Asymmetries in Stock Price Co-movements

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Abstract

It is generally accepted that stock market prices tend to move together. However, very little is known about what factors influence the underlying co-movements between two stock markets. This thesis contributes to the literature by presenting a number of studies exploring different sources of stock market dynamic spillovers.

The first part of the thesis presents a theoretical framework to link stock market integration with economic activity. Chapter 2 introduces international equity trading in a stochastic general equilibrium model. We explore the role of international portfolio diversification on transmission of shocks as well as the role of supply shocks in generating international stock returns co-movements.

The second part of the thesis empirically investigates stock price co-movements using high frequency data sets. Chapter 3 analyses stock price spillovers between the London and New York equity markets. With multivariate GARCH models for intra-day data, we test the "global factors hypothesis" to assess whether equity market linkages are attributable to reactions of traders to information originating from foreign stock price movements.

Chapter 4 explores the role of macroeconomic news as a source of international stock market co-movements using one minute frequency data. We use an unrestricted Vector Autoregressive model with the DAX, the Eurostoxx 50 and the FTSE 100 futures' returns to examine the short-term dynamic spillovers between these markets. In addition, the second part of the chapter analyses how macroeconomic releases affect the cross-country stock prices interactions.

Chapter 5 describes a study of non-linear dynamics in stock market co-movements. Arbitrage activity motivates the introduction of a discrete regime-switching specification to model the dynamic relationship between the FTSE 100 cash and futures indices. In our model, arbitrageurs only enter the market if deviations from the theoretical non-arbitrage relationship level are sufficiently large to compensate for the transaction costs.

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Chapter 1

Introduction

Do stock prices respond to fluctuations in other equity markets? If so, why do stock prices co-move? It is generally accepted that stock market prices tend to move together across national borders. However, very little is known about what factors influence the underlying co-movements between stock prices. Unfortunately, finance theory does not unequivocally offer any clear explanation of the nature of movements in stock prices in response to fluctuations of other equity markets. The explanation lies somewhere between real and financial linkages of economies and "investor psychology".

The aim of this thesis is to explore different sources of stock market dynamic spillovers. In addition, we analyse how these sources may cause asymmetries in the dynamic relationship between stock prices.

The thesis is divided into two parts. The first part comprises Chapter 2 and presents a theoretical framework to link stock market integration with economic activity. Specifically, we develop a New Open Economy Model that introduces international equity trading and describes the role of international portfolio diversification on the transmission of supply shocks. This chapter contributes to a starting branch of theoretical literature of dynamic stochastic general equilibrium models trying to analyse the effects of imperfect financial integration on the international transmission of shocks.

The second part of the thesis comprises chapters 3, 4 and 5 and empirically investigates stock price co-movements using high frequency datasets. The increasing availability of high-frequency datasets provides an enormous potential to investigate short-term stock market interactions and to address new questions on sources of stock market co-movements.

Chapter 3 explores the transmission of stock market movements between the London Stock Exchange and the New York Stock Exchange. With a multivariate GARCH model, we test "the global factor hypothesis" to assess whether stock returns' linkages are attributable to information with a global character originated during the trading hours of the foreign market. Chapter 4 examines the role of macroeconomic news as a possible source of international stock market interactions between the FTSE, the Eurostoxx 50 and the DAX indices using high-frequency data, minute-by-minute stock returns. Chapter 5 focuses on dynamic spillovers between theoretically related markets, in particular, the cash and futures indices. This chapter describes a study of non-linear dynamics in stock price co-movements. Arbitrage activity motivates the introduction of a discrete regime-switching specification to model the dynamic relationship between the FTSE 100 cash and futures indices.

A better understanding of the factors underpinning stock market interactions has potential important implications for investors as well as for policy makers and academics. For investors, the design of a well-diversified portfolio depends on a correct understanding of how closely and why international stock market returns are correlated. Policy makers are interested in equity market linkages because of their implications for the stability of the global financial system. For example, monetary policy is affected by international stock market developments, due to the international propagation of shocks via equity markets and the wealth channel.

PART I. THEORETICAL MODEL

Chapter 2. Stock Market Integration and Economic Activity

In this chapter, we explore the theoretical links between stock market spillovers and economic activity. We focus both on the impact of international supply shocks on stock market interactions and on the role of stock markets as an extra channel of international transmission of shocks.

To this end, we use a New Open Economy Model with optimising agents characterized by nominal rigidities and imperfect competition based upon the Obstfeld-Rogoff (1995) framework. An important change to the model is the introduction of stock market variables. The international diversification of portfolios is explicitly modelled by the introduction of foreign equities; domestic investors can gain exposure to international supply shocks by buying foreign shares. Furthermore, the process of increasing stock market integration is modeled by reducing the adjustment costs of international transactions. In our model, dividends and companies' profits act as an extra channel of international transmission of shocks. Intuitively, as domestic investors own foreign shares, they receive dividends and profits generated by foreign firms, directly affecting their wealth exposure to foreign supply shocks and, consequently, their optimal decisions.

After the benchmark scenario with transaction costs is presented, the chapter investigates how the degree of stock market integration, which is modelled by the cost of investment in foreign shares, affects international transmission of shocks. We also investigate whether the level of initial foreign assets and asymmetries in holdings of foreign shares in the initial equilibrium affect the dynamic pattern of international transmission of shocks.

This chapter has three main contributions. First, we explore the role of stock markets as an extra channel of international transmission mechanism via the profits/dividends channel within a New Open Economy Framework. The endogenous inclusion of foreign shares and the dividend channel have not been explicitly modelled within the New Open Economy literature. Second, we explore whether the model can generate the stock market cross-correlations observed in empirical data by introducing supply shocks in our framework. Third, we pay special attention to how transaction costs and asymmetries in the composition of the country specific portfolios affect cross-country stock price correlations.

PART II. EMPIRICAL STUDIES

Since the stock market crash of October 1987 there has been substantial interest in research on why stock returns and volatility are propagated across world markets. Possible explanations are real, financial and informational links between markets: news revealed in one country is perceived as informative to fundamentals of stock prices in another country. An international asset pricing model (e.g. Adler and Dumas (1983) and Solnik (1974)) can incorporate correlations between stock returns in different countries. Another possible explanation is market contagion: stock prices in one country are affected by changes in another country beyond what is conceivable by connections through economic fundamentals. According to this view, overreaction, speculation, and/or noise trading are transmitted across borders. The principal objective of this part of the thesis is to investigate possible sources of stock returns interactions.

Chapter 3. Intra-day Spillovers between the FTSE 100 and the Dow Jones Industrial Average Returns

Does Wall Street lead the FTSE 100 Index returns? If so, why? This chapter empirically investigates the intraday transmission of stock prices and volatility between the FTSE 100 index and the Dow Jones Industrial Average index returns.

Given the increasing international economic integration and the deregulation and globalisation of financial markets, corporate and economic news released in one country may not reveal information only about that particular country, but may contain "global factors" affecting the world economy and thus, the world equity markets. This chapter tests the hypothesis that international stock market spillovers are due to the fact that domestic traders learn from stock prices movements observed in foreign exchanges. This hypothesis is called "global factor hypothesis".

As the London and New York Stock Exchanges share only two trading hours per day (out of seven in New York and nine in London), we specify four different time regimes based on intra-day time spans. Namely, we differentiate time spans depending on whether both stock exchanges are open for trading, both stock exchanges are closed or only one of the exchanges is open while the other is closed. If markets are efficient, the stock returns dynamic interactions should be different depending on which regime we estimate.

The econometric specification uses an aggregate shock model to model investors' learning behaviour. A different multivariate GARCH model for each regime is specified to analyse how domestic investors process information contained in foreign stock price movements. This decomposition if intra-day price changes is crucial in our analysis to test how information is transmitted from one market to the other.

