisis and the European debt crisis. Importantly, the latter has a larger impact on bond markets than the former since the significant area after 2011 covers more timescales. Moreover, I note that the Poland–Germany pair is in-phase in the significant area for both interest rates in all cases. The results also suggest that the interest rate movements in Poland mirror those in Germany.

In the case of Czech Republic, the degree of integration with Germany is relatively high since the significant area across the entire sample period covers the two- and three-year scales for the short-term interest rate. In particular, the degree of integration peaks around 2008, which also indicates the occurrence of the contagion effect. For the long-term interest rate, there is a large significant area across the sample period. However, the global financial crisis is shown to have a minor effect on the bond market of Czech Republic compared with that of the European debt crisis. Meanwhile, the Czech Republic and Germany pair is in-phase in the significant area for both short- and long-term interest rates in all cases. These results imply that the interest rate movements in Czech Republic mirror those in Germany.

Compared with Poland and Czech Republic, the degree of integration with Germany is relatively low for Hungary (see the small significant area in our sample period). The degree of integration for both interest rates is high and significant before 2003 at the two-year scale but it decreases thereafter. Meanwhile, the Hungary–Germany pair is in-phase in the significant area for both the short-term and the long-term interest rates, suggesting that the interest rate movements in Hungary mirror those in Germany before 2003. In particular, there is also another significant area for both interest rates around 2008 with a straight down pattern, indicating that the contagion effect occurs from Germany to Hungary. The other significant area for both interest rates around 2011 has an in-phase pattern, also indicating that a contagion effect occurs but not from Germany during the European debt crisis period.

4.6 Conclusion

In this paper, I investigated the interdependence of the bond markets of CEEC-3 and Germany by using wavelet coherence analysis. Based on the empirical results presented herein, I compared and contrasted these interdependence structures and found that a contagion effect occurred in these markets during the two recent crises. In addition, the degree of bond market integration was relatively high before 2004 for both Poland and Hungary and very high throughout the entire sample period for Czech Republic.

Moreover, by analyzing the phase pattern, I showed that the interest rate movements in both Poland and Czech Republic mirror those in Germany for the sample period, while the interest rate movements in Hungary mirror those in Germany before 2003. However, the transmission channel for the global financial crisis is from Germany to Hungary, whereas that for the European debt crisis is not from Germany but rather from other countries.

Our findings have at least three implications for investors and policymakers. First, the detection of significant interdependence over time and across the different scales of bond yields provides valuable information that can aid duration management and international diversification. For instance, the benefit of diversification will be low at particular times. Second, comparing phase patterns can also provide investors with useful information on the transmission of asset prices. For example, investors may hedge risk in one market when they can foresee a slump in another market. Finally, our findings indicate that policymakers should implement monetary and fiscal policies in order to enhance economic cooperation, especially in Hungary.

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Table 4.1

Descriptive statistics for raw data

	Poland		Czech Republic		Hungary		Germany	
	2Y	10Y	2Y	10Y	2Y	10Y	2Y	10Y
Mean	6.816	6.615	3.016	4.439	8.277	7.735	2.541	3.667
Median	5.210	5.920	2.860	4.243	8.040	7.550	2.553	3.881
Std. Dev.	3.740	2.096	1.447	1.156	1.551	1.009	1.450	1.029
Skewness	1.968	1.740	0.474	0.550	0.658	1.131	−0.159	−0.610
Kurtosis	5.719	5.162	2.802	3.434	3.347	5.361	1.951	2.741
Jarque-Bera[8]	3229.76	2368.34	132.83	197.64	261.22	1508.43	169.45	219.42
Observations	3386	3386	3386	3386	3386	3386	3386	3386

Note: 2Y denotes 2 year bond yield and 10Y denotes 10 year bond yield. Our sample period is from April 10, 2000 to April 1, 2013 using daily frequency

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[8] The results of the Jarque–Bera (J–B) test also show that the null hypothesis of the normal distribution (unconditionally) is rejected in all cases at 1% significant level.

Table 4.2

Correlations of raw data between CEEC-3 and Germany

	Poland		Czech Republic		Hungary	
	2Y	10Y	2Y	10Y	2Y	10Y
Germany 2Y	0.634	0.589	0.868	0.676	0.333	−0.039
Germany 10Y	0.633	0.660	0.857	0.788	0.433	0.041

Note: 2Y denotes 2 year bond yield and 10Y denotes 10 year bond yield. Our sample period is from April 10, 2000 to April 1, 2013 using daily frequency

Table 4.3

Correlations of DWT between CEEC-3 and Germany for 2 year bond yield.

	Germany D1	Germany D2	Germany D3	Germany D4
Poland D1	0.029	0	0	0
Poland D2	0	0.031	0	0
Poland D3	0	0	0.135	−5.64E-22
Poland D4	0	0	2.46E-23	0.275
Czech Republic D1	0.114	0	0	0
Czech Republic D2	0	0.154	0	0
Czech Republic D3	0	0	0.210	−9.51E-23
Czech Republic D4	0	0	3.48E-24	0.276
Hungary D1	−0.047	0	0	0
Hungary D2	0	−0.083	0	0
Hungary D3	0	0	−0.037	−1.68E-22
Hungary D4	0	0	−1.43E-21	−0.039

Note :D1, D2, D3, D4 denote 2 days, 4 days (one-weak), 8 days (half-month), 16 days (one-month) frequency, respectively.

Table 4.4

Correlations of DWT between CEEC-3 and Germany for 10 year bond yield.

	Germany D1	Germany D2	Germany D3	Germany D4
Poland D1	0.040	0	0	0
Poland D2	0	0.134	0	0
Poland D3	0	0	0.205	−5.42E-22
Poland D4	0	0	7.68E-22	0.283
Czech Republic D1	0.265	0	0	0
Czech Republic D2	0	0.359	0	0
Czech Republic D3	0	0	0.356	−4.73E-22
Czech Republic D4	0	0	−1.89E-21	0.465
Hungary D1	−0.118	0	0	0
Hungary D2	0	−0.038	0	0
Hungary D3	0	0	−0.0412	−5.53E-22
Hungary D4	0	0	−8.25E-22	0.082

Note :D1, D2, D3, D4 denote 2 days, 4 days (one-weak), 8 days (half-month), 16 days (one-month) frequency, respectively.

