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Testing for Financial Contagion: New Evidence from the European Debt Crisis

Summary: This paper tested for a contagion effect between the foreign exchange market of the Eurozone and the markets of seven emerging and growth leading economies - EAGLEs - during the European Debt Crisis. For this purpose, we used the daily domestic currency per unit of US Dollar of seven EAGLEs countries from 01.01.2007 to 31.12.2012. The tranquil period was from 01.01.2007 to 19.10.2009 and the turmoil period was from 20.10.2009 to 31.12.2012. We found a contagion effect between the foreign exchange market of the Eurozone and the markets of Brazil, Mexico, and Turkey. The evidence suggests that foreign trade is likely to be the source of the contagion during the European Debt Crisis. The evidence presented in this paper is important for policy makers, international investors, and portfolio managers.

Key words: Financial contagion, Economic crisis, European debt crisis, DCC-GARCH.

JEL: E44, F31, G01.

The global crisis of 2008-2009, which was the biggest economic crisis since the Great Depression, started with the declaration by Bear Stearns, one of the biggest banks of the US, that two hedge funds had collapsed. This became a global liquidity crisis following the bankruptcy of Lehman Brothers, one of the most important investment banks. Although the US mortgage market-based crisis was a credit crisis that initially only affected developed countries, it resulted in a European Debt Crisis (EDC) that later spilled over into developing countries and became severe, especially in 2010. The spillover effect of unanticipated local shocks that affect the expectations of investors, any adverse effect on the economic data of a country notwithstanding, in other countries during periods of crisis is called pure contagion (Marcello Pericoli and Massimo Sbracia 2003). Kristin Forbes and Roberto Rigobon (2002) define contagion as an increasing correlation between markets during a crisis period. Because two markets are mutually correlated during periods of stability, contagion therefore exists if cross-market co-movement increases significantly when a shock to one market affects other markets (Forbes and Rigobon 2002; Sibel Çelik 2012).

The aim of this study is to test for the contagion of EDC, which started in Greece and spilled over to the Eurozone, to emerging and growth leading economies - EAGLEs countries - and to reveal the channels of contagion. EAGLEs, an economic

concept introduced by BBVA research in November 2010, refers to a group of countries whose incremental GDP in the next 10 years is expected to be larger than the average of the G7 economies, excluding the US. EAGLEs consists of seven countries: Brazil, China, India, Indonesia, Mexico, Russia, and Turkey. This study differs from others in that it addresses the contagion spreading through foreign exchange markets and aims to detect the source, through international trade channels or financial channels, and also examines its effects on EAGLEs. Focusing on foreign exchange markets reduces the problems caused by the differences in time zones of markets. The findings of the paper are important in terms of its influence on important decisions relating to monetary policy, asset allocation, risk management, capital adequacy, and asset pricing. This study also contributes to the literature in terms of methodology and interpretation of the findings, and provides useful insights for policy-makers in the field of international economics and finance.

The following chapter reviews the literature related to contagion of crises, the second chapter presents the study data, and the third chapter defines the methodology. The fourth chapter presents the analysis and key findings, which is then followed by suggestions and conclusions in the final chapter.

1. Literature Review

Contagion in financial markets may occur in different ways. If spillover is based on macro-economic fundamentals as a result of normal cross-market linkages, it is called fundamental-based contagion (Rudiger Dornbusch, Yung Chul Park, and Stijn Claessens 2000). If spillover occurs as a result of unverified market information and irrational investor behaviors, rather than macro-economic indicators, it is called herd behavior contagion (Thomas Moser 2003). If an increase in permanent and common interaction between asset prices arises from structural changes in the channels transmitting common shocks in periods of crisis, it is called change contagion (Nathaniel Frank and Heiko Hesse 2009). If contagion arises from behaviors, future expectations, or the decisions of several investors (who unconsciously influence each other) and becomes common behavior, it is called emotional contagion. If positive expectations are related to the spillover, it is called positive contagion, while negative expectations affecting investors' vulnerability is known as negative contagion (Elaine Hatfield, John T. Cacioppo, and Richard L. Rapson 1994). The development of international commerce, liberalization policies in financial markets, the irrational emotional behavior of investors, and developments in information technologies have caused many different positive and negative events to be triggered and extended across the markets. Therefore, identification of degrees of spillover and modes of contagion in terms of the negative impacts of crises spreading from one country to another has become one of the most important economic issues.

Following the economic crises at the end of the 1980s and the beginning of the 1990s, an extensive literature emerged that defined and reviewed contagion. The concept of contagion then began to be used more frequently in the literature, especially after the 1997-1998 Asian financial crisis. When the crisis in Thailand arose following devaluation in 1997, it penetrated Indonesia, Philippines, Malaysia, Hong Kong, and Korea. Knowing why the original crisis spilled over was therefore as important as

knowing what triggered the events in Thailand. Scholars argued that foreign currency crises may result in contagion through direct economic routes, such as bilateral commercial dealings, or through indirect linkages, such as changes in investor behavior. Some of the important statements on financial contagion were based on changes in investor behavior after the Russian crisis in 1998. This was followed by the global crisis of 2008-2009 which arose first in developed countries and then deeply affected both developed later and developing countries. A few years after the global crisis, EDC emerged as a huge global threat. During this period, the concept of contagion became increasingly prevalent in the literature, emphasizing that the developing countries are especially vulnerable to crisis due to their interdependent financial markets, the risks of banks, and real sector channels (Claessens and Forbes 2001; Joshua Aizenman et al. 2016).