The contribution of this chapter lays in the use of intra-day stock prices to model investors' learning behaviour. This overcomes a shortcoming of previous studies. In previous studies based on daily stock returns, it is commonly stated that the FTSE returns respond to the New York stock price movements. Given the later close of the U.S. market, news released in the evening (London time) is first incorporated into New York stock prices. As a consequence, it is statistically observed that New York returns lead FTSE returns but not vice versa. In this chapter we avoid this problem in a novel way: we specify four different time regimes based on intra-day time spans. Namely, we differentiate time spans depending on whether both stock exchanges are open for trading, both stock exchanges are closed or only one of the exchanges is open while the other is closed. A different multivariate GARCH model in each regime is specified to identify how intra-day stock price movements in the FTSE and Dow Jones influence each other. We can assess whether the findings of previous studies are mainly due to the fact that daily data is used.

The decomposition if intra-day price changes is crucial in our analysis to test how information is transmitted from one market to the other. If markets are efficient, the stock returns dynamic interactions should be different depending on which regime we estimate.

Chapter 4. Stock Market Interactions and Macroeconomic News: An Exercise with High Frequency Data

This chapter explores the role of macroeconomic news in explaining international stock market co-movements. As far as we know, it is the first empirical attempt to characterise price interactions in three important European futures markets, the German (DAX), the Pan-European (Eurostoxx 50) and the British (FTSE 100) indices using high frequency data, in particular, minute-by-minute observations.

The main question addressed is:

- Question one: What are the dynamic spillovers between the futures returns on the DAX, the DJ Eurostoxx 50 and the FTSE 100 indices?

We extend our analysis by examining if economic news is a possible source of international stock return co-movements. In particular, we test whether stock market interdependencies are attributable to the reactions of foreign traders to public economic information. To the extent that there are common factors in business cycles, macroeconomic news in one country may reveal information about future cash flows or discount rates in many countries, not just in the home country. This suggests that one source of market return co-movements may be macroeconomic announcements. Connolly and Wang (2003) and McQueen and Roley (1993) present evidence to test this "public information hypothesis". In order to evaluate this view, we address two further questions:

- Question two: How do the stock indices react to economic information emanating from Germany, the Euro-Zone and U.K.?

- Question three: Do cross-market linkages remain the same or do they increase around periods in which economic news is released in any one of the countries?

The econometric framework uses an unrestricted Vector Autoregressive approach for the futures returns of the three indices. The unexpected part of the macroeconomic releases is included to account for the effects news on stock market spillovers.

Our contribution to the literature has several facets. First, the data used in this research consists on minute-by-minute futures prices for the FTSE 100, the DAX and the DJ Eurostoxx 50 indices. The richness of the dataset allows us to investigate several empirical facts between the European futures markets. This is the first empirical research that explores the short term return spillovers including the Eurostoxx and the DAX indices. Second, regarding the role of economic news in explaining stock returns co-movements, relative little research has measured the impact of economic news from one country on stock markets in another nation. We analyse the reaction of index futures' returns in the U.K., Germany and Euro-Zone to economic announcements released in each country.

Chapter 5. Non-linear Dynamics between the FTSE 100 Cash and Futures Indices

Chapter 5 focuses on the dynamic interaction between theoretically related markets, namely the index future and index value markets. Index arbitrage activity and transaction costs motivate the use of regime-switching models to shape the short-term relationship between cash and futures indices. This chapter explores the existence of intraday non-linearities in the FTSE 100 cash and futures markets during the month of July 2001. We test whether the intertemporal relations between these markets are different depending on whether arbitrage is possible or not.

From an econometric perspective, transaction costs and arbitrage activity in the cost of carry model motivates the use of non-linear specifications to model the lead-lag relationship between a stock index and its futures markets. The chapter contains an analysis of the mean-reversion of the basis, i.e., the difference between the futures price and the index value. Our framework assumes that arbitrageurs only enter the market if the deviation from the non-arbitrage value is large enough to offset the transaction costs. To model the mean reversion of the mispricing error, we suggest that the basis in the cost of carry model follows a non-linear Self Exciting Threshold Autoregressive model. If this is the case, endogenous regimes are specified within the model and the mean reversion to the cost of carry will only occur when its magnitude is large.

Non-linearities in the dynamic behaviour of the basis imply non-linearities in the index and the futures interactions. Given that both prices are cointegrated, we suggest a Threshold Error Correction Specification to characterise the dynamic relation between the FTSE 100 futures and spot returns. The model allows for non-linear adjustment processes of the returns towards their long-term equilibrium.

This chapter has two main contributions. First, this is the first study that presents a discrete regime-switching model to analyse the index arbitrage in the FTSE 100 markets after the introduction of electronic trading systems. Our analysis permits us to test whether the introduction of the electronic trading systems in the London Stock Exchange in 1997 and in the London International Financial Futures and Options Exchange in 1999 has eliminated the non-linear dynamic relationship between the cash and futures prices. Second, from an econometric perspective, this study generalises previous models as we use an integrated approach suggested by Tsay (1998) in which the threshold values that define the different regimes are endogenously determined within the model.

Part I

THEORETICAL MODEL

Chapter 2

Stock Market Integration and Economic Activity

2.1 Introduction

Financial markets may play a role in shaping the patterns of international transmission of shocks across countries. This aspect is stressed, for example, in the IMF World Economic Outlook (2001): *'Several observations hint at the role that structural factors and policy regimes play in determining the strength of the international business cycle linkages...Co-movements in output gaps in United States, Canada and United Kingdom remained positive during the entire 1990's...The close affiliation in business cycle of the United Kingdom with that of the United States, despite much more important trade links with Euro area countries may have been the result of strong financial market linkages'; IMF (2001), chapter 2.* At the same time, asset volatility shocks appear now to move rapidly across international boundaries. This may have been possible due to the decline in number of barriers with regards to international capital movements and reductions in transaction costs when investing in international portfolios.

The aim of this chapter is to establish a theoretical link between stock market integration and the international transmission of shocks across countries. To accomplish this, we explicitly introduce stock market behaviour in an New Open Economy framework with optimising agents characterised by nominal rigidities and imperfect competition.[1] Agents can hold wealth in the form of bond, domestic and foreign shares, which are used to model international stock exchanges. The model does not have an analytical solution. Thus, it is calibrated and simulations of the impulse response functions and quantitative statistics are presented for different scenarios.

The model in this research builds upon three parts. First, we focus on international transmission of shocks. In particular, we stress the role of supply shocks in analysing the sources of international stock market co-movements. In other words, we investigate to what extent domestic stock prices respond to international productivity shocks. Section 2.4 in this chapter presents the results of the benchmark model. Second, we explicitly introduce concave adjustment costs when investing in foreign shares to account for the fact that in reality stock exchanges are not perfectly integrated at an international level. Section 2.5 in the chapter illustrates the analysis of how various degrees of stock market integration affect international dynamic spillovers. Finally, once the dynamics of the simple version of the imperfect integrated stock markets model are understood, a more general case with asymmetric holdings of foreign shares in the initial equilibrium is presented. Section 2.6 is devoted to discussing as to whether the level of initial foreign assets affects the dynamic patterns of international transmission of shocks.

Two major contributions are forthcoming in this chapter. First, at a theoretical level, recent developments of dynamic general equilibrium models have been successful in explaining some of the variability and comovements of aggregate variables such as output, consumption, investment or exchange rates.[2] However, little attention has been paid to their implications for asset returns and stock market behaviour.

[1] The aim of the New Open Economy Models is to establish a new generation of open macroeconomic models that rely upon stochastic general equilibrium frameworks with well-specified microfundations. Obstfeld-Rogoff (1995) Redux model is the pionneering work in this field.

[2] See, for instance, Lane (2001) and Sarno (2001) for survey of the literature on New Open Economy Models. See also Section 2.2 in this chapter.

This chapter marks the first attempt at explicitly including shares and stock market integration in a New Open Economy Model. Second, our model explores the role of profits and dividends as a channel of international transmission of shocks and to what extent they help to explain cross-country stock returns co-movements.

What nowadays makes this profit and dividends channel more interesting and relevant is the rapid growth of foreign assets and liabilities relative to GDP observed in recent decades in advanced countries. Lane and Milesi-Ferretti (2003) document that this ratio has increased 250 percent from 0.8% to 2.3% over the period 1983-2001. Maybe even more relevant for this chapter, in 2003 holdings of international shares accounted for 52% of European equity portfolios and 31% of UK equity portfolios, meanwhile they accounted for less than 10% of the portfolio in 1983.[3] In practice, Tille, Stoffels and Gorbachev (2001) estimate that this valuation channel may account fro up to 12% of the international transmission of shocks.