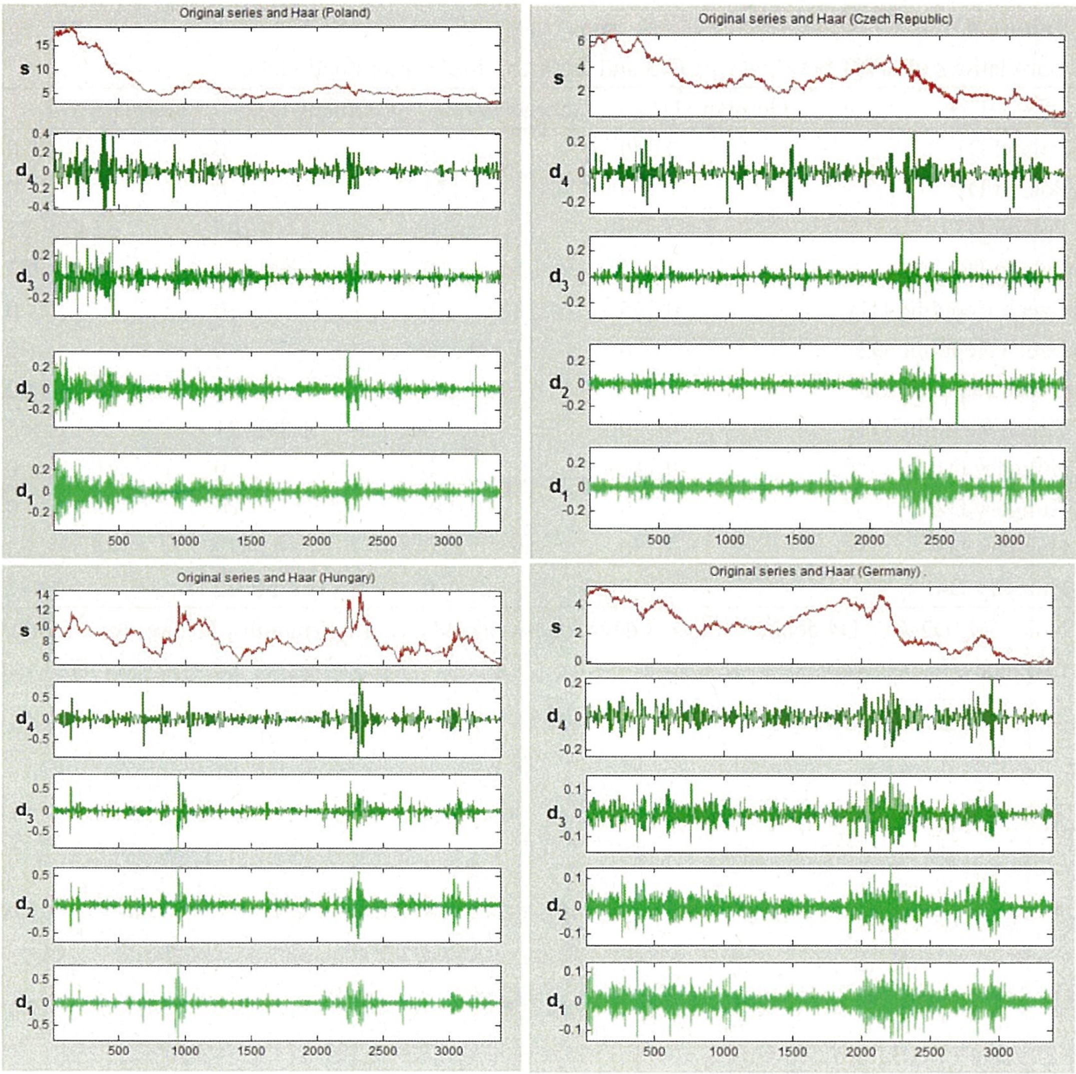

Fig.4.1. This figure plots the raw data (2 years bond yields) and discrete wavelet transform (DWT) based on Haar wavelet from April 10, 2000 to April 1, 2013 using daily frequency.

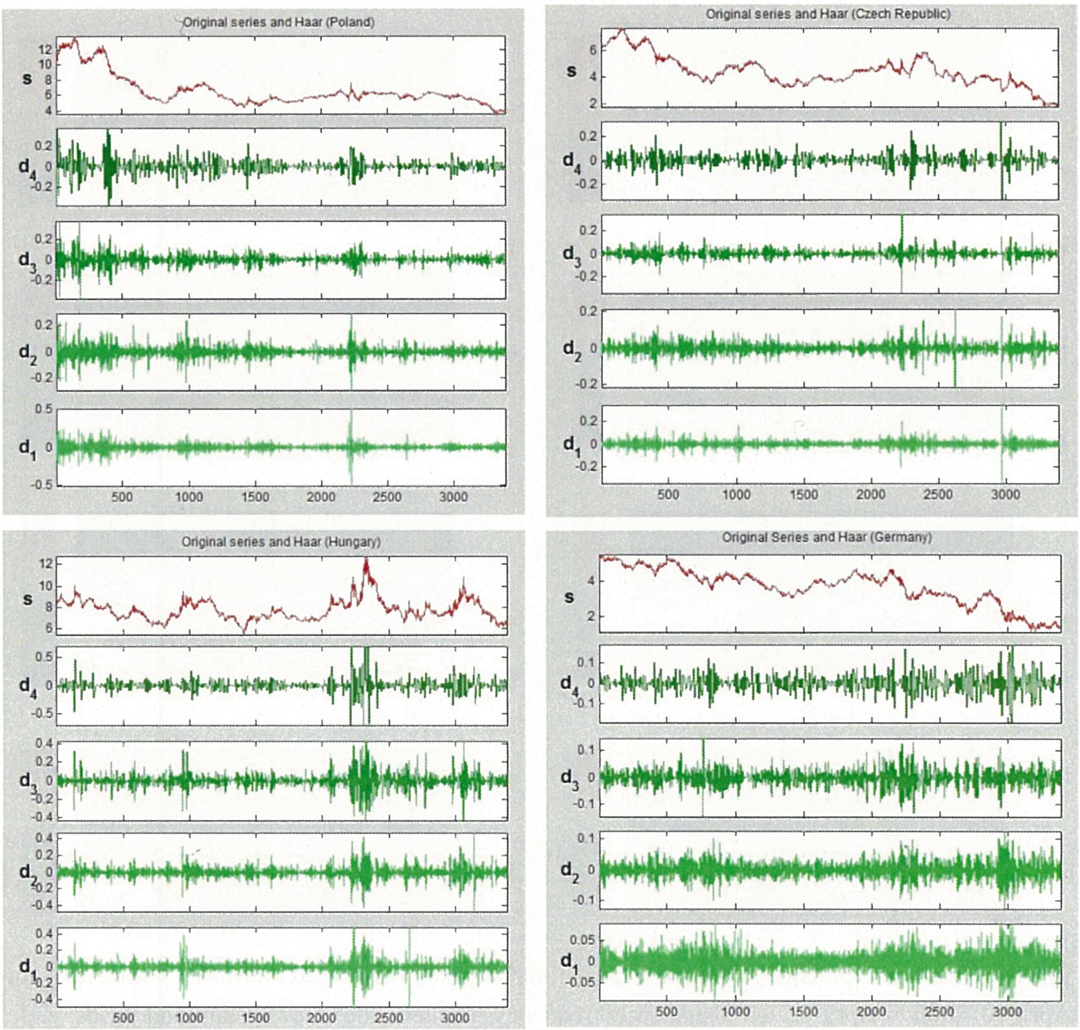

Fig.4.2. This figure plots the raw data (10 years bond yields) and discrete wavelet transform (DWT) based on Haar wavelet from April 10, 2000 to April 1, 2013 using daily frequency.