Articles in the literature have tested for the existence of a contagion effect of economic crises in various financial markets such as Stock Exchange Markets, Foreign Exchange Markets, Bond Markets, Derivatives Markets, and Credit Default Swap Markets (Brian Boyer, Tomomi Kumagai, and Kathy Yuan 2006; Mardi Dungey et al. 2006; Neeltje Van Horen, Henk Jager, and Frank Klaassen 2006; Thomas C. Chiang, Bang Nam Jeon, and Huimin Li 2007; Sheng Chu Tai 2007; Jang Hyung Cho and Ali M. Parhizgari 2008; Virginie Coudert and Mathieu Gex 2008; Saleheen Khan and Kwang Woo Park 2009; Dimitris Kenourgios, Aristeidis Samitas, and Nikos Paltalidis 2011; Meriam Chihi Bouaziz, Nadhem Selmi, and Youness Boujelbene 2012; Kenourgios and Puja Padhi 2012; Costas Karfakis and Theodore Panagiotidis 2015; Bong Han Kim, Hyeongwoo Kim, and Bong Soo Lee 2015). Several studies analyzed the spillover mechanisms of crisis from one country to another in terms of international commercial linkages and real sectors other than financial markets (Paulo Horta, Carlos Mendes, and Isabel Vieira 2010; Dirk G. Baur 2012; Kenourgios and Dimitrios Dimitriou 2014). Recent studies in contagion literature can be categorized as studies that only analyze the US global crisis (Baur 2012; Dimitriou, Kenourgios, and Theodore Simos 2013; Geert Bekaert et al. 2014; Horta, Sérgio Lagoa, and Luís Martin 2016), studies that only analyze EDC (Carlos Caceres, Vincenzo Guzzo, and Miguel Segoviano Basurto 2010; Go Tamakoshi, Yuki Toyoshima, and Shigeyuki Hamori 2012; Mark Mink and Jakob De Haan 2013; Samitas and Ioannis Tsakalos 2013; Tamakoshi and Hamori 2013) and studies that analyze both (Karfakis and Panagiotidis 2015; Aizenman et al. 2016). Some of these studies underline the fact that developing countries are more vulnerable to shocks than developed countries, especially in periods of crisis (Kee Hong Bae, Andrew G. Karolyi, and Renee M. Stulz 2003; Kim, Kim, and Lee 2015; Aizenman et al. 2016), while others have aimed to reveal the relations between markets during and after a crisis (Bouaziz, Selmi, and Boujelbene 2012; Karfakis and Panagiotidis 2015).

For instance, Kim, Kim, and Lee (2015) reviewed the US global crisis and aimed to identify the existence of a contagion effect in financial markets. The authors suggested a new approach that simultaneously estimated conditional correlation coefficient and the effects of temporal predictive factors in order to estimate the dynamic conditional correlation of financial asset returns. This enabled them to test the contagion spillover effect of the global crisis on developing Asian countries. Using the

MGARCH model, they concluded that foreign exchange markets have a stronger spillover effect than the stock exchange market. Karfakis and Panagiotidis (2015), using the GARCH model and a dynamic conditional correlation method, analyzed three different exchange rates to test for the effect of financial contagion on foreign exchange markets. Following the collapse of Lehman Brothers, they found financial contagion was present for foreign exchange markets. Horta, Lagoa, and Martin (2015) researched whether there was contagion from the NYSE Euronext group to the European Stock Exchange Market during the global crisis. They conducted their analysis using dynamic conditional correlation and Copula models and identified financial contagion in all the stock exchange markets analyzed. They concluded that the market in France has a higher correlation than the markets in Belgium, the Netherlands, and Portugal. Bekaert et al. (2014) examined the transfer of the 2007-2009 financial crisis to the industrial stock portfolios of 415 countries and found evidence of contagion arising from both the United States financial markets and the global financial sector, which resulted in a small impact on the stock portfolios. They concluded that there was considerable contagion in the domestic market stock portfolios of individual investors. Kenourgios, Dimitriou, and Apostolas Cristopoluos (2013) analyzed the contagion effect of the 2007-2009 global financial crisis on numerous asset markets and several regions. They identified an information channel that acted as a contagion mechanism among US stocks, real estate, commodities, and the emerging Brazilian market bond index. Using the DCC-GARCH model, Bouaziz, Selmi, and Boujelbene (2012) reviewed the contagion effects of the US stock market on the markets of developed countries during the economic crisis that originated from the US property market. They found that relations between the markets increased during the crisis and therefore it had spilled over into many markets. Alexander Chudik and Marcel Fratzscher (2012), using the VAR method, showed that investors secured themselves during the US crisis and financial capital was transferred from developing economies to the US bond market and other developed economies. Riadh Aloui, Mohamed Safouane Ben Aïssa, and Duc Khuong Nguyen (2011) investigated the scope of the current global crisis and its contagion effect by conducting an empirical review of BRIC countries' excessive financial dependence on the United States. They found powerful evidence for time-varying interdependence between BRIC and US markets. To describe interdependence between financial markets, Lalith P. Samarakoon (2011) created shock models examining the transfer of shocks induced by contagion of the US financial crisis between US and foreign markets. He identified major regional changes as well as significant bi-directional, albeit asymmetric, interdependence and contagion between the US and emerging markets, with dramatic variations in different regions.

Using a cross-country multiple indicator multiple cause model, Andrew K. Rose and Mark M. Spiegel (2010) sought to determine whether there was a contagion spillover of the 2008 financial crisis from the US to other countries using both financial and real channels. They could not find a strong relationship between international linkages and the possibility of crisis. Wei Zhou (2017) examined the dynamic and asymmetric contagion reactions of financial markets caused by low-income group loans during the latest crisis and found that financial contagion reactions are predictive of changes in financial markets and can thus provide indications for risk management

during crisis periods. Kenourgios and Dimitriou (2014) analyzed the contagion effects of the crisis for the real sector as well as the financial sector. To do so, they conducted a regional and comparative analysis of the contagion effect of the global crisis on both sectors. The results showed that the global crisis affected all sector indexes in the US, while many regional sectors in Europe were not affected. Kenourgios and Dimitriou (2015) then investigated the contagion effects on ten sectors in six developed and developing regions during different phases of the crisis. They analyzed different financial contagion channels between territories and real economy sectors using dynamic conditional correlation from the multivariate Fractional Integrated Asymmetric Power ARCH model. They found that the global financial crisis could be characterized by the effects of contagion between regional stock markets and financial and non-financial sectors. Baur (2012) explored the contagion effect of 2007-2009 global crises from the financial sector to the real economy by reviewing 10 sectors in the securities markets of 25 major developed and newly developing countries. Baur (2012) concluded that crises caused financial sector capitals to move increasingly "between countries" and "between financial sector and real economy capital". Baur (2012) also concluded that sectors such as health, telecommunication, and technology are less affected by crises. Horta, Mendes, and Vieira (2010) compared the effects of contagion on the financial sector and the industrial sector by analyzing the effects of the NYSE - Euronext group on the European market during the US high interest rate crisis. They focused on the financial and industrial sectors in the stock exchange markets of four European countries and concluded that contagion from the US high interest rate crisis spilled over into all the markets analyzed.