The rest of the chapter is organised as follows. The next section reviews the related literature. Section 2.3 presents the theoretical model that emphasises the introduction of transaction costs in the international stock markets. Section 2.4 displays the simulation results. In section 2.5 the implications of various degrees of stock market integration are studied. Section 2.6 analyses a more general case, in which the initial holdings of foreign shares are different from zero and asymmetric across countries. Finally, Section 2.7 serves as a conclusion for the results of this chapter.

2.2 Related Literature

The theoretical model in this chapter is built upon the Redux framework of Obstfeld and Rogoff (1995), which is the pioneer model in the "New Open Economy Models" (NOEM). Their analysis led to a novel perspective on the international spillovers and welfare effects due to monetary and fiscal policies.

[3]Source: Deutsche Bank Asset Management.

Lane (2001) and Sarno (2001) provide broad surveys of the studies on the NOEM literature. Among the variants and generalisation of the redux model, some of the issues that are at the core of current research on this literature are: the source of nominal rigidities and the currency denomination of sticky prices, market segmentation and pricing to market, the analysis of fiscal policy in an open economy and the analysis of a framework with an incomplete asset market structure. For the purposes of this chapter, we are more interested in the later group of papers. The departure of complete markets assumptions stresses the role of the current account as a dynamic propagation mechanism. Most of these papers analyse monetary policy in open economies in a model of incomplete markets, where households in both the home and foreign country can trade internationally in only a risk-free bond.[4] The model used here is similar to theirs in the sense that it also includes an incomplete asset market structure and therefore, some of the predictions of our research should be compatible with their results. However, there is one crucial distinction between both analysis. While they focus on the role of monetary policy and welfare analysis under incomplete markets, the goal of our research is to introduce stock exchanges that are not perfectly integrated at an international level in order to analyse the relationship between stock exchanges and macroeconomic activity.

In a literature survey on the key elements of open economies models, Lane and Ganelli (2002) discuss the role of the current account and net foreign assets in the adjustment process. They point out that among the key issues to be addressed by future research in this area *'it would be desirable to allow for international trade in equities in addition to trade in bonds'*. From a theoretical point of view, this is the contribution of this paper to this growing literature, namely to incorporate stock exchange elements in a NOEM model.

Martin and Rey (2000) examine financial market integration within a theoretical framework. They focus on the impact of financial integration on the cost of capital

[4]Related works in the literature are: Benigno G. (1999), Benigno P. (2002), Gali and Monacelli (2001), Devereux and Engel (2000), Kollmann (2001), Obstfeld and Rogoff (2001) and Tille (2000).

within a model in which the number of financial markets is endogenous, assets are imperfect substitutes and cross-border asset trade entails some costs of transporting assets across national borders. They introduce iceberg costs on asset markets, which create a risk premium for foreign securities.[5] The introduction of iceberg costs in our model would act as lump sum taxes on the stock exchanges transactions. They would not induce additional dynamics in the model when shocks are introduced.

Trading frictions in a dynamic general equilibrium model are also introduced by Sutherland (1996), who assumes that only bond trade is possible, but the purchase of foreign bonds involves convex adjustment costs. The impact of the trading frictions is to allow the domestic interest rate to deviate from the foreign interest rate. He primarily focuses on the impact of financial market integration on exchange rate dynamics. He finds that imperfect financial integration leads to lower volatility in exchange rate and consumption, but to larger volatility in output and interest rates. There are, however, two major criticisms of his framework. First, he postulates a cost function that is convex in the level of funds transferred to the foreign bond market for each period. Intuitively, convex adjustment costs in international financial markets are difficult to justify; broker's fees, resources and time spent collecting information about foreign markets, etc. are essentially concave costs. Second, in Sutherland's (1996) framework, permanent changes in the net foreign asset position provide technical problems in the simulations since solution techniques typically rely on the existence of a stationary steady state: a unit root in the net foreign asset position is obviously inconsistent with model stationarity. Typically, a stochastic general equilibrium setting, in which the equilibrium rate of consumption growth is independent of the economy's net foreign assets, yields indeterminacy in the value of net foreign assets in steady state, which in turn, introduces non-stationarity.

We overcome these two problems by introducing a cost function that depends on the total holdings of foreign equities and that induces a stock return premium that

[5] Iceberg costs τ are transaction costs whereby part of the dividend melts during the transit. The foreign purchaser gets a fraction $1 - \tau$ of the total dividend.

is equity-elastic. First, as is described in Section 2.3, this function will be concave and thus is empirically justifiable. Second, this functional form will be useful in securing a unique, well defined steady state for consumption and assets, ensuring stationarity in our model.

Authors like Benigno (2002) and Kollmann (2002) provide examples of employing a debt-elastic interest rate premium to ensure stationarity in their models. Schmitt-Grohe and Uribe (2003) consider several alternatives in a small open economy model to induce stationarity.[6] Alternatively, Ghironi (2002) achieves stationarity by imposing an overlapping generations structure. The main difference between our research and these papers is that whereas they specify a cost function such that the interest rate faced by domestic agents is increasing in the aggregate level of foreign debt, we explicitly include equity markets in this research and we adapt the cost function to a framework with equity markets. Furthermore, while these papers use the cost function as an analytical tool, this chapter exploits the fact that the trading frictions translate into imperfect stock market integration and analyses how various degrees of stock market integration affect the existing relationship between stock exchanges and economic activity.

Our work is related to Benigno (2002). He evaluates the welfare implications of monetary policy rules when international financial markets are incomplete. He uses a two-country dynamic general equilibrium monetary model to evaluate the magnitude of the welfare costs of imperfect risk sharing. He finds that with non-zero holdings of net foreign assets there exist non-negligible gains from following a coordinated monetary policy instead of a price-stability policy. In contrast to his work, no attempt is made in this chapter to evaluate monetary policy in open economies and to conduct a welfare analysis. However, we introduce the transaction cost in a similar way to his but adapted to equity holdings instead of debt levels.

[6]Schmitt-Grohe et al. (2003) also show that a model with concave adjustment costs delivers virtually identical dynamics as a model with debt-elastic interest rate premium. This cost is specified in the level of foreign assets, not in the level of funds transferred to the foreign economy.

The structure of this chapter is similar to his. First the zero initial asset holdings case is presented. Then, once the dynamics of the simple version or the model are described, a more general case with asymmetric holdings of foreign shares is put forth.

Matsumoto (2002) explores exchange rate volatility with a NOEM model in which he allows international risk sharing through equity. In his model, the percentage of foreign dividends from equity that home households receive is fixed and determined by an exogenous parameter. The key difference between the model in this chapter and his is that in our model the holdings of foreign shares are an endogenous variable. Consequently, when a technology shock occurs, households optimally adjust their holdings of foreign shares. An additional difference between both models is while he uses imperfect international risk sharing to study exchange rate excess volatility, we introduce equity to analyse international stock exchanges spillovers within a NOEM framework.

Finally, among the few papers that empirically relate stock exchanges with the macroeconomic activity, it is worth mentioning the work of Lewis (1995, 1999). In particular, Lewis (1999) evaluates different explanations for equity home bias and consumption home bias.[7] Among the possible explanations she considers are: the presence of non-tradeable goods in the model, the fact that gains from risk sharing are insufficient to merit the cost of diversifying and the presence of capital market restrictions that impede the investor's ability to diversify. The empirical evidence shows that "consumption home bias" is quite pronounced and statistically significant. Even if we do not address these puzzles in this chapter, her work is considered a basic background for any study trying to link portfolio diversification

[7]A theoretical model in which investors can optimally sell off claims on their output to foreigners would predict a high correlation of consumption rates across countries. Empirically, it is shown that consumption growth rates tend to have a lower correlation across countries than do output growth rates. This is known as "consumption home bias". "Equity home bias" relates to the fact that in reality domestic investors hold a substantially larger proportion of their wealth portfolios in domestic assets than standard portfolio theory would suggest.

with risk sharing.