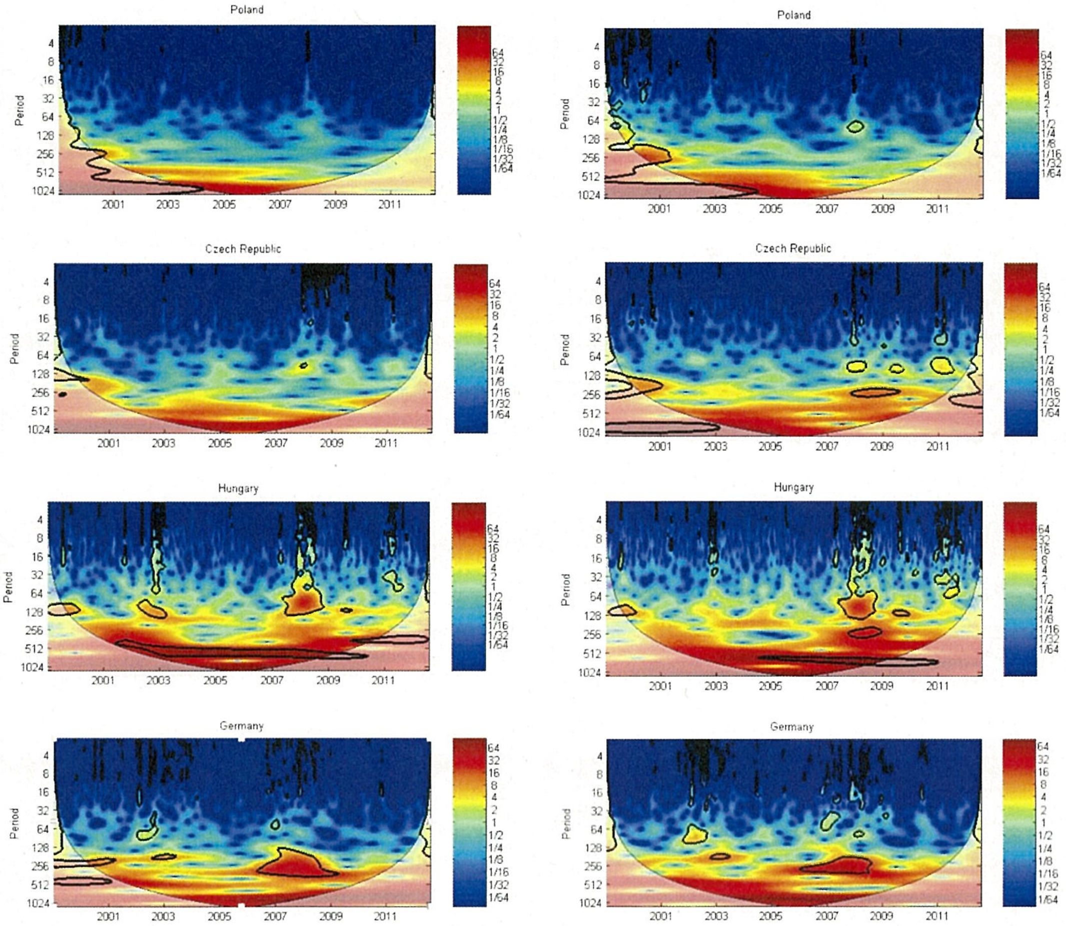

Fig.4.3. This figure plots the continues wavelet transform (CWT) based on Morlet's wavelet from April 10, 2000 to April 1, 2013 using daily frequency. The left-side is for 2 year bond yields while the right-side is for 10 year bond yields. The interrupted line isolated the statistical significant at the 5% level.

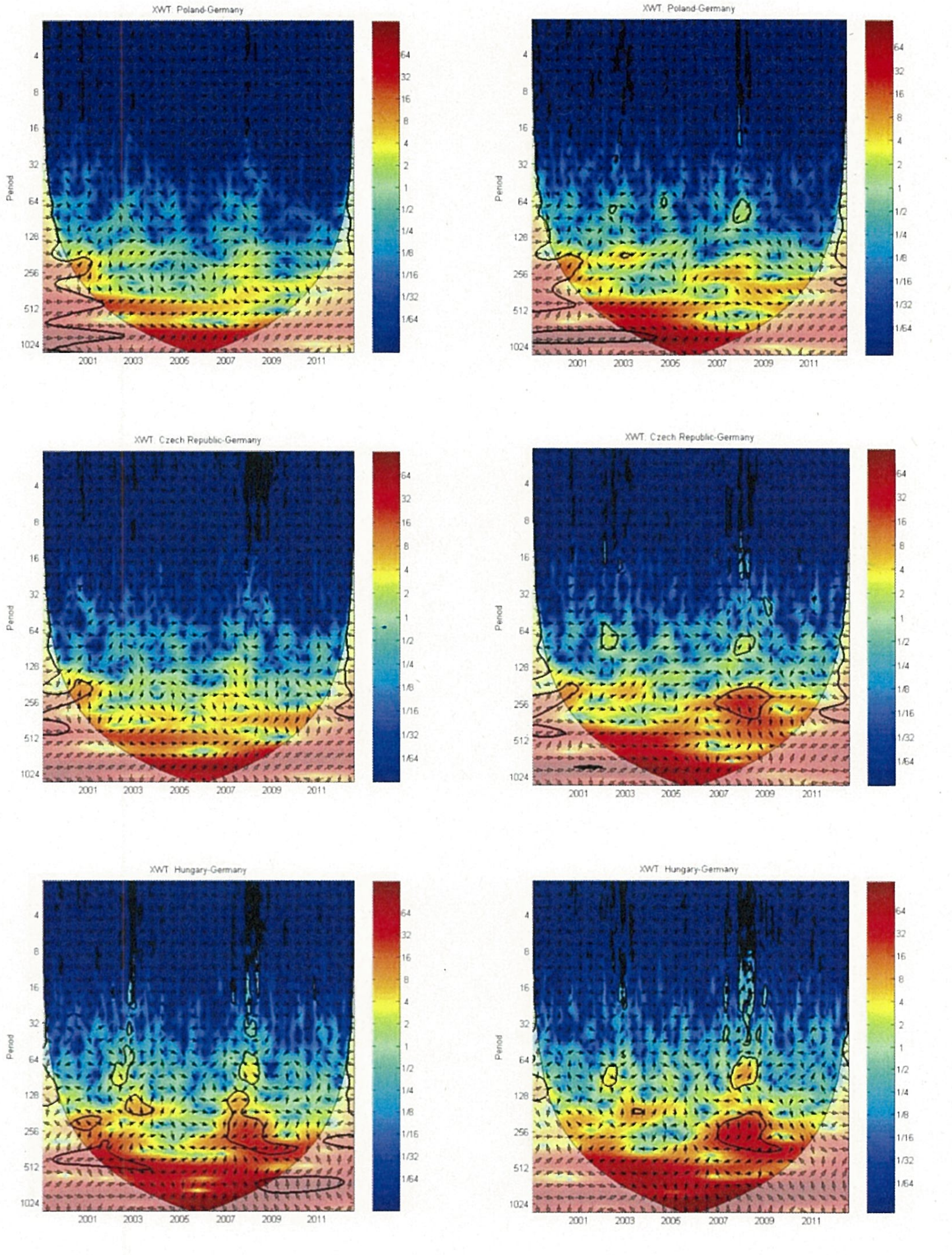

Fig.4.4. This figure plots the cross-wavelet transform (XWT) from April 10, 2000 to April 1, 2013 using daily frequency. The left-side is for 2 year bond yields while the right-side is for 10 year bond yields. The interrupted line isolated the statistical significant at the 5% level. The relative phase relationship is shown as arrows (with in-phase pointing right, anti-phase pointing left, and Germany leading CEEC-3 by 90 pointing straight down).