The methods used differ in literature related to EDC. Event study, copula models, and the standard contagion test are all frequently used. The common ground in many studies regarding the crisis in European regions is a focus on the spillover modes of country-specific shocks to other countries. For instance, Mink and De Haan (2013) argue that the decline of credit rate in a country, statistically and economically, has a spillover effect on both countries and financial markets. They used an event study approach to analyze the effects of credit rate decline in Greece on the stock returns of 48 commercial banks. They found that the news on Greece had not resulted in extraordinary returns, excluding the banks, whereas the news on the recovery package had resulted in extraordinary returns for Greece and other countries of the Eurozone who were highly in debt. Roberto A. De Santis (2014) conducted a similar study of how the credit rate decline in Greece affected other countries in the Eurozone using complementary approaches. De Santis (2014) concluded that the spillover effect originating from Greece resulted in increases in exchange differences, increases in the need for foreign capital, and decreases in competitive capacity in countries with relatively poor financial fundamentals. Caceres, Guzzo, and Basurto (2010) established a spillover coefficient for 10 countries of the Eurozone by assessing the Eurozone spreads as spreads in common metric standard in government bond returns. They concluded that challenges in one country increase the possibility of a credit problem in other countries. A similar study, which sheds light on the spillover of country-specific shocks to other countries, was conducted by Albi Tola and Sebastien Walti (2015). Using a standard contagion test for 9 Eurozone countries, they discussed bond markets in connection

with country-specific shocks and developed an approach to distinguish global shocks and Eurozone shocks from country-specific shocks. They concluded that three-quarters of country-specific shocks spilled over into the Eurozone. Samitas and Tsakalos (2013) used an asymmetric dynamic conditional correlation model and copula function to search for correlation dynamics between Greek and European markets during the debt crisis. They found that the Greek Debt Crisis arose after the mortgage crisis with high interest rates and that the debt incurred by Greece had not affected European markets. They argued that a contagion effect was present in the collapse period, but this was not the case during the Greek Debt Crisis.

In comparative studies of the effects of the global crisis period and EDC, Aizenman et al. (2016) reviewed the spillover effect of both crises on developing countries using event study methodology. They concluded that the global crisis clearly has a negative effect on stock markets and bond markets in developing countries; however, they could not establish a systematic model capturing the effect that news on the Eurozone crisis had on financial markets in developing countries. They therefore concluded that the Eurozone crisis was limited to the Union.

2. The Data and Crisis Period

2.1 The Data

This paper assesses the contagion effect between the foreign exchange market of Eurozone and the exchange markets of seven emerging and growth-leading economies (EAGLEs) during the EDC. For this purpose, the dataset includes the daily domestic currency per unit of US Dollar of seven EAGLEs countries: Brazil (BRL/USD), China (CNY/USD), India (INR/USD), Indonesia (IDR/USD), Mexico (MXN/USD), Russia (RUB/USD), and Turkey (TRY/USD). EUR/USD represents the domestic currency of the Eurozone since the first sign of EDC emerged in Greece for the period 01.01.2007-31.12.2012. There are several reasons for using foreign exchange market data to test the contagion effect. First, the foreign exchange market continuously operates 24 hours a day except for weekends and is the most liquid financial market in the world; this reduces the problem of different time zones between the countries. Second, most of the literature on contagion of crises has focused on the stock market, bond, or CDS market. Therefore, the evidence from foreign exchange markets contributes to the existing literature.

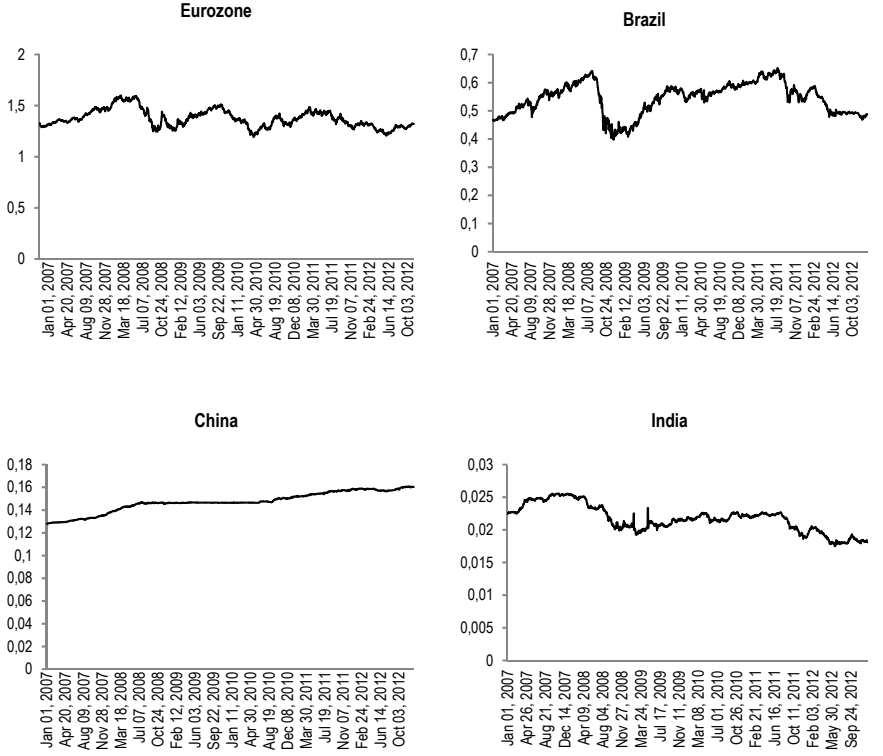
2.2 Identification of Crisis Period

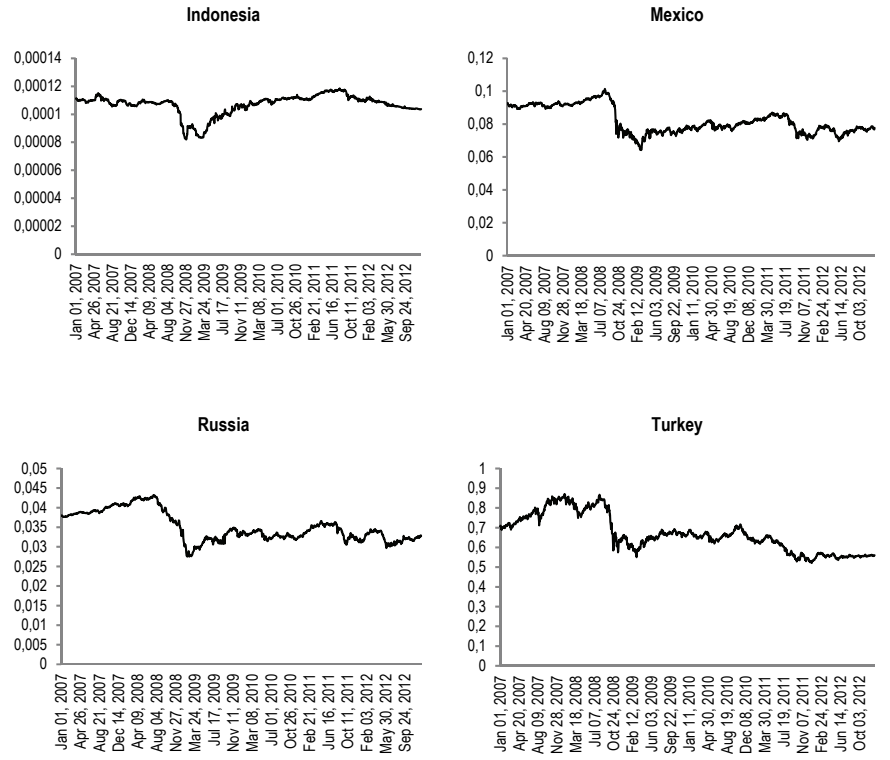
The detection of a crisis period in the literature is somewhat controversial. However, there are two main approaches to doing so (Dungey et al. 2011). The first method is based on *ex post* observation of events (Forbes and Rigobon 2002; Dungey et al. 2006; Dungey 2009). The second method is based on the threshold models (Barry Eichengreen, Rose, and Charles Wyplosz 1996; Julia Lowell, Carl Richard Neu, and Daochi Tong 1998; Carlo A. Favero and Francesco Giavazzi 2002). We used an event based approach to identify the crisis period and therefore identified 20 October 2009 as the beginning of the EDC. This date coincides with the day when the Greek Government announced that the public deficit of Greece was expected to be 12.5% of GDP,