2.3 A Model with Imperfect Integrated Equity Markets

The model in this chapter belongs to the class of stochastic general equilibrium models in open economies. The framework is similar to Obstfeld-Rogoff (1995). The important addition is the introduction of the stock market's dynamics within the model. The international diversification portfolio is explicitly modeled by the introduction of foreign equities. The process of increasing financial market integration is modeled by reducing the adjustment costs of international transactions.

The world economy is composed of two countries, *Home* and *Foreign* which are equal in size. In the supply size of the economy, producers are monopolists and every firm produces a single differentiated product indexed by $z \in [0, 1]$. Goods prices are subject to sluggish adjustment a la Calvo (1983). All goods are tradeable.

2.3.1 Consumers and Financial Markets

Consumers are risk averse and infinite lived. They consume a variety of goods, supply labour, invest in asset markets and run the monopolistic production unit that produces good z. The utility of a generic consumer j belonging to country $s = H, F$ is given by

$$U^j = E_0 \left\{ \sum_{\tau=0}^{\infty} \beta^\tau \left[\frac{1}{1-\sigma} C_\tau^{j,1-\sigma} - \frac{1}{1+\phi} N_\tau^{j,1+\phi} \right] \right\}$$

where E_0 denotes the expectation conditional on the information set at date 0, while $0 \leq \beta \leq 1$ is the intertemporal discount factor and σ and ϕ are parameters. Households obtain utility from consumption, C^j and receive disutility from working and producing goods, N^j. The utility function U is an increasing, concave function of the consumer bundle index defined as a CES aggregator over domestic produced goods, C_H^j and foreign produced goods, C_F^j:

$$C_t^j = \left[(1-b)^{\frac{1}{\theta}}\left(C_{H,t}^j\right)^{\frac{\theta-1}{\theta}} + b^{\frac{1}{\theta}}\left(C_{F,t}^j\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}}$$

where $\theta > 1$ is the degree of substitution between the bundles C_H and C_F and b is the weight of home versus foreign goods in the home consumption basket. The foreign consumption index $C_t^{j,*}$ for a consumer j belonging to country F is defined analogously. In what follows, * superscripts denote country F variables.

The general price index for domestic consumers P_t is defined as the minimum expenditure needed to buy one unit of the consumption index C_t^j

$$P_t = \left[(1-b)P_{H,t}^{1-\theta} + bP_{F,t}^{1-\theta}\right]^{\frac{1}{1-\theta}} \tag{2.1}$$

where $P_{H,t}$ represents the price index of total domestic produced goods and $P_{F,t}$ is the price index for foreign produced goods in units of the domestic currency.

It is assumed that all goods are tradeable and that there is no cost of trade. It follows that the law of one price holds for each individual good. Let e be the nominal exchange rate, $p(z)$ the domestic currency price of good z and $p^*(z)$ the foreign currency price of good z. Then, $p(z) = ep^*(z)\ \forall z$. Given that preferences are identical across countries, purchasing power parity holds and $P_{H,t} = e_t P_{H,t}^*$, $P_{F,t} = e_t P_{F,t}^*$ and $P_t = e_t P_t^*$.[8] The terms of trade is defined as the relative price of home and foreign goods, $s \equiv \frac{P_F}{P_H}$.

Given these aggregators, the optimal allocation of expenditure between domestic and foreign goods implies

$$C_{H,t}^j = \left(\frac{P_{H,t}}{P_t}\right)^{-\theta}(1-b)C_t^j \quad ; \quad C_{F,t}^j = \left(\frac{P_{F,t}}{P_t}\right)^{-\theta} bC_t^j$$

Combining the above equations, the total demand of good H produced at home, which depends on the total expenditure on home goods, can be written as

$$Y_t^d(H) = \left(\frac{P_{H,t}}{P_t}\right)^{-\theta}\left[(1-b)C_t + bC_t^*\right] \tag{2.2}$$

[8]As pointed out in Obstfeld and Rogoff (1998, pg 663), it is important to understand that Purchasing Power Parity (PPP) does not imply that relative prices of various individual goods need to remain constant.

Similarly, the total demand for good F produced in the foreign country is

$$Y_t^{*,d}(F) = \left(\frac{P_{F,t}^*}{P_t^*}\right)^{-\theta} [(1-b)C_t^* + bC_t] \tag{2.3}$$

We assume that households belonging to country H can allocate their wealth among three assets: domestic bonds, B_t^j, domestic equities, x_t^j, and foreign equities, $x_{F,t}^j$, the last ones are denominated in the foreign currency. In contrast, households that belong to country F can allocate their wealth only in foreign bonds, $B_t^{j,*}$, and shares in the foreign country, $x_{F,t}^{j,*}$. Thus, only foreign equities are traded in the international financial markets. Each unit of domestic (foreign) equity pays out the output Ω (Ω^*) in the form of dividends in the next period. As is defined later in this section, Ω_t is the firm's profits in period t.

Note that we assume that households in country F do not hold country H equity. This assumption is innocuous. The fact that only domestic agents hold foreign equity helps to highlight the response of stock exchanges to foreign shocks. In case foreign investors would hold domestic equities, their response to domestic shocks would be exactly symmetric to the response of domestic holdings of foreign shares to foreign shocks, namely, the same response as the one discussed in Section 2.4.2 later on in this chapter. If anything, this situation would amplify the magnitude of the dividends/profit channel discussed in Section 2.4 in this chapter.

As mentioned in the literature review section Matsumoto (2002) also allows the ownership of firms to be shared internationally. In his model home households also receive dividends from foreign equity holdings, whose value is $\gamma e \Omega^*$, where γ is an exogenous parameter and represents the degree of international equity sharing. The key difference between his model and ours is that holdings of foreign shares is an endogenous variable in our framework and thus, home agents optimally choose it.

At the beginning of each period t, the consumer j observes the technology shocks z_t and z_t^*. Then, stock markets open and she decides the quantity of shares she will buy in order to carry into the next period. Afterwards, goods markets open. Period t budget constraint of household j in country H, expressed in real terms with respect to the consumption-based price index, is

$$\begin{aligned}&\frac{w_t}{P_t}N_t^j + \frac{x_{t-1}^j}{P_t}(q_t + \Omega_t) + \frac{x_{F,t-1}^j e_t}{P_t^*}(q_t^* + \Omega_t^*)\Psi(x_{F,t-1}) + \frac{B_{t-1}^j}{P_t}(1 + i_t) + T_t \\ = \;& C_t^j + \frac{x_t^j}{P_t}q_t + \frac{x_{F,t}^j e_t}{P_t^*}q_t^* + \frac{B_t^j}{P_t}\end{aligned}$$

where w_t is the nominal wage in the economy and q_t represents the nominal ex-dividend price of one domestic share. Analogously, q_t^* is the nominal ex-dividend price of one foreign equity share.

Stock markets in the two countries are not perfectly integrated. The function $\Psi(.)$ captures the transaction costs that the household in country H has to pay when adjusting her foreign equity holdings. Broker's fees, institutional and regulatory differences and any other type of market friction are captured by this cost function. The function $\Psi(.)$ depends on the entire home economy's foreign share holdings. This means that domestic households take the function $\Psi(x_{F,t-1})$ as given when deciding on the optimal holdings of foreign shares. These costs are paid to the intermediaries in the foreign asset market, which are owned by the foreign households. Some restrictions are required on $\Psi(.)$: $\Psi(\overline{x}_F) = 1$ and it assumes the value 1 only if $x_{F,t} = \overline{x}_F$; $\Psi(.)$ is a differentiable and decreasing function in the neighbourhood of $\overline{x}_F$.[9] Furthermore, this function is useful in pinning-down a unique, well defined steady state for consumption and assets.[10]

The following functional form for the transaction costs is used

$$\Psi(x_{F,t}) = e^{-\psi x_{F,t}} \tag{2.4}$$

where $\psi > 0$ is the parameter that measures the degree of equity market integration, $\psi = -\Psi'(0)$. This cost function is concave and is, therefore, consistent with reality; the higher the level of funds that agents transfer abroad, the less than proportional transaction costs increase.

[9] $\overline{x}_F$ equals the steady state level of foreign assets.

[10] Authors such as Benigno (2002) and Kollmann (2002) provide examples of employing similar cost functions that imply a debt-elastic interest rate premium to ensure stationarity. Schmitt-Grohe and Uribe (2003) also discuss their benefits in a small open economy model.