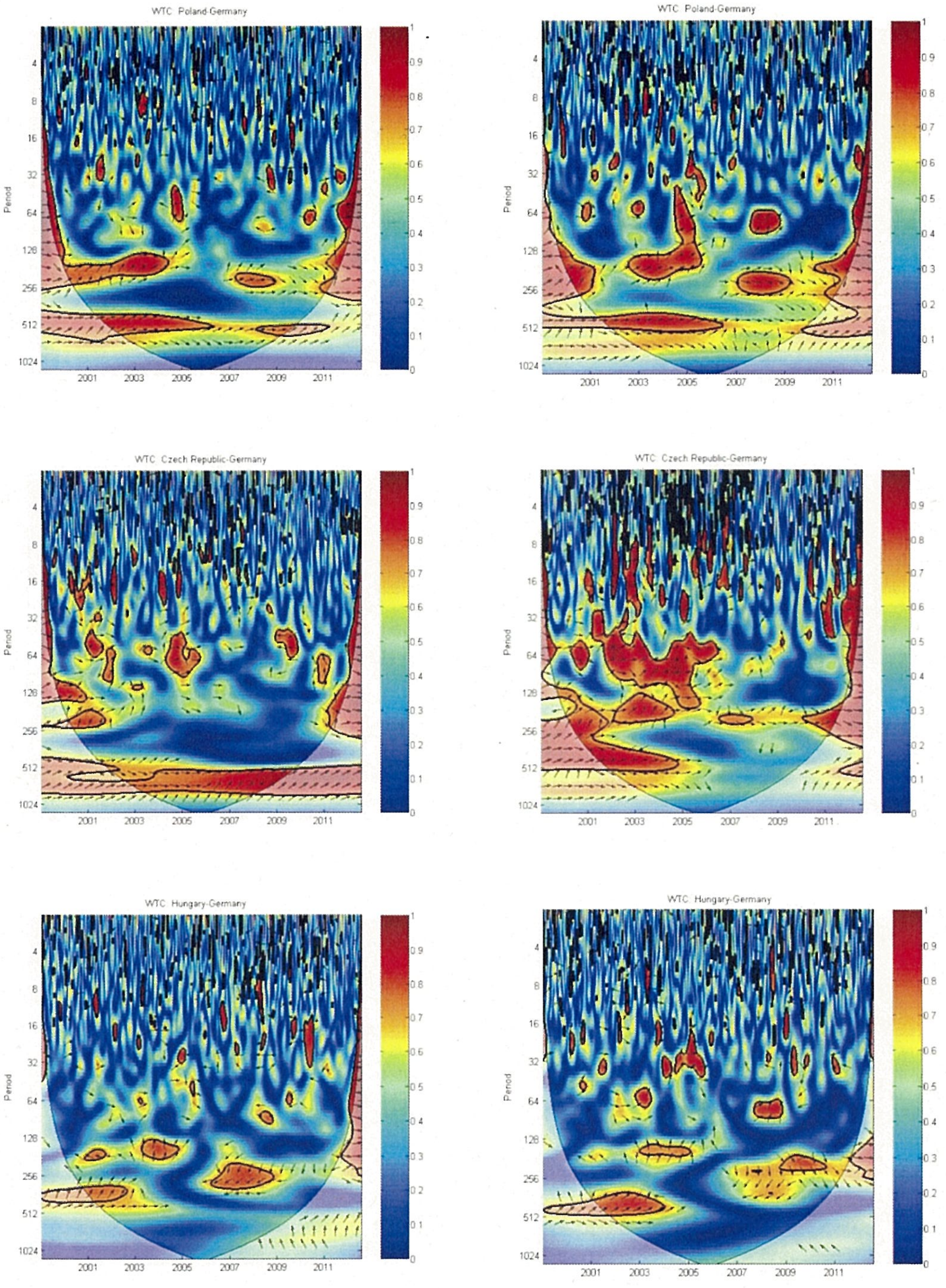

Fig.4.5. This figure plots the wavelet transform coherence (WTC) from April 10, 2000 to April 1, 2013 using daily frequency. The left-side is for 2 year bond yields while the right-side is for 10 year bond yields. The interrupted line isolated the statistical significant at the 5% level. The relative phase relationship is shown as arrows (with in-phase pointing right, anti-phase pointing left, and Germany leading CEEC-3 by 90 pointing straight down).

Chapter 5

Financial integration of financial markets in CEEC-3 countries

5.1 Introduction

Financial market integration in Europe has evolved dramatically with the political, economic, and monetary developments in the European Union (EU). In 2004, 10 countries from Central and Eastern Europe and the Mediterranean region joined the EU, which was the largest ever enlargement of the EU and a historic step towards unifying the whole of Europe after several decades of division that resulted from the Cold War. In an integrated financial market, local shocks occurred in one country will also causes financial marketer actions in neighboring countries. Needless to say, this even more likely to be the case when the countries share some key characteristics, like CEEC-3 countries (Poland, Czech Republic, and Hungary), which are all emerging transition economies.

Since international investors always treat them as one group not an individual country, it obvious to see that financial contagion[9] occurs. Moreover, since CEEC-3 countries become EU members in 2004, the degree of integration of financial markets in CEEC-3 countries should increase as expected. The question of whether there is a persistent increase of correlation among the integrated financial markets should be a great concern to the investors, if this phenomenon occurs, diversification will be ineffective.

I investigate the financial markets of CEEC-3 countries for several reasons. First, they have the largest financial markets in the region in the light of liquidity and market capitalization. Second, the three economies are closely interrelated in terms of trade relations and geographic proximity. Third, they are particularly prone to financial crisis in a basis of properties of emerging economy. Finally, all of them are in the process of integrating into the European Union. Since our data period covers recent two financial crises (international financial crisis in 2008 and European debt crisis in 2011), it also our best interest to investigate the integration since these three countries become EU's member (EMU) but also to analyze the contagion effect among these markets. Particularly, the international financial crisis is treated as world shocks while European debt crisis is treated as local shock.

Most previous studies apply a multivariate extension of Engle's (1982) ARCH model in order to investigate regional financial integration and contagion. For example, Galati and Tsatsaronis (2003) analyzed how the introduction of the euro influenced Europe's financial structure and provided evidence of convergence in EU bond markets. Barr and Priestley (2004) applied time-varying expected returns to evaluate international bond market integration based on an asset pricing model. Christiansen (2007) provided evidence that regional effects have come to dominate both domestic and global effects in European Monetary Union (EMU) bond markets following the introduction of the euro based on the AR-GARCH model of Bekaert et al. (2002). Finally, Kim et al. (2006) found evidence of strong contemporaneous and dynamic linkages between eurozone bond markets with that of Germany using Haldane

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[9] For the details of contagion effect, please refer to, Didier et al (2008) and Fazio (2007).

and Hall's (1991) Kalman filtering method and bivariate EGARCH modeling perspectives (Nelson 1991).

However, few studies have examined the dynamic changes in financial integration between accession and established members in the EU. Although it is clear that market correlations increase through economic integration, especially monetary integration as in the case of the EU, the most recent research focuses on the dynamic correlations of asset returns. For example, Engle (2002) introduced a new class of dynamic conditional correlation (DCC) model that permits time-varying correlations and estimated such correlations based on a series of univariate GARCH models (Bollerslev 1987). Büttner and Hayo (2010) examined the correlations of CEEC-3 financial markets based on DCC-MGARCH model. They concluded that there are no broad effects of international news on correlations while local news exerts an influence.

Based on the DCC-MGARCH model, Engle and Kelly (2012) propose an advanced version of DCC-MGARCH model, namely, DECO-MGARCH (dynamic equicorrelation multivariate generalised autoregressive conditional heteroscedasticity).Following the contribution of Engle and Kelly (2012), I use DECO-MGARCH model to describe the DECO among the financial markets in CEEC-3 countries. The reason that I do not use the DCC-MGARCH (dynamic conditional correlation multivariate generalized autoregressive conditional heteroscedasticity) is when DECO is the true model, DCC estimation is akin to estimating the correlation of a single pair, sampled n(n-1)/2 times. The difference between each pair is the measurement error. By averaging pair correlations at each step, DECO attenuates this measurement error (Engle and Kelly, 2012). In other word, DECO-MGARCH model are more suitable to estimate the correlation of n-dimension variables while DCC-MGARCH are more suitable for the estimation of the correlation for two variables. Since I choose foreign exchange markets, stock markets, and bond markets as our object to examine the questions above, the DECO-MGARCH model will provide more robust results more DCC-MGARCH model does.

Compared to the study of Büttner and Hayo (2010), I investigate the major economic events that influenced the CEEC-3 financial market after 2002 when Euro enter into circulation, including the recent two crises that they did not cover. Moreover, the study of Büttner and Hayo (2010) only considered the bivariate correlation between the two markets based on the DCC-MGARCH model, contrast to their study, I consider the multivariate correlation among the financial markets. Specifically, I measure how the DECOs among financial markets in CEEC-3 affected by the EMU, world shocks (using the global financial crisis as a proxy), and regional shocks (using the European sovereign debt crisis as a proxy). The existence of contagion among interdependent financial markets is a crucial issue when I diversify our portfolios, because such diversification becomes ineffective in the case of financial crises or other economic shocks.

Our contribution to the current financial literature can be summarized as follows. First, I examine a board numbers of financial markets that are included in previous studies. Second, I analyze the dynamic equicorrelaions among the financial markets in CEEC-3 countries which is latest econometric model for correlation analysis. Finally, I consider recent two financial crises differently; one is world shock while the other is local shock to the financial markets in CEEC-3 countries.

