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Interdependence of foreign exchange markets: A wavelet coherence analysis☆

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ABSTRACT

Based on the wavelet decomposition approach, we study co-movement among foreign exchange markets using the returns of exchange rates (GBP/USD, EUR/USD, and JPY/USD). We focus on the interdependence among returns of exchange rates during the recent global financial crisis and European debt crisis. We use a wavelet analysis because of its ability to decompose signals into high and low frequencies. This approach allows us to study shorter time periods independently of longer time periods. The results reveal strong interdependence between the euro and pound sterling at all frequency bands of scale over the sample period. With regard to the yen–pound pairwise, covariation is localized at high scales. Further, we find that interdependence is more pronounced during crises.

1. Introduction

A major issue facing international investors is to identify whether observed financial market fluctuations are mainly due to contagion or fundamentals.[1] This is because when increasing volatility and cross-market linkages are due to a contagion, they disappear after a few days. However, if increasing fluctuation and co-movements are due to fundamental variables, they are likely to continue for a long time. Thus, an investigation into financial contagion is critical because of its damaging impact on the global economy in relation to portfolio risk management, the formulation of monetary and fiscal policy, and strategic asset allocation and pricing.

Recently, authors have subdivided financial market "linkage" into "interdependence" and "contagion." Interdependence represents a state of stable period relationships that are driven by fundamentals (Jung and Maderitsch, 2014). This interdependence theory emphasizes real linkage and fundamental integration as channels for transmission shocks between two markets in crisis and non-crisis periods. In this regard, Flavin and Sheenan (2015) define interdependence as market correlations that exist in all global conditions and arise because of standard asset market linkages and exposure to common risk sources. Ahmad et al. (2013) examine financial contagion and interdependence in the stock markets of Brazil, Russia, India, Indonesia, China, South Korea, and South Africa (BRIICKS) during the eurozone crisis. The study reports that Brazil, Russia, India, China, and South Africa were strongly affected by the contagion shock during the crisis; however, Indonesia and South Korea reported only interdependence and not contagion. Further, Shen et al. (2015) estimate a time-varying parameter correlation coefficient for the stock returns of the eurozone and China. This tests whether the European debt crisis was contagious and identifies interdependence and pure contagion across countries.

In contrast, the state of contagion is characterized by strong and sudden changes in measured market linkages. Despite the large amount of literature on financial market contagion, disagreement exists about the exact definition of what constitutes contagion and how we should measure it. In this study, we follow the definition of Forbes and Rigobon (2002) who define contagion as a significant increase in cross-market linkages after the occurrence of a shock in one country. In this context, Jung and Maderitsch (2014) provide evidence of volatility transmission among international financial markets and find the volatility spillover effect from foreign markets. Kenourgios and Dimitriou (2015) investigate the contagion effects of the global financial crisis (2007–2009) by examining 10 sectors in six developed and emerging regions and indicate that the most severe contagion effects existed after the failure of Lehman Brothers, thereby limiting the effectiveness of portfolio diversification. Loaiza-Maya et al. (2015) test contagion among the exchange rates of the six largest Latin American countries by implementing a regular vine copula approach. Their study reports that they find evidence of contagion among the Brazilian, Chilean, Colombian, and Mexican exchange rates and that there are differences in contagion during periods of large exchange rate depreciation and appreciation. Thus, understanding the direction of financial contagion not

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[1] Baele and Inghelbrecht (2010) and Kallberg and Pasquariello (2008) assume that market linkages are driven by fundamentals.

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only has important implications for cross-market risk management and international asset pricing; governments must also design economic policies to diminish the negative effects caused by external crises. Particularly in recent years, in the context of U.S. subprime issues and subsequent eurozone disturbance, distinguishing between contagion and interdependence, and examining the direction and degree of financial contagion, is of significant concern. Thus, these topics form the basis of our research.

Interdependence or contagion, in contrast to linear correlation, leads to causality relationships across financial markets. Moreover, the conventional Pearson correlation is not appropriate for measuring dependence across financial markets with different time horizons. In our analysis, we consider wavelet analysis because it is a useful analytical tool for studying the properties of multi-resolution.[2] The multi-resolution decomposition and property of the wavelet transform provide a different perspective on the empirical problem of identifying contagion and interdependence by using frequency domain analysis. Examples of prior studies that test for contagion by associating contagion and interdependence with distinct frequency ranges (high and low frequencies respectively) are relatively recent (see Aloui et al., 2015; Bodart and Candelon, 2009; Breitung and Candelon, 2006; Orlov, 2009).