Nominal gross return on home country equity between periods $t-1$ and t is the total cash flow generated by all firms in country H. Home nominal equity return, $1+R_{s,t}$, and foreign nominal equity return, $1+R^*_{s,t}$, are defined as

$$1+R_{s,t} \equiv \frac{q_t+\Omega_t}{q_{t-1}} \qquad (2.5)$$
$$1+R^*_{s,t} \equiv \frac{q^*_t+\Omega^*_t}{q^*_{t-1}}$$

The introduction of the stock returns and the cost function to account for imperfect asset market integration are the key features of this chapter, which make it possible to examine stock market behaviour in a NOEM framework.

It is further assumed that the initial level of wealth is identical for all the households belonging to the same country. This assumption, combined with the fact that all the households within a country supply the same amount of labour to the firms, implies that within a country all the households face the same budget constraint. In other words, all the households within a country will choose the same path of consumption when making their optimal decisions. Therefore, we can drop the index j and consider a representative household for each country.

The representative household in country H maximises her life-time utility function subject to her budget constraint and the definitions of equity returns. The optimal allocations of $\{C_t, B_t, x_t, x_{F,t}, N_t\}$ are characterised by the following First Order Conditions (FOC)

$$\frac{U'_{C_t}}{P_t} = \beta(1+i_t)E_t\left\{\frac{U'_{C_{t+1}}}{P_{t+1}}\right\} \qquad (2.6)$$

$$\frac{U'_{C_t}}{P_t} = \beta E_t\left\{\frac{U'_{C_{t+1}}}{P_{t+1}}(1+R_{s,t})\right\} \qquad (2.7)$$

$$\frac{U'_{C_t}e_t}{P_t} = \beta\Psi(x_{F,t})E_t\left\{\frac{U'_{C_{t+1}}e_{t+1}}{P_{t+1}}(1+R^*_{s,t})\right\} \qquad (2.8)$$

$$-U'_{N,t} = -U'_{C,t}\frac{w_t}{P_t} \tag{2.9}$$

Equation (2.6) represents the demand for bonds. Equation (2.7) represents the optimal decision of home equity holdings. Equation (2.8) constitutes the foreign equity demand equation. Equations (2.6)-(2.8) together are the optimal wealth allocation between domestic and foreign assets. Notice that frictions in the foreign asset market enter in equation (2.8) reducing the foreign equity return, which affects the household's intratemporal asset allocation and her optimal consumption path. In other words, if individuals use international financial markets to diversify country specific risks, the adjustment costs to invest in foreign assets influences the ability of agents to take optimal decisions. Finally, equation (2.9) is the labour supply rule. Labour markets are assumed to be competitive in each country and labour is immobile internationally.

Similarly, the optimal decisions for the foreign household in choosing the holdings of foreign nominal bonds and foreign equities are given by

$$\frac{U'_{C_t^*}}{P_t^*} = \beta(1+i_t)E_t\left\{\frac{U'_{C_{t+1}^*}}{P_{t+1}^*}\right\} \tag{2.10}$$

$$\frac{U'_{C_t^*}}{P_t^*} = \beta E_t\left\{\frac{U'_{C_{t+1}^*}}{P_{t+1}^*}(1+R_{s,t}^*)\right\} \tag{2.11}$$

Note that money does not appear in either the budget constraint or the utility function. Woodford (1998) illustrates that is possible to analyse the equilibrium inflation determination without any reference to either money supply or demand. The key point to his approach is that policy actions should depend upon the degree to which the current or expected future price level differs from the target. Later on in the chapter we will specify a monetary policy rule as an inflation stabilistion regime, which is consistent with Woodford's (1998) analysis.[11]

[11] A natural extension of the model in this research would be to introduce money and monetary

2.3.2 Firms and Price Setting Decisions

Producers are monopolists. Each firm produces a single differentiated product i. Goods are produced using labour supplied by consumers, N_t. Firms operate a constant returns to scale technology: $y_t(i) = z_t N_t(i)$, where z_t is the random productivity factor and represents the country specific technology shock. Cost minimisation leads to the following efficiency condition for the choice of labour input

$$\frac{MC_t(i)}{P_{H,t}} = \frac{1}{z_t}\frac{w_t}{P_{H,t}} \tag{2.12}$$

where MC indicates the nominal marginal cost. The profits of the firm producing commodity i are

$$\Omega_t(i) = y_t(i)\left(p_t(i) - \frac{w_t}{z_t}\right)$$

With respect to price determination, it is assumed that firms are subject to sluggish price adjustment of the form described by Calvo (1983).[12] In each period, a fraction $1-\alpha$ of firms have the opportunity to charge a new price $p_t(i)$ and the other fraction α must charge the price fixed on the previous period, $P_{H,t-1}$. This way, the price set in the current period may have an impact on profits in future periods. A firm adjusting its price level in period t chooses $p_t(i)$ to maximise the discounted value of the current and future profits with each future period weighted by the probability that the current price will still remain in that period.

$$\underset{p_t(i)}{Max} \quad E_t\left\{\sum_{\tau=0}^{\infty}\alpha^{t+\tau}\beta_{t,t+\tau}^{firm}\frac{\Omega_{t+\tau}}{P_{t+\tau}}\right\}$$

$$s.t. \quad y_t^d(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\theta}((1-b)C_t + bC_t^*) \quad \forall t$$

shocks to analyse how international stock market spillovers would be affected. However for the purposes of this chapter, the focus is on the role of supply shock in generating international stock market correlation.

[12]The approach used in this subsection is the standard in models with staggered price settings a la Calvo. For further discussion on this topic see Calvo (1983), Kollmann (1999) and Lane (2001).

$y_t^d(i)$ is the total demand of product i as described in the above equation. $\beta_{t,t+\tau}^{firm}$ is the firm's discount factor to value random payoffs at date $t+\tau$. Following Kollmann (1999), if we assume that firms are owned by the country's representative household, then firms value future payoffs according to the consumers' intertemporal marginal rate of substitution in consumption, i.e., $\beta_{t,t+\tau}^{firm} = \beta^{\tau}\frac{U'_{C_{t+\tau}}}{U'_{C_t}}$.

Note that we assume that foreign firms care only about the welfare of foreign households. The situation in which foreign firms are part-owned by home households would not change the model results under perfect integrated stock markets as there is perfect risk sharing. However, under imperfect integrated stock markets, the discount factor included in the above equation would change as $\frac{U'_{C_{t+\tau}}}{U'_{C_t}} \neq \frac{U'_{C^*_{t+\tau}}}{U'_{C^*_t}}$. Tille (2000b) analyses the welfare effects of such situation introducing an intermediary who imports goods from producers and sells them to consumers. He finds that the direction of the welfare effect depends on who owns the firm importing the goods.

From the first order condition of the above decision-making problem for firm i, the optimal price $p_t(i)$ can be obtained.

$$p_t(i) = \frac{\theta}{\theta - 1}\frac{E_t \sum_{\tau=0}^{\infty} \alpha^{t+\tau}\beta_{t,t+\tau}^{firm}\frac{C_{t+\tau}^W}{P_{t+\tau}}\left(\frac{1}{P_{t+\tau}}\right)^{-\theta}\frac{w_{t+\tau}}{z_{t+\tau}}}{E_t \sum_{\tau=0}^{\infty} \alpha^{t+\tau}\beta_{t,t+\tau}^{firm}\frac{C_{t+\tau}^W}{P_{t+\tau}}\left(\frac{1}{P_{t+\tau}}\right)^{-\theta}} \tag{2.13}$$

C_t^W stands for the total real demand in the home economy, i.e., $C_t^W = (1-b)C_t + bC_t^*$. We focus on a symmetric equilibrium where all producers in the same country take identical decisions. As a consequence, any producer in the home country will set her price according to equation (2.13).

The number of home firms that set their price $p_t(i)$ at time t is $1-\alpha$. Similarly, the number of firms that set their price in period $t-1$ is $(1-\alpha)\alpha$. Therefore, it is possible to rewrite the price index of domestic produced goods in each period in a recursive form in the following way

$$P_{H,t} = \alpha P_{H,t-1} + (1-\alpha)p_t(i) \tag{2.14}$$

A similar optimal price-setting decision also applies to country F, with the appropriate starred variables.