The remainder of this paper is organized as follows. Section 2 discusses the theoretical framework. Section 3 describes the data and statistical issues. Section 4 provides the empirical results and Section 5 concludes.

5.2 Econometric methods

Engle and Kelly (2012) raise a different version of DCC-MGARCH model, namely, DECO-MGARCH[10]. They assume the average of conditional correlation equal to all pair correlations in order to simplify the calculations of large scale correlation matrices. Following the studies of Engle and Kelly (2012), this paper examines the Dynamic Equicorrelation (DECO) among the financial markets in CEEC-3 across several key periods by adopting the following two-step approach. In the first step, I estimate the conditional variance of bond yields in each country based on an autoregressive (AR) model for the conditional mean and an GARCH model (Bollerslev, 1986). The AR (*k*)-GARCH (*p*, *q*) specification is expressed as follows:

$$r_t = C + \sum_{i=1}^{k} AR_i r_{t-i} + \varepsilon_t,\ E_{t-1}(\varepsilon_t) = 0,\ E_{t-1}\left(\varepsilon_t^2\right) = \sigma^2 \qquad (5.1)$$

and

$$h_{i,t} = \omega_i + \alpha_i \varepsilon_{i,t-1}^2 + \beta_i h_{i,t-1} \qquad (5.2)$$

where E_{t-1} is the conditional information operator based on the information at time *t*-1. Eq. (3.1), the AR(*k*) model, indicates that the current movement of a variable x_t can be explained by its own past movement $(r_{t-1}, r_{t-2}, \ldots)$. In this paper, the variable r_t is represented by asset returns. Eq. (3.2), the persistence of shocks to the conditional variance is given by $\sum_{i=1}^{q} \beta_i$.

Since the residuals ε_t express skewed and heavy tailed, I assume the density function of ε_t follow Student's t-distribution[11] given by:

$$f(t) = \frac{\Gamma\left(\frac{\nu+1}{2}\right)}{\sqrt{\nu\pi}\,\Gamma\left(\frac{\nu}{2}\right)}\left(1 + \frac{t^2}{\nu}\right)^{-\frac{\nu+1}{2}} \qquad (5.3)$$

where ν is the number of degrees of freedom and Γ is the gamma function.

The maximum likelihood method was used to estimate each model. The Schwarz Bayesian information criterion (SBIC) was used to evaluate the AR terms by choosing smallest values of its. The Ljung-Box Q (1978) test was applied to examine the residuals of the AR term.

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[10] For the detail of definition of equicorrelation, please refer to Engle and Kelly (2012).

[11] The generalized error distribution does not provide robust results according to the properties of data nor does it generalize to a multivariate process.

According to the SBIC and residual diagnostics, the values of *k*, *p*, and *q* range from *k*=1, 2…, 5; *p*=1,2; and *q*=1,2, respectively.

In the second step, based the conditional volatilities from Eq. (5.2), I calculate the conditional correlations from the conditional covariance matrix:

$$H_t = E[\varepsilon_t \varepsilon_t'] = D_t R_t D_t \tag{5.4}$$

where the diagonal matrix D_t is the conditional volatilities from Eq. (5.2).

Therefore, the trend of the generalized DCC model (Engle, 2002) can then be specified as

$$Q_t = (\overline{Q} - A'\overline{Q}A - B'\overline{Q}B) + A'z_{t-1}z_{t-1}'A + B'Q_{t-1}B \tag{5.5}$$

where $\overline{Q}$ represents the unconditional correlation matrices of z_t. Therefore, the conditional correlation matrix R_t is derived as

$$R_t^{DCC} = Q_t^{*-1} Q_t Q_t^{*-1} \tag{5.6}$$

where the diagonal matrix $Q_t^* = \sqrt{q_{ii,t}}$ contains the square roots of the diagonal elements of Q_t.

DECO sets ρ_t equal to the average pairwise DCC correlation

$$R_t^{DECO} = (1 - \rho_t)I_n + \rho_t J_{n\times n} \tag{5.7}$$

and

$$\rho_t = \frac{2}{n(n-1)} \Sigma_{i>j} \frac{q_{i,j,t}}{\sqrt{q_{i,i,t}q_{j,j,t}}} \tag{5.8}$$

where I_n denotes the n-dimensional identity matrix , $J_{n\times n}$ denotes the $n \times n$ matrix of ones, and $q_{i,j,t}$ is the *i*, *j*th element of Q_t. The following restriction conditions are required $a + b < 1, a > 0, b > 0$, where $a = A'A$ and $b = B'B$.Clearly, DCC only describes the correlation between assets *i* and *j* at time t based on the history of assets *i* and *j* alone, while DECO assumes this kind of correlation depend on the history of all pairs. Since the financial market are linked closely with each other, especially, during the financial crisis period (contagion effect), it is have enough evidence to believe that the DECO model can provides better estimation results than DCC does. Meanwhile, with the process of EU, I also expect dependence among the financial markets to be increasing. I estimate DECO model by employing Gaussian quasi-maximum likelihood method.

Finally, I consider the several key events that can affect the DECO derived from the second step[12]. Specifically, the dummy variables Di triggered by the EMU on May 1, 2004, the global financial crisis from August 7, 2007 to March 7, 2009 when Dow had fallen to 6440, and the European sovereign-debt crisis from November 5, 2010 to September 12,2012 when European Financial Stabilization Mechanism had been confirmed, are applied to test whether the events significantly altered the dynamics of the estimated conditional correlation of financial markets among the CCEC-3 countries; that is:

$$DE\hat{C}O_t = \delta_0 + \delta_1 DE\hat{C}O_{t-1} + \delta_2 D_1 + \delta_3 D_2 + \delta_4 D_3 + v_t \tag{5.9}$$

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[12] The same methodology is applied in Yiu et al. (2010).

where $\hat{DECO}_t$ is the dynamic equicorrelation estimated from Eq. (5.8) and v_t is the white noise.

5.3 Data and descriptive statistic

In this paper, I try to investigate the integration of stock markets, bond markets, and foreign exchange markets in CEEC-3 after the Euro enter into circulation. For the stock markets, I choose WIG Index, PX Index, and BUX Index for Poland, Czech Republic, and Hungary, respectively. For bond markets, I choose 10-year government bond yields for each country. For foreign exchange market, I use Euro based exchange rate for each country. All data are daily frequency from January 1, 2002 to September 10. 2013 (3051 observations). All data are from DataStream.

In all cases, the returns from market are calculated as one hundred times the first difference in the log of raw data. Table 5.1 summarized the statistical properties of the data. Table 5.2 present the unconditional correlation matrixes. The results of the Jarque-Bera test show that the null hypothesis of normal distribution is rejected for all cases. Therefore, I choose t distribution to deal with this kind of properties. The results of the Ljung–Box Q statistics (1978) also demonstrate the ARCH effects in the time series for all variables. Thus, the GARCH-based models are able to describe the series well. According to Table 5.2, it is straightforward to see that the degree of correlation between stock markets is highest, while the degree of correlation between foreign exchange markets is lowest.

5.4 Empirical results

Until now, I only describe the basic methodology and data properties in this paper. Still, I do not know how the correlation between the financial markets evolves with the time, especially after Euro comes to circulation. And this is a very important topic of integration of EU zone, particular, when CEEC-3 become EU members in 2004. In this section, I try to examine the dynamic equicorrelation of the financial markets in CEEC-3 by employing DECO model.

5.4.1 AR-GARCH specifications

The first step is designed to estimate the univariate AR(k)-GARCH(p, q) models for each series of returns. Table 5.3, 5.4, and 5.5 summarizes the estimation results for the AR(k)-GARCH(p, q) model for Poland, Czech Republic and Hungary, respectively. As indicated in this table, the AR(1)-GARCH(1, 1) specifications are suitable for foreign exchange markets; the AR(2)-GARCH(1, 1) specifications are suitable for stock markets; the AR(3)-GARCH(1, 1) specifications are suitable for bond markets. Second, all coefficients of the GARCH term (β) that have values less than one are statistically significant at the 1% level. Moreover, the sum of α and β is less than one indicating our models fit the data well. Finally, the t distribution is justified at the 1% significance level, suggesting that the tails of the error terms are heavier compared with the normal distribution and that ARCH effects exist.