although this was previously calculated as 6%. There are many papers in the literature which use this date as the beginning of EDC (Karfakis and Panagiotidis 2015). Consequently, the entire dataset in this paper runs from 01.01.2007 to 31.12.2012. The tranquil period is from 01.01.2007 to 19.10.2009 and the turmoil period is from 20.10.2009 to 31.12.2012.

2.3 Data Analysis

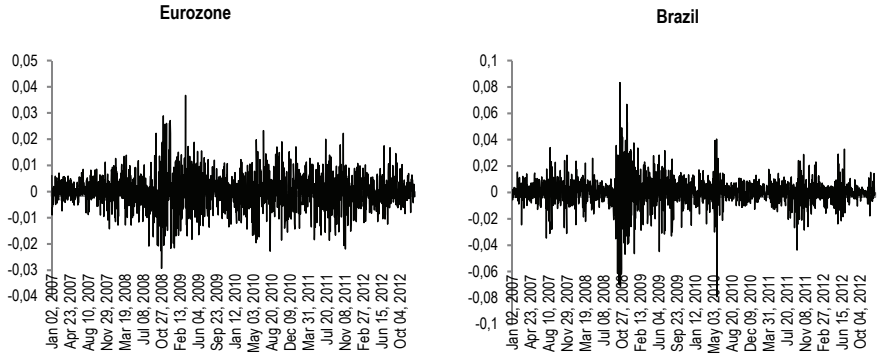
The return on domestic currencies is calculated as follows: $ln(P_t/P_{t-1})$, where P_t is the price level of domestic currency at time t. The graphs of price and return on domestic currencies are presented in Figure 1 and Figure 2 respectively.

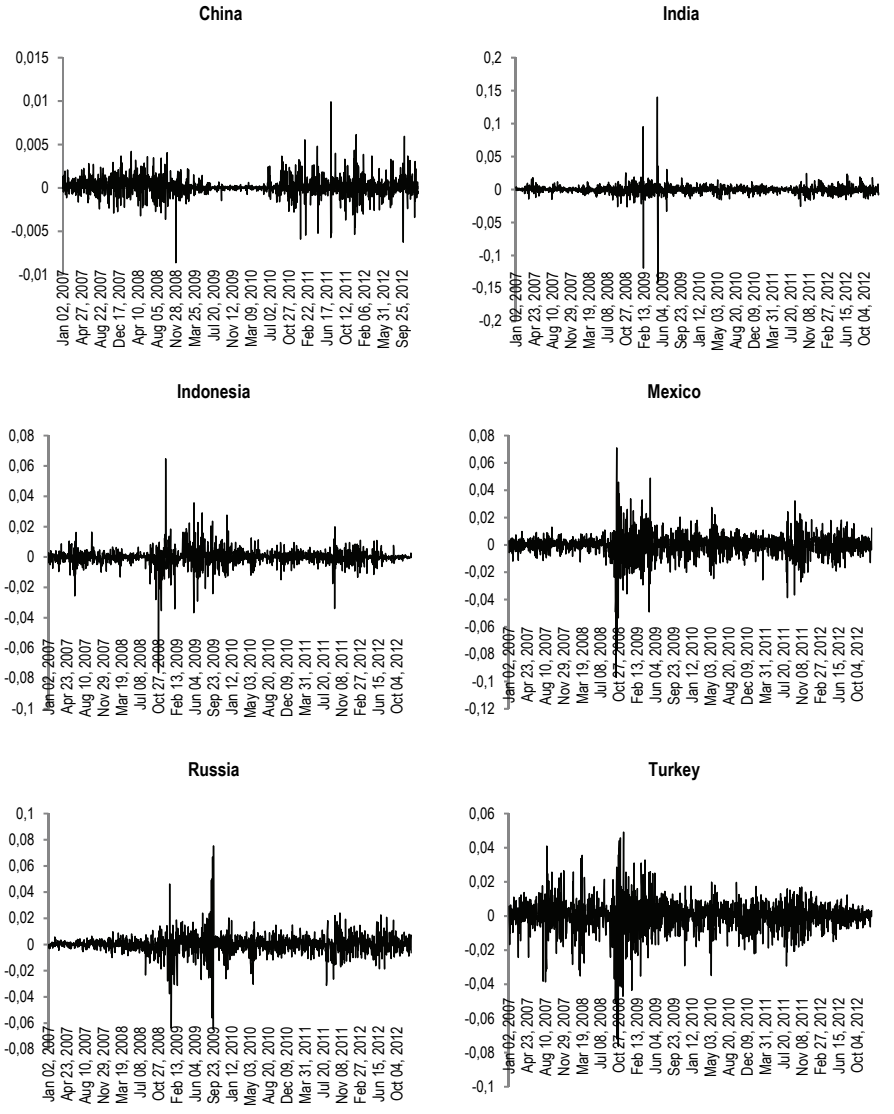




Source: Authors' calculations.

Figure 1 Time Series of Domestic Currencies





Source: Authors' calculations.

Figure 2 Time Series of Each Domestic Currency Return

Table 1 presents descriptive statistics for domestic currency returns over the tranquil period, turmoil period, and whole period, respectively. Except for Mexico and Russia, the means of the domestic currency returns during the tranquil period are higher than those during the turmoil period. Unexpectedly, except for China, the standard deviations of the returns are higher in the tranquil period than those of the turmoil

period. According to the Jarque-Bera test, none of the time series of currency returns show normal distribution in all periods.