Finally, we obtain the aggregate profits for the firms in country H by integrating over i

$$\Omega_t = Y_t\left(P_{H,t} - \frac{w_t}{z_t}\right) \tag{2.15}$$

This profit function pays a crucial role in transmitting shocks at an international level. Technology shocks directly influence the level of profits as shown in equation (2.15), which translate into a change in the dividends perceived by agents and therefore, it modifies their wealth. Because shares are tradeable in the international stock exchanges, shocks in the foreign country affect domestic households' optimal decisions, creating additional international spillovers.

2.3.3 Market Clearing Conditions

Since producers are monopolists, the supply of goods accommodates the demand for goods in each period.

The labour market clears in each period. The supply of labour is expressed by equation (2.9) and the demand for labour by the firms in denoted by $y_t(i) = z_t N_t(i)$.

In order to simplify matters, the condition that bonds are in zero-net supply within each country, i.e., $B_t = B_t^* = 0$.

In the equity markets, the supply of each security is normalised to one. Therefore, the equilibrium in the home equity market is represented by $x_t = 1$ for each period. Equilibrium in the foreign equity market is $x_{F,t} + x_{F,t}^* = 1$ for each period.

2.3.4 Current Account

The current account is defined as the change in the net foreign asset position of a country. In our framework, the capital account inflow or outflow equals the net exports for each period. The current account for the Home country can be expressed as

$$x_{F,t}q_t^*\frac{e_t}{P_t} - x_{F,t-1}\frac{e_t}{P_t}(q_t^* + \Omega_t^*)\Psi(x_{F,t-1}) = Y_t\frac{P_{H,t}}{P_t} - C_t \tag{2.16}$$

The international linkages imply that in nominal terms $CA_t + e_t CA_t^* = 0$. By using the Walras' law the aggregate resource constraint of country F is redundant.

2.3.5 Equilibrium Definition

Equilibrium in the world economy is a set of consumption, output, bonds, shares, labour, goods prices, share prices, exchange rate and wages that enable market clearing in goods, labour and asset markets. Namely, they are a set of variables that:

i. satisfy the optimal evolution of intertemporal consumption as expressed by the consumers' Euler equations in each country, *ii.* meet the conditions for optimal wealth allocation between domestic and foreign shares, *iii.* clear domestic and foreign share markets as well as clear bond markets at each given period, *iv.* clear labour markets at each given period, *v.* fulfill the conditions for optimal price setting by domestic and foreign firms at each time period and *vi.* satisfy the aggregate resource constraint of each country.

The model does not have an analytic solution. Therefore, the system is log-linearised around a steady state.[13] The complete system of expectational difference equations is calibrated and simulated using Uhlig (1997) algorithm.[14,15]

What remains to be added is the specification of the monetary policy rule for each country.

2.3.6 Monetary Policy Arrangements

Benigno (2002) shows that a price stability plan, which entails the stabilisation of the markup, is a quasi-optimal policy plan with incomplete asset markets. He

[13] Appendix A presents the steady state solution and the log-linearised system.

[14] The Matlab computer codes used to compute the calculations presented in this chapter are based in Uhlig's (1997) programs. They are available at: http://cwis.kub.nl/~few5/STAFF/uhlig/toolkit.dir/tooklit.htm

[15] See Appendix B for a brief description of the functioning of the algorithm.

demonstrates that the impact of asymmetric shocks on asset accumulation and on the consumption gap are nearly the same under a price stabilisation policy as those under the optimal monetary policy with incomplete markets.[16] Since our theoretical framework includes incomplete asset markets, the monetary policy arrangement is considered to be similar to that as suggested by Benigno (2002) and Woodford (1998). It consists of a price stability plan, in which the central bank of each county pursues a policy of complete stabilisation of the price level that aims at a full stabilisation of the marginal cost in a non-coordinated fashion. In other words, the presence of nominal rigidities is a source of suboptimality in the equilibrium allocation in our framework and consequently and the monetary authority tries to fully neutralise the effect of the nominal rigidities. In order to achieve this aim, the monetary authority seeks to stabilise the real marginal cost at its steady state level during all periods, which means price stability. As a result, current prices of domestic firms are always consistent with the mark up that would be desired in the absence of constraints on a price adjustment. Accordingly, the following conditions must be satisfied at all dates t

$$\begin{aligned} \pi_{H,t} &= 0 = \pi^*_{F,t} \\ \frac{MC_t}{P_{H,t}} &= \frac{\overline{MC}}{P_H}; \frac{MC^*_t}{P^*_{F,t}} = \frac{\overline{MC^*}}{P^*_F} \end{aligned} \tag{2.17}$$

where $\pi_{H,t}$ is the producer inflation rate at home, which is defined as the rate of change in the index of domestic good prices, i.e., $\pi_{H,t} \equiv \log(\frac{P_{H,t+1}}{P_{H,t}})$. Similarly, $\pi^*_{F,t}$ is the producer inflation rate in the Foreign country. Upper bars represent steady state equilibrium levels.

Once the system is log-linearised, the interest rate rule consistent with this monetary policy target of price stabilisation can be gleaned from Appendix A. Equation

[16] Actually, Benigno (2002) shows that with under incomplete asset markets, the optimal policy is to pursue a state-contingent producer inflation rate. In such situations, inflation rates move to coordinate changes in the exchange rate. He illustrates that the exchange rate adjustment has only a minor impact on real variables since movements in the inflation rates are of a very small magnitude.

(A.25) displays in a log-linearised form the optimal interest rate in the domestic economy. This interest rate expression is a function of the foreign interest rate, the evolution of the terms of trade and the domestic production shocks.[17]

To understand the effects of monetary policy actions on stock exchanges, it is useful to write down the relationship between the domestic nominal interest rate, i_t, and the stock return, $R_{s,t}$. Combining the FOC of each consumer j belonging to H with respect to bonds (equation 2.6) and equity (equation 2.7) the following non-arbitrage condition shows a positive relationship between the current domestic interest rate and expected stock returns.

$$1 + i_t = \frac{E_t\left\{\frac{U'_{C_{t+1}}}{P_{t+1}}(1 + R_{s,t})\right\}}{E_t\left\{\frac{U'_{C_{t+1}}}{P_{t+1}}\right\}} \tag{2.18}$$

2.4 Simulation Results

In this section we present the simulation results of the benchmark log-linear model. We start with the calibration of the model. Then, we present the impulse response functions and the cross-country correlations predicted by our benchmark model. Finally, we present some sensitivity analysis to changes in the parameters b and θ.

2.4.1 Calibration

The two countries are assumed to be symmetric in preferences and technology parameters. Time is measured in quarters. The model is parametrised as follows:

Preferences. The discount rate is set at $\beta = 0.975$, which means a long term average annual real return on equity of 10 percent.[18] As in most of the literature on International Business Cycles (IBC), we set the elasticity of substitution between domestic and foreign goods θ equal to 1.5 and σ equal to 2. We assume $\phi = 1$,

[17]For a study comparing the effects of various monetary policy rules on economic variables, not including stock exchanges, with incomplete markets see Benigno (2002).

[18]See Lewis (1999) for summary statistics for returns on equity markets in a worldwide basis.

which signifies a unit labour supply elasticity. For the openness index b a value of 0.27 is presupposed, which is the average share of imports in GDP for European economies. Later on this section, a sensitivity analysis is carried out, in which the degree of openness varies between $b = 0.10$ and $b = 0.4$. We assume identical values of β, θ, σ and b for the foreign economy.

Imperfect integrated stock markets. There are no comprehensive measures of stocks of equities thus, making it difficult to obtain a proper value for the calibration of the parameter ψ, which measures the cost of intermediation in the foreign market. In the benchmark model we choose the value of $\psi = 0.0001$ so that the correlation of stock returns predicted by the model is close to the one observed in the data. This small value of ψ reflects the fact that the degree of stock market integration among industrialised countries is quite high. In Section 2.5 we vary the value of this parameter ψ to analyse how the predictions of the model change when various degrees of stock market integration are taken into account.

Note that there is no need to calibrate the parameters indicating the degrees of monopolistic competition and price adjustment horizon since a zero inflation-targeting policy in both countries makes the optimal allocations independent of these parameters.