Table 5.3, 5.4, and 5.5 also presents the $Q(s)$ and $Q^2(s)$ statistics, which aim to justify the empirical results of the AR-GARCH models. Its null hypothesis assumes that there is no autocorrelation up to lag s for standardized residuals. The $Q^2(s)$ statistic at lag s proposes a null hypothesis of no autocorrelation up to order s for standardized squared residuals. According to Table 3.3, the null hypothesis of no autocorrelation up to order 20 for standardized residuals and standardized squared residuals is accepted for all countries, supporting our model specifications.

5.4.2 DECO specifications

The second step is to estimate the DECO model based on the conditional variance from step one. Fig. 5.1, 5.2, and 5.3 illustrate the DECOs of stock markets, foreign exchange markets and bond markets among CEEC-3, respectively, while Fig 5.4 illustrates the DECO for the entire samples. Table 6 shows the results of the DECO model for the entire sample period.

As Table 5.6 shown, the sum of a and b is less than one for all cases, indicating that the DECO parameters are in the range of typical estimates from GARCH model. Moreover, rounded to three decimals place, the sum of a and b rounds to one, suggesting that the equicorrelation is nearly integrated. Fig 5.1 plots the fitted DECO of bond markets for CEEC-3. The clearest feature of the plot is the average correlation to suddenly decrease when European debt crisis occurs in 2011. However, the EU membership (EMU) in 2004 and the international financial crisis in 2008 have little effects on the average correlations. All this results indicate that the bond markets in CEEC-3 still have low degree of integration with the world financial markets. Fig 5.2 plots the fitted DECO of foreign exchange markets for CEEC-3. It is clear that the tendency of the average correlation to rise when the CEEC-3 becomes EU member after 2004. Nevertheless, the average correlation suddenly decreases when the international financial crisis in 2008 and European debt crisis in 2011 occur. Such phenomenon may contribute to the policy of exchange rate control and capital control employed independently by the CEEC-3's governments. Fig 5.3 plots the fitted DECO of stock markets for CEEC-3. I can see that the tendency of the average correlation to rise after the CEEC-3 joined to EU in 2004. However, the effect from 2008 international financial crisis and the 2011 European debt crisis still are unknown.

From the Fig 5.1, 5.2 ,and 5.3, I can compared the degree of integration of the different financial markets among CEEC-3. It is clear to see the stock markets show highest integrations while bond markets show lowest integrations. These results also indicate that the bond can be considered to be a good asset to diversify the stock heavy portfolio. In addition, in order to examine the capacity of diversification of the portfolio, I use equal weights to estimate the DECO of these nine assets. The estimated result is presented last column of Table 5.4 and DECO is plotted in Fig 5.4. It is obviously to see that the average correlation of these nine assets is less than the average correlation of bond markets, foreign exchange markets, or stock markets solely. Our results also demonstrate the benefit to diversify the portfolio in different asset across the countries.

5.4.3 AR Model for the Estimated Dynamic Equiorrelation

To specify and confirm our findings, I use the AR(1) models to describe the trend in estimated DECOs by taking account of the dummy variables. Table 5.7 presents the results of these estimations. Both the constant term (δ_0) and the AR term (δ_1) are shown to be significant at the 5% level for all sample countries. Moreover, as observed in the figures, the EMU effect (δ_3) is significant at 5% level for both stock markets and foreign exchange markets. Meanwhile, I can observe the contagion effect occurred in both stock markets and foreign exchange markets across countries since parameters δ_4 and δ_5 are positive with a significant level at 10%. However, the events affect the DECO of bond market little. For the investors, I also investigate what kind of effect on our portfolio from these events. As stated in the final column of Table 5.7, I still can obtain the diversification benefit from these countries since the parameters δ_3, δ_4 and δ_5 are negative. Particularly, only the parameters δ_3 and δ_5 are significant at 5% level indicating that the financial markets in CEEC-3 are more sensitive to the local shock than the international shock. And I can state that the financial market in CEEC-3 still have long way to go to integrate their markets to the world market.

5.5 Conclusion

In this paper, I investigate the equicorrelaiton of financial markets in CEEC-3 based on the DECO model (Engle and Kelly, 2012). Moreover, I choose stock market, foreign exchange market, and bond market to represent the financial markets in CEEC-3. By analyzing the average correlations of stock markets, foreign exchange markets, and bond markets, I find that these markets still not integrate with the world financial market well. For instance, the 2008 international financial crisis hardly influence the equicorrelation of bond market in CEEC-3. By comparing the average correlation among the different markets, I find that the stock markets show highest degree of integration while the bond markets show lowest degree of integration among CEEC-3. Particularly, as to foreign exchange market and stock market I find that it sensitively to not only local shock but also international shock indicating a high degree of integration with the world financial markets.

Since CEEC-3 joined EU in 2004, I also examine the EUM effect based on the DECOs for different financial markets. Our results show that the degree of integration for both foreign exchange market and stock market increases after 2004. Only exception is the bond market. Meanwhile, I also demonstrate the benefit of diversifications among the different asset across countries.

Our results have at least one implication for policymakers and one implication for investors.

For the policymakers, I find that even though the degree integration of financial markets in CEEC-3 increase after 2004, the degree of integration with the world financial market is still low. For the investors, it is our best interest to diversify our portfolio in different asset across the countries.

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Table 5.1
Descriptive statistics

	Czech Republic			Hungary			Poland		
	Stock	FX	Bond	Stock	FX	Bond	Stock	FX	Bond
Mean	0.006	−0.006	0.006	0.041	0.029	0.031	−0.020	−0.022	−0.003
Std.	0.648	0.411	0.648	1.278	1.476	1.609	1.147	1.450	1.465
Skew	0.221	−0.080	0.627	−0.379	−0.546	−0.104	0.649	0.110	0.001
Kurtosis	8.636	7.277	11.12	6.380	17.16	9.58	23.681	24.46	11.93
J-B test[13]	4063	2328	8590	1525	25658	5519	54591	58572	10154
Q(20)[14]	78.13	43.11	69.46	69.22	63.69	44.22	31.63	66.96	84.42
Obs	3051	3051	3051	3051	3051	3051	3051	3051	3051

Notes: Stock, FX, and Bond denote stock market, foreign exchange market, and bond market, respectively.

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[13] J-B test denotes Jarque-Bera test. And all of observations are significant at 1% level.

[14] *Q*(20) is the Ljung–Box *Q* statistic for the null hypothesis that there is no autocorrelation up to order 20 for residuals. And all of observations are significant at 1% level.

Table 5.2
Unconditional correlation matrix

	Stock			FX			Bond		
	CZ	HU	PO	CZ	HU	PO	CZ	HU	PO
CZ	1.000			1.000			1.000		
HU	0.568	1.000		0.179	1.000		0.115	1.000	
PO	0.626	0.588	1.000	0.182	0.589	1.000	0.168	0.233	1.000

Notes: Stock, FX, and Bond denote stock market, foreign exchange market, and bond market, respectively. CZ, HU, and PO denote Czech Republic, Hungary, and Poland respectively.

Table 5.3

Empirical results of the AR(k)-GARCH(1, 1) model for Poland.