Table 1 Descriptive Statistics for Domestic Currencies

Tranquil period: (01.01.2007 to 19.10.2009)

Country	Mean	Median	Maximum	Minimum	Std. dev.	Skewness	Kurtosis	JB
Eurozone	0.000172	0.000283	0.036720	-0.029330	0.007305	0.168216	5.438228	184.2685***
Brazil	0.000306	0.000938	0.083363	-0.071210	0.014200	-0.391060	8.862429	1060.968***
China	0.000186	0.000042	0.004209	-0.008610	0.001050	-0.542790	10.64771	1814.839***
India	-0.000074	-0.000052	0.140061	-0.140770	0.011077	-0.852440	97.50885	271767.7***
Indonesia	0.000059	0.000000	0.064710	-0.076170	0.007313	-0.906760	30.78165	23576.22***
Mexico	-0.000247	0.000125	0.071022	-0.097000	0.010965	-1.144120	19.59725	8538.104***
Russia	-0.000148	0.000174	0.075279	-0.064720	0.009065	0.105211	26.42603	16693.37***
Turkey	0.000034	0.000525	0.049136	-0.076250	0.012701	-0.688630	8.196097	878.9283***

Turmoil period: (20.10.2009 to 31.12.2012)

Country	Mean	Median	Maximum	Minimum	Std. dev.	Skewness	Kurtosis	JB
Eurozone	-0.000148	0.000000	0.023251	-0.022760	0.006758	-0.101810	3.545439	11.76497***
Brazil	-0.000186	0.000000	0.040444	-0.079050	0.008615	-0.899810	13.63026	4034.534***
China	0.000108	0.000000	0.009912	-0.006250	0.001228	0.464254	13.61603	3941.555***
India	-0.000189	0.000000	0.024178	-0.025480	0.005309	0.027502	5.242272	174.6109***
Indonesia	-0.000033	0.000000	0.027539	-0.033870	0.004145	-0.310090	12.22785	2968.874***
Mexico	0.000016	0.000364	0.032165	-0.038580	0.007671	-0.397530	5.391027	220.3678***
Russia	-0.000056	0.000164	0.024094	-0.031140	0.006620	-0.314300	5.425390	217.8872***
Turkey	-0.000235	0.000334	0.019794	-0.034770	0.006925	-0.601820	4.757048	157.4355***

Whole period: (01.01.2007 to 31.12.2012)

Country	Mean	Median	Maximum	Minimum	Std. dev.	Skewness	Kurtosis	JB
Eurozone	-0.000000	0.000146	0.036720	-0.029333	0.007016	0.046046	4.617858	171.1241***
Brazil	0.000026	0.000305	0.083363	-0.079050	0.011579	-0.506786	11.56925	4852.269***
China	0.000144	0.000000	0.009912	-0.008606	0.001148	0.093449	12.88403	6368.670***
India	-0.000044	0.000000	0.064710	-0.076165	0.005839	-0.893827	36.95892	75358.98***
Indonesia	-0.000139	0.000000	0.140061	-0.140771	0.008500	-0.861948	131.4702	1075743.0***
Mexico	-0.000112	0.000280	0.071022	-0.097000	0.009352	-0.990086	18.60405	16122.72***
Russia	-0.000095	0.000179	0.075279	-0.064722	0.007853	-0.031280	23.31663	26898.81***
Turkey	-0.000148	0.000393	0.049136	-0.076248	0.010042	-0.736613	10.32391	3636.959***

Source: Authors' calculations.

Because this paper uses a time series dataset, it is crucial to test the stationary of variables; therefore we applied a ADF (Augmented Dickey-Fuller) test before estimation of the DCC-GARCH model. The findings are shown in Table 2. According to the findings, none of the series are stationary at level. We then tested the stationary of the return series and concluded that all return series are stationary. Therefore, we used a return series to test for the contagion effect.

Table 2 Stationary Test: The Findings of the ADF Unit Root Test

Country	*t*-statistic (level)	*t*-statistic (return)
Eurozone	-2.1708	-38.79860***
Brazil	-2.0071	-43.41720***
China	-2.3677	-32.55673***
India	-1.6329	-41.06448***
Indonesia	-0.5584	-37.43255***
Mexico	-1.6895	-32.60682***
Russia	-1.2502	-24.88251***
Turkey	-1.2553	-40.87020***

Notes: *** denotes the rejection of the null hypothesis (variables have a unit root) of ADF unit root test at the 1% significance level. James G. MacKinnon (1996) critical values are -3.4343, -2.8631, -2.5676 for 1%, 5% and 10% levels, respectively.

Source: Authors' calculations.

3. Econometric Methodology

Many different methods have been used in the literature to assess the contagion effect of the financial crisis. These include probit-logit models (Eichengreen, Rose, and Wyplosz 1996), regime switching models (Giampiero M. Gallo and Edoardo Otranto 2008), the copula approach (Juan Carlos Rodriguez 2007), and the heteroscedasticity-adjusted correlation measure (Forbes and Rigobon 2002). As an alternative to these tests, Sabur Mollah, Goran Zafirov, and Shahiduzzaman A. M. M. Quoreshi (2014) used GARCH based contagion tests while Alexei G. Orlov (2009) analysed contagion using Fourier's analysis which decomposes the covariance into different frequency levels and estimates contagion as the change in the high-frequency components of the covariance between crisis and non-crisis periods. Vincent Bodart and Bertrand Candelon (2009) used a Vector Autoregressive (VAR) model and developed a contagion test based on a causality measure for different frequencies. Marco Gallegati (2012) used wavelet analysis to test the contagion effect. Aviral Kumar Tiwari, Mihai Ioan Mutascu, and Claudiu Tiberiu Albulescu (2016) used a continuous wavelet transform to test the level of co-movements, contagion, and rolling correlation between stock markets.

In this paper, we use the DCC-GARCH model of Robert Engle (2002) to test for the existence of contagion during EDC. This model has four advantages over other estimation methods. First, it estimates correlation coefficients of the standardized residuals and thus accounts for heteroscedasticity directly. Second, the model allows us to detect changes in conditional correlations over time. Unlike the volatility-adjusted cross-market correlations employed in Forbes and Rigobon (2002), the DCC-GARCH model continuously adjusts the correlation for time-varying volatility. Third, the model allows us to include additional independent variables in the mean equation to ensure that the model is well specified. Fourth, the multivariate GARCH model can be used to examine multiple asset returns without adding too many parameters (Krishna Reddy Chittedi 2015). Hence, DCC provides a superior correlation measure (Cho and Parhizgari 2008).