Exogenous shocks. It is common in the IBC literature to assume autoregressive productivity shocks with a degree of persistence around 0.9. We adopt this assumption for domestic and foreign productivity shocks. The volatility of the shocks is calibrated to obtain an output volatility that is close to the one in the data for U.S. and the Euro area. All the impulse response functions presented in this chapter correspond to positive temporary technology innovations.[19]

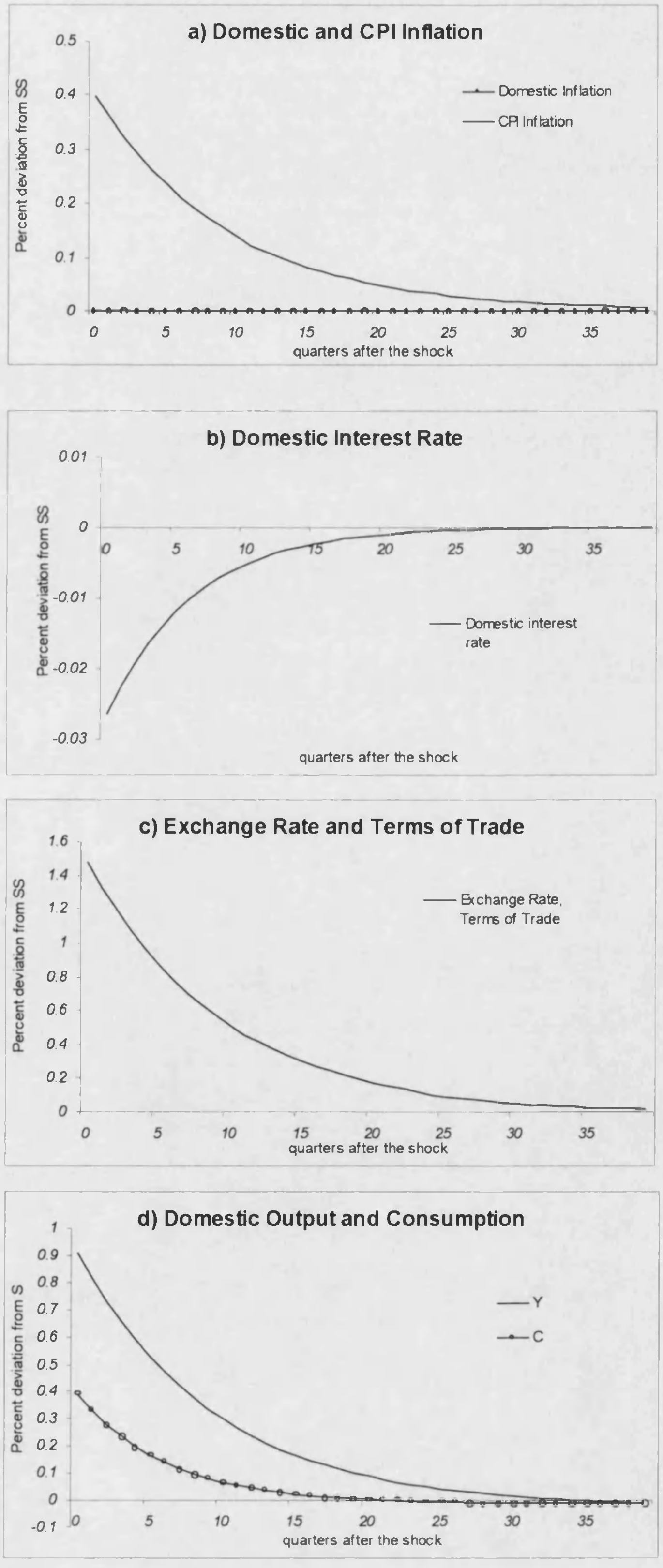
[19]Temporaty refers to the fact that the shock only occurs in period t.

2.4.2 Impulse Response Functions

Figure 2.1 displays the impulse response functions of the domestic variables to a positive temporary one percent innovation in home productivity in period t, z_t. By design of the price stabilisation rule, domestic inflation and the real marginal cost remain unchanged as shown in panel (a). Panel (b) plots the impulse response function of the domestic interest rate. As the interest rate expression (A.25) shows, monetary policy is counter-cyclical in response to domestic productivity shocks and, in turn, interest rate decreases. Intuitively, an increase in domestic productivity decreases domestic marginal costs and, as a result, the prices of domestically produced goods also decrease. To stabilise domestic inflation, the monetary authority responds by lowering domestic interest rates. This decrease in interest rates denotes the initial depreciation of the domestic currency followed by a gradual reversion to its initial level; thus generating the path of nominal exchange rates as seen in panel (c). Due to the price stabilisation rule, the evolution of the terms of trade correspond to that of the nominal exchange rate. Note also in panel (a) that the level of the CPI jumps up during the shock period because of the exchange rate depreciation and then reverts back to its trend.

Panel (d) shows the positive response of the domestic output when a positive domestic technology shock occurs. This observed pattern is due to the fact that the productivity increase in country H raises the wealth of that country's representative household. This expansion of output is absorbed by an increase both in consumption, which is also shown in panel (d) and an increase in net foreign assets.

Figure 2.1: Impulse response functions to a positive temporary Home productivity shock



The later will be discussed further on in this subsection.

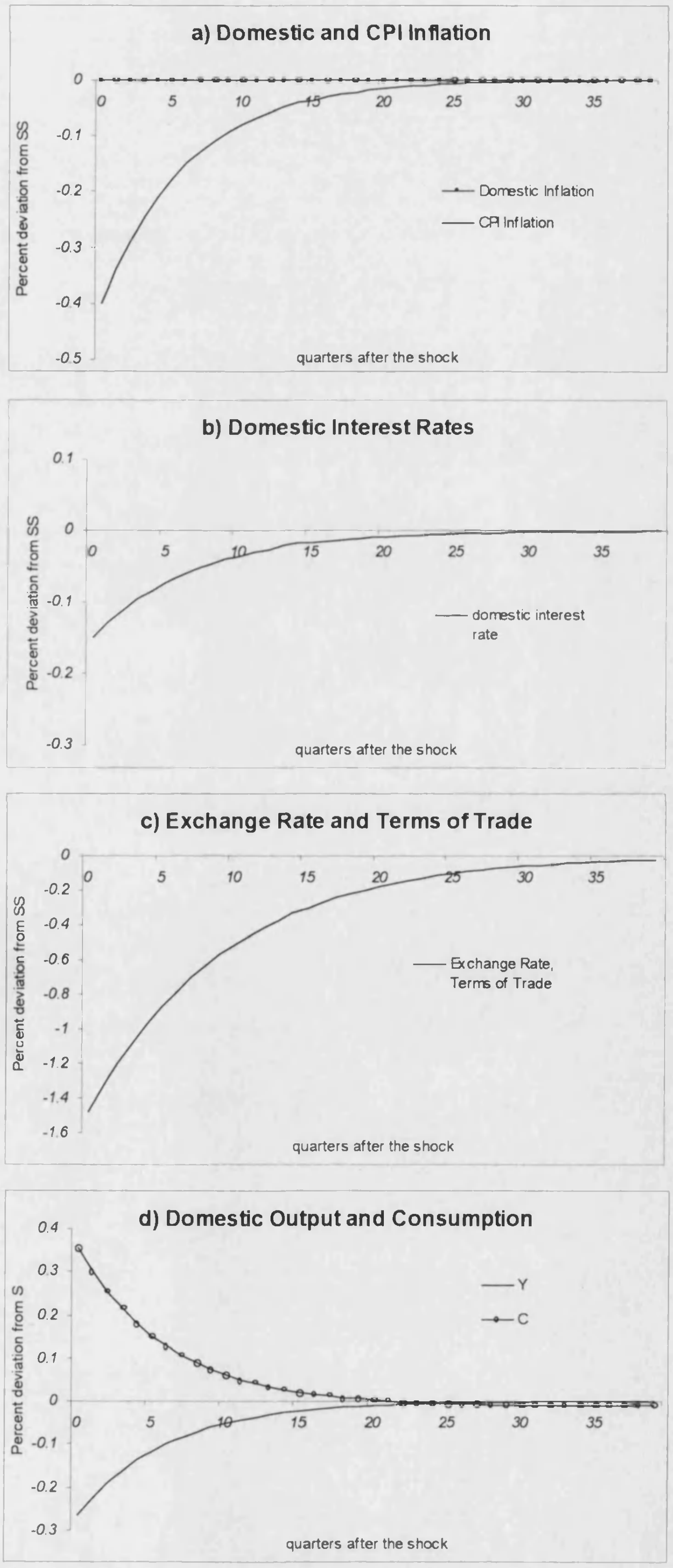
Figure 2.2 displays the dynamic response of the domestic variables to a positive temporary technology shock abroad, z_t^*. The shocks are assumed to be symmetric and uncorrelated. Three points are worth noting from Figure 2.2. First, for the same reasons as the domestic nominal exchange rate and domestic terms of trade increases when a domestic technology shock occurs, foreign terms of trade increase when a positive foreign technology shock occurs. Because of $\widehat{s}_t^* = -\widehat{s}_t$, the impulse response functions of domestic terms of trade and exchange rate are just the opposite of those displayed in Figure 2.1 panel (c).[20] Second, an increase in the foreign terms of trade translates into an increase in the relative price of imported goods in the foreign country. This shifts the demand of foreign households towards goods produced in country F and away from imports, namely goods produced in country H. This shift explains the decrease in home output when a foreign positive technology shock takes place as observed in panel (d). Third, in spite of this, panel (d) shows that home consumption increases. As it will be described later in the subsection, when a positive shock occurs in the foreign country, domestic consumers sell foreign shares because they are risk averse, which translates into a capital account deficit. Domestic agents use this capital account deficit to increase current domestic consumption.