	Poland		
	Stock	FX	Bond
Mean Equation			
C	0.074(0.017)***	−0.021 (0.008)***	−0.028 (0.012)**
$AR(1)$	0.034(0.017)**	−0.054 (0.019)**	−0.020 (0.018)
$AR(2)$	−0.017(0.016)		−0.007 (0.018)
$AR(3)$			−0.035 (0.016)**
Variance Equation			
ω	0.015(0.005)***	0.005(0.001)***	0.021 (0.007)***
α	0.062(0.009)***	0.074 (0.011)***	0.122 (0.025)***
β	0.930(0.009)***	0.914 (0.012)***	0.872 (0.022)***
T DOF	6.358(0.740)***	6.310 (0.715)***	3.747 (0.295)***
Log likelihood	−4671.9	−2456.3	−3967.6
Diagnostic			
$Q(20)$	17.657[0.411]	17.896 [0.395]	28.091 [0.438]
$Q^2(20)$	29.253[0.322]	13.495 [0.702]	8.405 [0.493]

Notes: Stock, FX, and Bond denote stock market, foreign exchange market, and bond market, respectively. The numbers in parentheses are standard errors. The numbers in square brackets are p-values. $Q(20)$ ($Q^2(20)$) is the Ljung–Box Q statistic for the null hypothesis that there is no autocorrelation up to order 20 for standardized residuals (standardized squared residuals). * ,** and *** represent significance at the 10%, 5% and 1% levels, respectively.

Table 5.4

Empirical results of the AR(k)-GARCH(1, 1) model for Czech Republic.

	Czech Republic		
	Stock	FX	Bond
Mean Equation			
C	0.096 (0.018)***	−0.008 (0.006)	−0.033 (0.016)**
$AR(1)$	0.032 (0.019)*	0.025 (0.019)	−0.014 (0.018)
$AR(2)$	−0.043 (0.021)		−0.044 (0.017)**
$AR(3)$			0.028 (0.017)*
Variance Equation			
ω	0.045 (0.010)***	0.002 (0.000)***	0.071 (0.019)***
α	0.113 (0.014)***	0.076 (0.011)***	0.168 (0.034)***
β	0.863 (0.016)***	0.914 (0.013)***	0.826 (0.028)***
T DOF	6.513 (0.713)***	7.629 (0.984)***	3.352 (0.244)***
Log likelihood	−4769.4	−1131.4	−4602.1
Diagnostic			
$Q(20)$	25.212 [0.161]	15.867 [0.533]	15.525 [0.557]
$Q^2(20)$	19.268 [0.313]	15.461 [0.562]	0.257 [1.000]

Notes: Stock, FX, and Bond denote stock market, foreign exchange market, and bond market, respectively. The numbers in parentheses are standard errors. The numbers in square brackets are p-values. $Q(20)$ ($Q^2(20)$) is the Ljung–Box Q statistic for the null hypothesis that there is no autocorrelation up to order 20 for standardized residuals (standardized squared residuals). * ,** and *** represent significance at the 10%, 5% and 1% levels, respectively.

Table 5.5

Empirical results of the AR(k)-GARCH(1, 1) model for Hungary.

	Hungary		
	Stock	FX	Bond
Mean Equation			
C	0.061 (0.022)***	−0.018 (0.007)***	−0.024 (0.015)
$AR(1)$	0.011 (0.019)	−0.014 (0.019)	0.033 (0.018)*
$AR(2)$	−0.038 (0.018)**		−0.035 (0.016)**
$AR(3)$			−0.021 (0.016)
Variance Equation			
ω	0.044 (0.012)***	0.003 (0.001)***	0.181 (0.063)***
α	0.081 (0.012)***	0.105 (0.019)***	0.158 (0.056)***
β	0.900 (0.014)***	0.873 (0.014)***	0.779 (0.034)***
T DOF	8.706 (1.285)***	4.216 (0.334)***	2.438 (0.149)***
Log likelihood	−4769.4	−2302.9	−4671.9
Diagnostic			
$Q(20)$	14.672 [0.619]	19.275 [0.313]	28.717 [0.372]
$Q^2(20)$	18.160 [0.378]	0.794 [1.000]	7.330 [0.979]

Notes: Stock, FX, and Bond denote stock market, foreign exchange market, and bond market, respectively. The numbers in parentheses are standard errors. The numbers in square brackets are p-values. $Q(20)$ ($Q^2(20)$) is the Ljung–Box Q statistic for the null hypothesis that there is no autocorrelation up to order 20 for standardized residuals (standardized squared residuals). * ,** and *** represent significance at the 10%, 5% and 1% levels, respectively.

Table 5.6
DECO

	Stock	FX	Bond	CEEC-3
a	0.019 (0.004)***	0.016 (0.003)***	0.079 (0.012)***	0.053 (0.016)***
b	0.973 (0.006)***	0.981 (0.004)***	0.895 (0.017)***	0.850 (0.055)***
Log likelihood	−11618.9	−12792.1	−12405.2	−38446.9

Notes: Stock, FX, and Bond denote stock market, foreign exchange market, and bond market, respectively. The numbers given in parentheses are standard errors. *** means statistical insignificance at the 1% level. The restriction condition is $a + b < 1$.

Table 5.7
Regression of equicorrelation evolution for several key events.

	Stock	FX	Bond	CEEC-3
$\delta_0 \times 10^{-3}$	4.038 (1.218)***	1.206 (0.598)**	10,25 (1.943)***	6.380 (0.635)***
δ_1	0.991 (0.003)***	0.992 (0.002)***	0.934 (0.006)***	0.890 (0.008)***
$\delta_2 \times 10^{-3}$	1.872 (0.586)***	1.232 (0.577)**	1.764 (1.996)	−0.954 (0.449)**
$\delta_3 \times 10^{-3}$	1.699 (0.828)**	1.322 (0.706)*	−4.048 (2.676)	−0.925 (0.660)
$\delta_4 \times 10^{-3}$	1.182 (0.724)*	1.299 (0.711)*	−2.405 (2.537)	−1.859 (0.641)***
Log likelihood	9424.3	9531.4	5381.1	9641.7

Notes: Stock, FX, and Bond denote stock market, foreign exchange market, and bond market, respectively. The numbers given in parentheses are standard errors. * ,** and *** represent significance at the 10%, 5% and 1% levels, respectively.

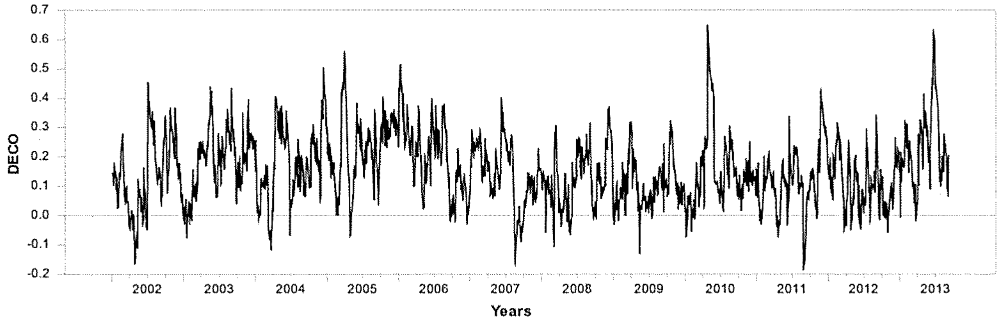

Fig.5.1. The dynamic equicorrelations for bond markets of CEEC-3..

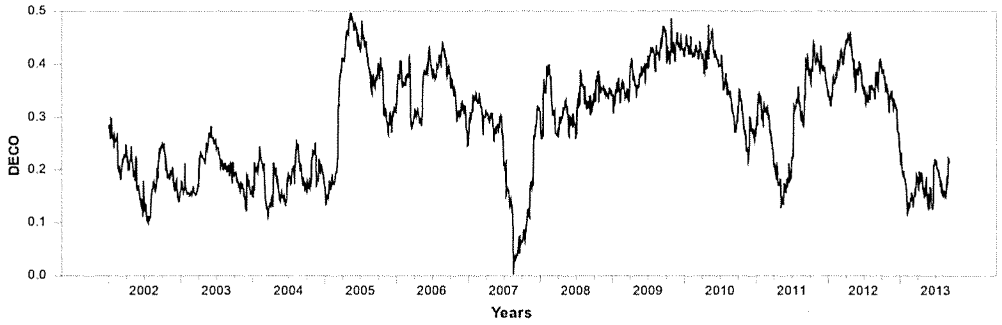

Fig.5.2. The dynamic equicorrelations for foreign exchange markets of CEEC-3.