The DCC-GARCH model is estimated in two steps, the first is a series of univariate GARCH estimates and the second the correlation estimate.

This paper uses the DCC-GARCH (1,1) model and, in the first step, the following regression has been estimated from which the residual returns will be obtained.

$$r_t = \alpha_0 + \alpha_1 r_{t-1} + \varepsilon_t. \tag{1}$$

In Equation (1), r_t is vector of asset returns and ε_t is vector of regression residuals. In the second step, the GARCH (1,1) model which is given in Equation (2), is estimated.

$$\begin{gathered} h_t = \beta_0 + \beta_1 {\varepsilon_{t-1}}^2 + \beta_2 h_{t-1}, \\ \beta_0 > 0 \;\; \beta_1 \geq 0 \; \beta_2 \geq 0. \end{gathered} \tag{2}$$

In the third step, the DCC-GARCH model is estimated as follows:

$$H_t = D_t R_t D_t, \tag{3}$$

where H_t is the multivariate conditional variance at time *t*, R_t is a $N \times N$ symmetric dynamic correlations matrix at time *t*, and D_t is a diagonal matrix of conditional standard deviations of residual returns, obtained from estimating a univariate GARCH (1,1) model.

For a pair of markets, *i* and *j*, the dynamic conditional correlations are estimated as in Equation (4):

$$Q_t = (1-\gamma-\theta)\bar{Q} + \theta Q_{t-1} + \gamma \varepsilon_{i_{,t-1}} \varepsilon_{j,t-1}{}'; \quad R_t = {Q_t}^{*-1} Q_t {Q_t}^{*-1}, \tag{4}$$

where $(Q_t) = \left[q_{ij,t}\right]$ is $(N \times N)$ time varying covariance matrix of standardized residuals, $\bar{Q}$ is the unconditional correlations of $\varepsilon_{i,t}\varepsilon_{j,t}$ and γ and θ are non-negative scalar parameters that satisfy $\gamma + \theta < 1$. In the DCC-GARCH model, as new information comes to the market, correlation coefficients change over time. When the new information decays, the correlation coefficients will revert to a long-run average. The two parameters, γ and θ of the DCC-GARCH model indicate the speed of this adjustment to new information (Yang Ding and Andrew Schwert 2010).

Therefore, for a pair of markets *i* and *j* the conditional correlation at time t can be defined as:

$$\rho_{ij,t} = \frac{(1-\gamma-\theta)\bar{q}_{ij} + \gamma \varepsilon_{i,t-1}\varepsilon_{j,t-1} + \theta q_{ij,t-1}}{\left[(1-\gamma-\theta)\bar{q}_{ii} + \gamma {\varepsilon^2}_{i,t-1} + \theta q_{ii,t-1}\right]^{1/2}\left[(1-\gamma-\theta)\bar{q}_{jj} + \gamma {\varepsilon^2}_{j,t-1} + \theta q_{jj,t-1}\right]^{1/2}}, \tag{5}$$

where q_{ij} is the element on the i^{th} line and j^{th} column of the matrix Q_t. The parameters are estimated using the maximum likelihood method. The log-likelihood of the estimators is given in Equation (6):

$$L = -\frac{1}{2}\sum_{t=1}^{T}(n\,log(2\pi) + 2\,log|D_t| + log|R_t|) + + {\varepsilon_t}' {R_t}^{-1'} \varepsilon_t. \tag{6}$$

In Equation (6), *n* is the number of equations and *T* is the number of observations.

Following the estimation of the DCC-GARCH (1,1) model, we use *t*-tests to identify significant differences in the mean between the tranquil and turmoil periods using dynamic conditional correlation coefficients.

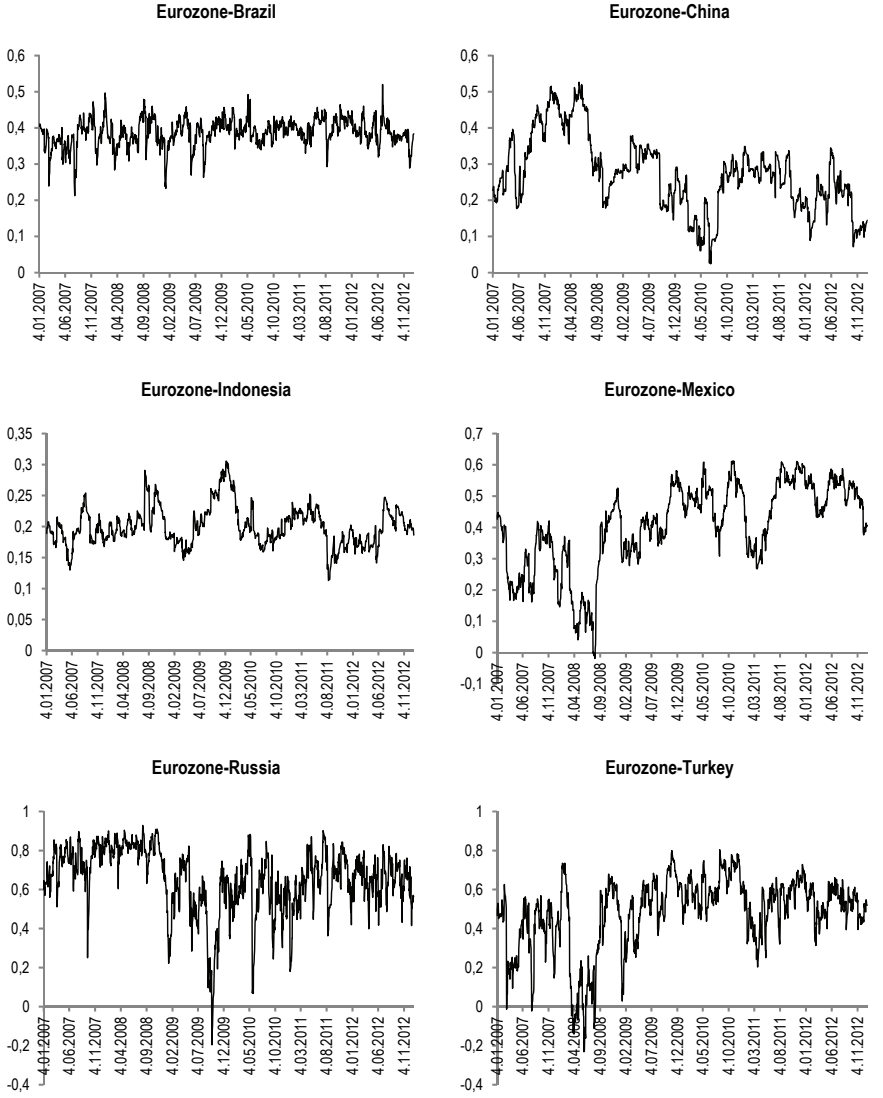
4. Empirical Findings

4.1 Detecting the Contagion Effect

Figure 3 shows the graph of DCC coefficients for the entire period.