Several studies use wavelet variance and wavelet correlation to investigate interdependence among markets that work to different timescales. For example, Dajcman et al. (2012) investigate the dynamics of stock market return co-movements among individual central and eastern European countries and developed European stock markets from 1997 to 2010. In this regard, they apply a maximal overlap discrete wavelet correlation and a running correlation technique. The study shows that the developed European stock markets of France, the UK, Germany, and Austria were more interdependent in the observed period than the central and eastern European (CEE) stock markets. Gallegati (2012) applies a wavelet-based approach in order to test whether contagion occurred during the U.S. subprime crisis of 2007 and to identify the contagion and interdependence of the original return series. Gallegati (2012) uses the discrete type of wavelet transformation, while in this paper we provide a richer analysis by employing wavelet coherence analysis in order to capture the dependence structure across different timescales and the causality relationships.[3] Numerous recent works have also researched cross-market linkages using wavelet coherence analysis. For example, Rua and Nunes (2009) examine co-movement among international stock markets and characterize simultaneously how international stock returns relate in the time and frequency domains. Rua and Nunes' (2009) study finds that co-movement among markets is stronger at the lower frequencies and that the strength of co-movement in the time-frequency space varies across countries and sectors. A similar methodology is applied by Ranta (2013) to the data of major world equity markets. Ranta's (2013) study reports that short timescale co-movements increase during a major crisis while long timescale co-movements remain approximately at the same level and gradually increase interdependence among markets. However, these studies only confirm that interdependence among markets is scale-dependent, thereby exhibiting the strength of interdependence. No general conclusions have been reached about distinguishing interdependence and contagion. We believe that our study is the first research that not only distinguishes between interdependence and contagion but also captures the degree and direction, or causality relationship, of contagion by applying wavelet coherence analysis. Further, our contagion analysis can be conducted more effectively than prior analyses and in a straightforward manner.

Over the past decades, a number of studies have investigated the interdependence and contagion of exchange rate series. Generally, three basic types of study focus on the issue of interdependence in foreign exchange markets. An example of the first type is a study by Engle et al. (1990), who contend that exchange rates react not only to shocks in individual markets but also to shocks transmitted across markets. This study is based on the generalized autoregressive conditional heteroskedasticity (GARCH) model, and since then many papers have discussed the interdependence of exchange rate returns based on the GARCH framework. For example, Pérez-Rodríguez (2006) finds, from research based on the dynamic conditional correlation (DCC) GARCH model, that the correlation between the EUR/USD and GBP/USD is particularly high. Moreover, Tamakoshi and Hamori (2014) find an asymmetric response in the correlations among the GBP, EUR, and CHF currencies by employing the asymmetric dynamic conditional correlation (ADCC) GARCH model.

The second type of study is one that considers the cause-and-effect relationship among different currencies. For example, Spagnolo et al. (2005) provide the causality relationship among forward and spot exchange rates by employing a Markov switching model and instrumental variables. Further, Nikkinen et al. (2006) find, by applying the vector autoregressive model and Granger causality tests, that the implied volatility of the EUR affects the GBP and the CHF. In addition, Inagaki (2007) discovers a unidirectional causality-in-variance from the EUR to the GBP based on the cross-correlation function. Beirne and Gieck (2014) also find, using a global vector autoregression (VAR) model, that the interdependence of foreign exchange markets is notable in developed markets.

The third type of study considers non-linear dependence based on the copula functions. For example, Patton (2006), by employing a time-varying copula model, provides evidence that the dependence between the DEM/USD and JPY/USD exchange rates is asymmetric. He also finds that the degree of dependence when the currencies depreciate is higher than when they appreciate. Further, Dias and Embrechts (2010) model the dependence of the EUR/USD and the JPY/USD returns based on the copula-GARCH model. They find that a time-varying copula with the proposed interdependence specification gives better results than alternative dynamic benchmark models.

Modeling the interdependence of exchange rates is often of interest in the areas of risk management, asset pricing, and portfolio management. Appropriate action to rebalance a portfolio and adjust exchange rate exposure can be initiated accordingly. However, few studies cover the most important issue in risk management: the interdependence of exchange rates over different timescales. For example, Nekhili et al. (2002) explore and compare the empirical distribution of the USD/DEM exchange rate returns with well-known continuous-time processes at different frequencies. In addition, Nikkinen et al. (2011) employ the cross-wavelet approach to analyze interdependence and provide the lead–lag relationship for exchange rates over different timescales. They find that the three major currencies (the euro, British pound, and Japanese yen) vis-à-vis the U.S. dollar are closely linked over different timescales and that there are significant lead–lag relationships between the expected exchange rate probability densities. However, the authors fail to provide dynamic interdependence maps and causality relationships in the foreign exchange markets. Thus, our paper, in contrast to Beirne and Gieck (2014) and Nikkinen et al. (2011), employs wavelet coherence analysis to explore the dynamic interdependence maps of exchange rates over different timescales with the causality test. Moreover, by inputting the GBP/USD returns into our analysis, we can consider more time horizons and draw more information about the foreign exchange markets than Dias and Embrechts (2010), who investigate the dependence of the EUR/USD and JPY/USD exchange rates in six different time horizons.

Our contribution can be summarized as multifold. First, we compensate for the lack of academic studies on the dynamic interdependence maps of exchange rates in the foreign exchange markets over different

[2] For a thorough review of wavelet analysis, see Gençay et al. (2001a, b) and Percival and Walden (2000).

[3] For the applications of wavelet coherence analysis, please refer to Aloui and Hkiri (2014) and Uddina et al. (2013).