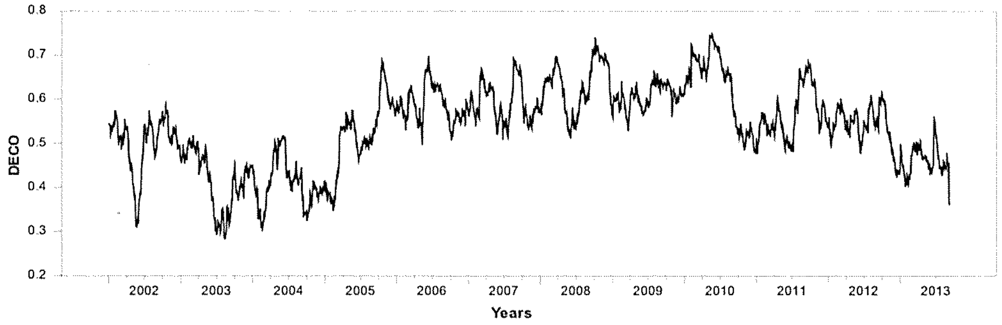

Fig.5.3. The dynamic equicorrelations for stock markets of CEEC-3.

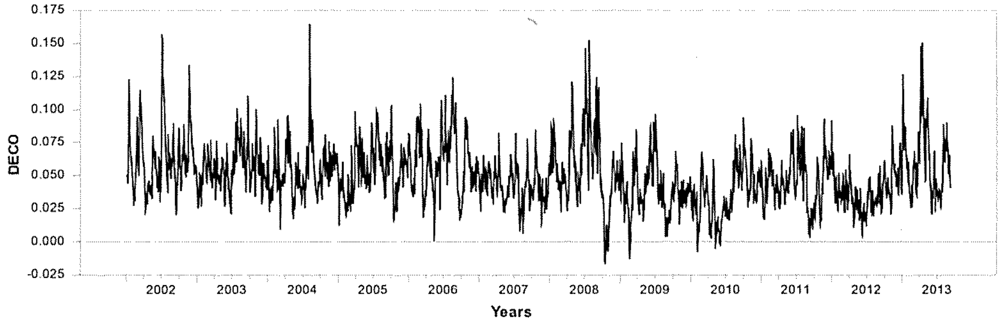

Fig.5.4. The dynamic equicorrelations for the financial markets of CEEC-3.

Chapter 6

In this thesis, I analyze the integration degree of financial markets between CEEC-3 and Germany by applying four different models. By employing the ADCC-GARCH model, I find that financial integration had already begun to evolve before the EU accession in 2004 in Czech Republic, while the financial integration process continues to advance in Poland but not in Hungary. Second, the bond markets in both Poland and Hungary decreased their dependence on that in Germany during the global financial crisis period. Finally, financial contagion did not occur across bond markets in CEEC-3 and Germany during the European sovereign debt crisis period. By separating the whole sample into four subsamples, I then compared the asymmetric effect of volatility on the correlations by period. First, in Poland, which is the largest economy in CEEC-3, even though the asymmetric effect exists throughout the whole sample period, the real asymmetric effect was felt from the beginning of the EMU period to the beginning of the global financial crisis. Second, the bond market in Hungary had no asymmetry effect in the whole sample period or in any of the subsample periods. Finally, the asymmetric effect existed only in the calm period before joining the EU for Czech Republic. In summary, the presented evidence confirms the fact that I observe the asymmetric effect when bond markets are calm.

Using copula models, I find that the dependence between CEEC-3 and Germany is greater in bond markets than it is in treasury markets, indicating that integration is greater for the long-term rather than the short-term interest rate. In particular, the degree of dependence increases significantly after EU accession for the long-term interest rate in the Czech Republic and Poland, indicating that the integration of the EU bond market is at an advanced stage (Kim et al., 2006). However, I also find that the degree of dependence of the bond markets between CEEC-3 and Germany decreases during the crisis period, which indicates that the bond markets in this area are only partially integrated (Abad et al., 2010). By applying Genest et al.'s (2009) GOF test, I find that the structural dependence between the treasury markets of CEEC-3 and Germany as well as between the bond markets of Poland and Germany is symmetric in both the pre-EU and the EU periods. However, right-side dependence is observed only between the bond markets of the Czech Republic and Germany in the pre-EU period, while left-side dependence is witnessed only between the bond markets of Hungary and Germany in the EU period. Further, I also examine the low level of weak left tail dependence (Clayton copula) between Poland and Germany in the treasury market during the crisis period, however, the dependence structure between CEEC-3 and Germany in the bond market seems to be symmetric.

Based on wavelet coherence analysis, I find that a contagion effect occurred in these markets during the two recent crises. In addition, the degree of bond market integration was relatively high before 2004 for both Poland and Hungary and very high throughout the entire sample period for Czech Republic. Moreover, by analyzing the phase pattern, I showed that the interest rate movements in both Poland and Czech Republic mirror those in Germany for the sample period, while the interest rate movements in Hungary mirror those in Germany before 2003. However, the transmission channel for the global financial crisis is from Germany to Hungary, whereas that for the European debt crisis is not from Germany but rather from other countries.

Applying the DECO-GARCH model, I find that these markets still not integrate with the world financial market well. For instance, the 2008 international financial crisis hardly influence the equicorrelation of bond market in CEEC-3. By comparing the average correlation among the different markets, I find that the stock markets show highest degree of integration while the bond markets show lowest degree of integration among CEEC-3. Particularly, as to foreign exchange market and stock market I find that it sensitively to not only local shock but also international shock indicating a high degree of integration with the world financial markets. Since CEEC-3 joined EU in 2004, I also examine the EUM effect based on the DECOs for different financial markets. Our results show that the degree of integration for both foreign exchange market and stock market increases after 2004. Only exception is the bond market..

Though the empirical results conflict occasionally, the possible reasons may due to the different econometric models. For example, I demonstrate that the asymmetry between Poland and Germany exist after EU accession in the chapter 1 while the asymmetry during the crisis period in the chapter 2. The possible reason may be due to the choices of best-fit copula based GOF test. Moreover, I demonstrate that contagion effect does not occur (the degree of dependence of bond decreases) during the crisis period from volatility-based model (ADCC-GARCH, copula-GARCH) while the contagion effect does occur at the long-term scales from mean-based model (wavelet coherence analysis). Since the volatility-based model examine the dependence at the current time while wavelet coherence analysis examine the dependence at the different time scale, the different results from them is reasonable.

Based on above discussions, the thesis provides the following implications: (1) financial integration with the EU has reduced investors' diversification benefits (Kim et al., 2006; Lamedica and Reno, 2007) but these gains still existed during the crisis period. For example, Poland and Czech Republic recover quickly from global financial crisis due to their floating exchange rate system and competitiveness towards key European trading partners, particularly towards Germany. (2) Monetary and economic policy coordination is still required to relieve the saving-investment imbalance between CEEC-3 countries and Germany, especially for Hungary. Firstly, during the period 2004/5-2007/8, all three economies were all running current account deficits in double digits. Secondly, these imbalances were driven by massive inflow of foreign direct investments remained around 10% of GDP. Finally, the fast rise in domestic household borrowing is fueled by cross-border loans that, for instance, made up close to 2/3 of all domestic credit in the these economies in 2007, especially from Germany. (3) By comparing phase patterns can also provide investors with useful information on the transmission of asset prices. For example, investors may hedge risk in one market when they can foresee a slump in another market. The Eastern European financial market was shown to transfer volatility risk to the Czech markets from Germany during the global financial crisis period.