Table 3 shows the unconditional correlations and the mean of DCC coefficients in the tranquil and turmoil periods. This shows that unconditional correlations increase in all countries in the turmoil period, except for Indonesia and Mexico. Similarly, DCC coefficients increase in all countries in the turmoil period except for China and Russia. Based on the increase in DCC mean values in percentage terms, Mexico and Turkey seem to be the most influenced by contagion effects during EDC. However, it is necessary to check whether DCC coefficients are statistically different in tranquil and

turmoil periods. Therefore we employed a *t*-test to identify the existence of contagion, the findings of which are presented in Table 4.



Source: Authors' calculations.

Figure 3 Graph of DCC Coefficients

Table 3 Unconditional Correlations and Mean of DCC Correlations

	Unconditional correlation			Dynamic conditional correlation		
	Pre-crisis	Crisis	Difference (%)	Pre-crisis	Crisis	Difference (%)
Brazil	0.3210	0.6108	90.28	0.3767	0.3957	5.01
China	0.3203	0.4830	50.80	0.3356	0.2167	-35.43
India	0.0405	0.2535	525.93	0.0472	0.0483	2.31
Indonesia	0.1712	0.1367	-20.15	0.1996	0.2014	0.87
Mexico	0.3426	0.0336	-90.19	0.3051	0.4932	61.66
Russia	0.3863	0.6520	68.78	0.6907	0.6240	-9.65
Turkey	0.4179	0.5142	23.04	0.3846	0.5661	47.19

Source: Authors' calculations.

Table 4 presents the findings of *t*-tests used to identify the contagion effect. In this table, we cannot reject the null hypothesis as the mean of DCC coefficients are the same. Therefore, there is no contagion effect in tranquil and turmoil periods for China, India, Indonesia, and Russia. However, we reject the null hypothesis that there is no contagion for Brazil, Mexico, and Turkey. Therefore, we find evidence of the contagion effect between the Eurozone and three of the seven foreign exchange markets during EDC.

Table 4 Contagion Test: Test of the Mean Differences of the Estimated DCC Coefficients

	Tranquil period			Turmoil period			
	N	Mean	Std. dev	*N*	Mean	Std. dev	$H_0 = \mu_\rho{}^{tranquil} = \mu_\rho{}^{turmoil}$ *t*-test (*p*-value)
Brazil	728	0.3767	0.0427	834	0.3957	0.0293	0.0000
China	728	0.3356	0.0934	834	0.2167	0.0735	0.0000
India	728	0.0472	0.0295	834	0.0483	0.0070	0.3014
Indonesia	728	0.1996	0.0283	834	0.2014	0.0345	0.2778
Mexico	728	0.3051	0.1158	834	0.4932	0.0781	0.0000
Russia	728	0.6907	0.1890	834	0.6240	0.1344	0.0000
Turkey	728	0.3846	0.2104	834	0.5661	0.1070	0.0000

Source: Authors' calculations.

4.2 Channels of Contagion

This study has therefore identified a contagion effect between the Eurozone and the foreign exchange markets of Brazil, Mexico, and Turkey during EDC. In the next stage, we aimed to establish by which channel; financial or foreign trade, EDC has been transferred. For this purpose, we first examined a variance-covariance matrix among the Eurozone, Brazil, Mexico, and Turkey. We then analysed foreign trade data from Brazil, Mexico, Turkey, Greece, and the EU to determine the channel of contagion.

4.2.1 Financial Channels

We investigated whether the transfer of crisis was through financial linkages. For this purpose, we analysed variance and covariance among the foreign exchange markets of Eurozone, Brazil, Mexico, and Turkey. The empirical findings are presented in Table 5.

Table 5 shows that variances and covariances among the foreign exchange markets of countries are lower in the turmoil period than in the tranquil period. For example, while the variances of Brazil, Mexico, Turkey in the tranquil period are 0.02%, 0.012% and 0.016% respectively, in the turmoil period they are 0.0045%, 0.0028%

and 0.0043%, respectively. Similarly, while the covariances of Brazil and the Eurozone, Mexico and the Eurozone, and Turkey and the Eurozone in the tranquil period are 0.0033%, 0.0027% and 0.0038% respectively, in the turmoil period they are 0.0017%, 0.00008% and 0.0014%, respectively.

Table 5 Variance and Covariances

Tranquil period: (01.01.2007 to 19.10.2009)				
	Eurozone	**Brazil**	**Mexico**	**Turkey**
Eurozone	0.0000533	0.0000333	0.0000274	0.0000387
Brazil	0.0000333	0.0002010	0.0000841	0.0001090
Mexico	0.0000274	0.0000841	0.0001200	0.0000810
Turkey	0.0000387	0.0001090	0.0000810	0.0001610
Turmoil period: (20.10.2009 to 31.12.2012)				
	Eurozone	**Brazil**	**Mexico**	**Turkey**
Eurozone	0.0000182	0.0000176	0.0000008	0.0000145
Brazil	0.0000176	0.0000456	0.0000011	0.0000250
Mexico	0.0000008	0.0000011	0.0000281	0.0000017
Turkey	0.0000145	0.0000250	0.0000017	0.0000438
Whole period: (01.01.2007 to 31.12.2012)				
	Eurozone	**Brazil**	**Mexico**	**Turkey**
Eurozone	0.0000492	0.0000288	0.0000276	0.0000333
Brazil	0.0000288	0.0001340	0.0000575	0.0000663
Mexico	0.0000276	0.0000575	0.0000874	0.0000566
Turkey	0.0000333	0.0000663	0.0000566	0.0001010

Source: Authors' calculations.

If contagion occurs due to financial linkages among the countries, the covariance structure should be higher in turmoil periods. However, Table 5 shows that covariance between countries decreases in the turmoil period. Therefore, the empirical evidence suggests that financial linkages are not the source of contagion between the Eurozone and Brazil, Mexico, and Turkey. In the next stage, we investigate whether the contagion is due to foreign trade channels.

4.2.2 Foreign Trade Channels

The US crisis that began in 2008 is responsible for the Greek crisis, which is the beginning of the EDC. The existence of structural problems such as high public expenditure and the fragile structure of the markets in member states of the European Union (EU) triggered the debt crisis. It is argued that EDC differs from the global crisis in that its extent was limited to Europe (Aizenman et al. 2016) and that Greece played a similar role to the Lehman Brothers in the high credit interest rate crisis (Samitas and Tsakalos 2013). However, when considered in relation to developing countries, both crises represent big external shocks spilling over from developed economies. The integration level of financial markets meant that the credit crunch effect of the developed countries was felt on the foreign trade volumes of all countries through finance. The effect of a decrease in consumer demand in developed countries can now be felt immediately on the production of developing countries. Global goods exportation, which was 15.5 trillion dollars in 2008, decreased by 23% in 2009. Global goods exportation of EAGLEs countries decreased by 25.71% in 2009. As a result of deteriorating financial conditions and declining total demand from 2009-2012, the share of countries in global foreign trade and international trade volume has decreased.

An answer to the question regarding how EDC is transferred is now sought. For this purpose, the foreign trade figures of Brazil, Mexico, and Turkey were tabulated and compared with the foreign trade figures of the EU. The mutual exports and imports for each country were proportioned to total export and import amounts using data at Trade Map (2016)[1]. As shown in Table 6, the EU constituted 21.22% of Brazil's total exports in the period 2009-2012. Although EDC is felt more in the Eurozone the member states of the EU are taken into consideration rather than the 19 Eurozone countries as the crisis affected all member states of the EU. In addition, although there are 28 member states of the EU as of 2013, there were only 27 EU member states during the period of analysis for this study. Brazil's total imports from the EU are 21.49%. Brazil and the EU are therefore important markets for each other. It should be noted that this share was 24.74% in the decade before the crisis and so the amount of exports from Brazil to the EU, one of its most important trade partners, proportionally decreased. During this process, Brazil increased agricultural and biodiesel production and tried to increase its exports in other markets. Thus, Brazil could compensate for the decrease in iron-steel and crude oil items. It can be concluded that the mode of transfer and contagion effect of the EDC from Europe to Brazil evolved out of commercial relations.

Table 6 Brazil's Foreign Trade Data between 2009 and 2012 (%)

	Exports to EU	Imports from EU
2009	22.28	22.90
2010	21.76	21.17
2011	20.69	20.52
2012	20.15	21.37

Source: Authors' calculations.

In Table 7, Mexico's total export and import rates show that its commercial relations with member states of the EU are by no means weak. The EU constitutes 5.34% of Brazil's total exports and 11.06% of Brazil's total imports. Mexico's economy went into recession as a result of constrictions in export opportunities to the US, which is its most important export market, despite market diversification efforts in 2009. The factor that affected deceleration of the rate of increase in Mexico's total export revenues was the US crisis, starting in 2008, which was behind the EDC, and the effects of the crisis then continued with a long-term decrease in demand. When foreign trade relations with the EU are taken into consideration, it is quite likely that the contagion effect resulted from commercial relations.

Table 7 Mexico's Foreign Trade Data between 2009 and 2012 (%)

	Exports to EU	Imports from EU
2009	5.08	11.65
2010	4.85	10.80
2011	5.48	10.75
2012	5.94	11.04

Source: Authors' calculations.

[1] **Trade Map.** 2016. Trade Statistics for International Business Development. http://www.trademap.org/ (accessed May 12, 2016).

In Table 8, export and import data for Turkey are compared to those of the EU for 2009-2012. Their shares in total export and imports are proportionally presented. The table shows that 45% of Turkey's total exports are made to the member states of the EU. Given that this share was 56.46% in the decade before the crisis, this represents a significant decrease. The total import rate of Turkey from the EU is 38.51%. Significant decreases in the export of motor land vehicles, trailers, and iron-steel products from Turkey to the EU, which is a market that comprises half of Turkey's foreign trade, shows that Turkey was affected by the crises through its foreign trade channel.

Table 8 Turkey's Foreign Trade Data between 2009 and 2012 (%)

	Exports to EU	Imports from EU
2009	46.76	40.19
2010	47.12	38.97
2011	46.97	37.87
2012	39.49	37.00

Source: Authors' calculations.

The EU is the most important foreign trading partner of Turkey and Brazil, both of which were included for the first time in the countries specified as the "fragile five" by Morgan Stanley in August 2013. There is therefore a high possibility of contagion to Turkey, Mexico, and Brazil through foreign trade channels. The analysis of foreign trade data thus provides strong evidence to show that EDC has infected other countries by means of EU trade.

5. Summary and Conclusion

This paper tested for the existence of financial contagion in foreign exchange markets during the EDC using the DCC-GARCH (1,1) model. The sample comprised seven countries: Brazil, China, India, Indonesia, Mexico, Russia and Turkey, known as EAGLEs countries in the literature. We found evidence of contagion during EDC between the foreign exchange market of the Eurozone and the markets of Brazil, Mexico, and Turkey. However, we could not find any evidence of contagion between the foreign exchange market of the Eurozone and the markets of China, India, Indonesia and Russia.

Only a few years after the USA precipitated global crises, the world economy had to face the EDC, the second phase of the financial crises caused by developed economies. EDC could affect emerging countries in two ways. The first is a decrease in credits and bad news from the EU which affects financial markets. This is the financial impact of the crisis. Furthermore, because the EU is an important commercial partner of numerous emerging countries, a recession in this region affects the export income and growth of emerging countries in a negative way. This is the impact of EDC on trade. In this paper, the evidence suggests that foreign trade is probably the source of the contagion during EDC.

Crises cause confidence problems for investors in the countries or regions in which they occur. With a tendency for risky investment alternatives in the decision-making process, the rational and irrational behavior of investors has an important effect on crises contagion. The expected returns from the financial and real markets vary in

crisis periods, which affect investors' behavior and leads to capital outflows. The decisions and behaviors of policymakers in anticipating and ending economic crises are particularly important to investors' confidence and expectations. For this reason, the transmission channels must be well understood because measures taken with the aim of mitigating the fragility caused by external shocks may vary according to the source of the contagion. The findings of this paper may be of interest to international investors and portfolio managers because the contagion effect decreases the diversification benefit. More pertinently, the findings are important for policy makers in Brazil, Mexico, Turkey, and EAGLEs countries because instability through financial contagion influences their development. Therefore, policy makers in these countries should seek ways to close the channels of contagion to decrease instability in their countries. The growth of EAGLES countries is indexed to exportation. The fact that countries index their economic growth to foreign trade creates significant problems due to long-term recessions in crisis periods. EAGLEs countries are required to reduce the weight of foreign demand for their growth. National exports should not be concentrated on a single country or bloc. Moreover, given the fact that the devastating effects of the global crisis on the real sector mostly occurred in the automotive industry and the iron and steel industry, it is necessary to consider the main export items of countries in this direction.

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