Remark 1. *Dividend payments become an extra channel of international transmission of shocks in our model.*

A shock abroad increases the dividends domestic agents receive from their holdings of foreign shares. This temporarily raises the wealth of country H's representative household and therefore, it affects optional decisions of agents in country H. By adding international shares in a New Open Economy framework, dividend payments, which are affected by country specific shocks, become an extra channel of international transmission of shocks.

[20]Note that $s \equiv \frac{P_F}{P_H}, s \equiv \frac{P_H^*}{P_F^*}$ and the law of one price holds.

Figure 2.2: Impulse response functions to a positive temporary Foreign productivity shock



The main contribution of this chapter is to characterise this role of profits and dividends as channel of international transmission of shocks and stock market behaviour when technology shocks happen. In Figure 2.3 impulse response functions of stock returns and share prices to positive domestic productivity shocks (left column graphs) and foreign productivity shocks (right column graphs) are reported.

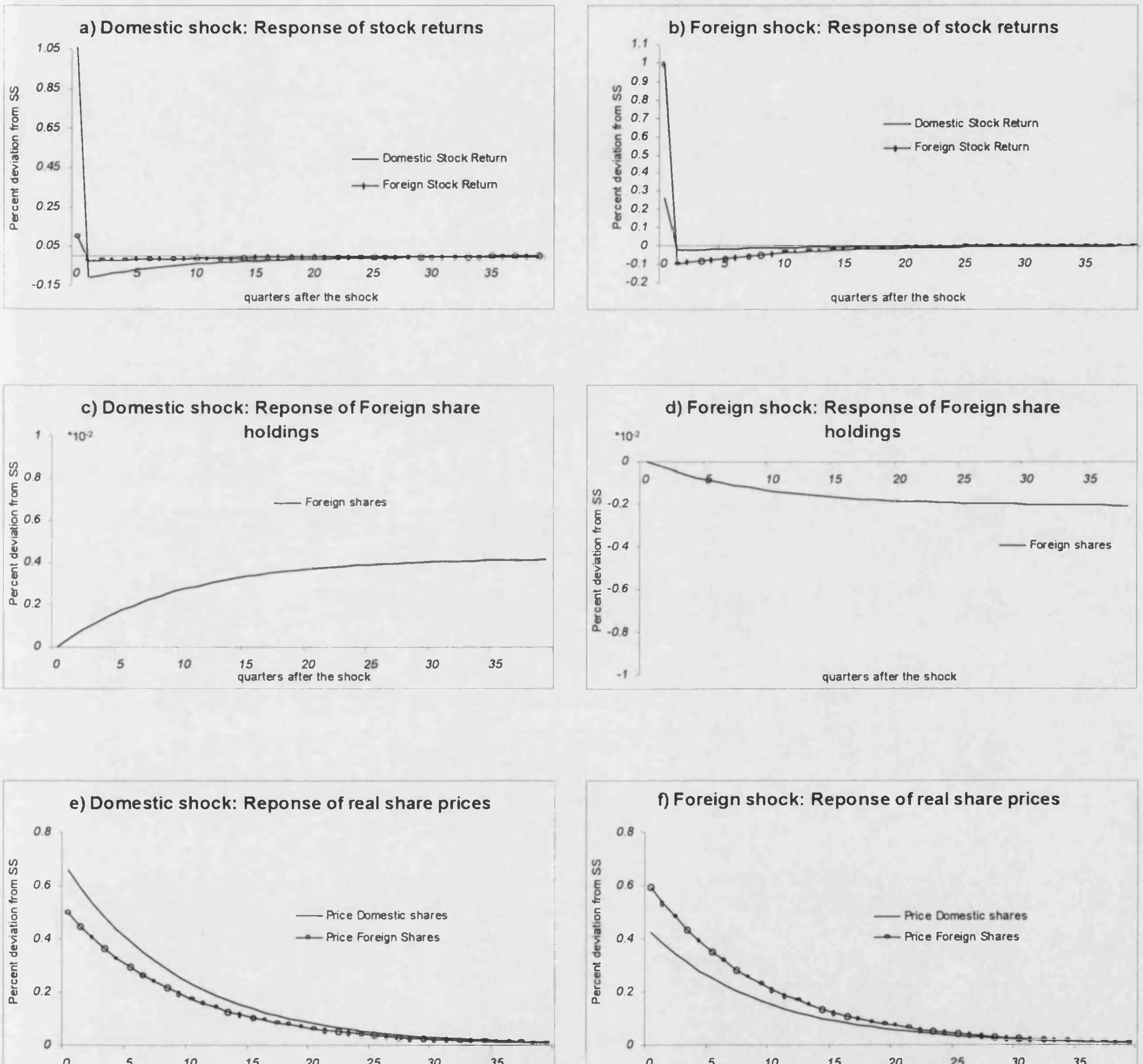
Remark 2. *Productivity shocks induce international stock return correlation.*

Panels (a) and (b) in Figure 2.3 plot the dynamic responses of domestic, $R_{s,t}$, and foreign stock returns, $R^*_{s,t}$, to technology shocks. The initial effect of a shock in z_t on domestic equity return has two components. First, there is a direct effect since a positive technology shock increases the cash flows of the domestic firm, which directly translates into higher dividends perceived by domestic agents and thus, it pushes current stock returns up. Second, there is an additional indirect effect due to the optimal response of monetary policy to a positive technology shock, namely a reduction in interest rates. Given equation (2.18), this reduction explains the predicted drop in stock returns in periods *after* the shock. This finding is consistent with actual observations and with the empirical results of Thorbecke (1997), who empirically documents that unanticipated expansionary monetary policy actions produce on impact a significant rise in equity returns. Further empirical evidence regarding this fact will be presented and examined on Chapter 4 of this thesis, where the impact of monetary policy surprises and other macroeconomic shocks on stock exchange markets will be analysed.

Arbitrage conditions in international stock markets indicate that foreign stock returns also increase as a response to a home productivity shock. This produces a positive correlation between domestic and foreign stock returns.

Panel (c) in Figure 2.3 plots the dynamic response of foreign shares' holdings, $x_{F,t}$, when a technology shock occurs in the domestic country. As emphasised in the introduction, equity markets act as channels of international transmission of shocks. In order to underline this point, the response of foreign share holdings to productivity shocks in Figure 2.3 indicates that agents use international equity

Figure 2.3: Impulse response functions. Response of stock markets



markets to reallocate wealth across countries. First, when a domestic technology shock occurs, the wealth of domestic households is increased through participation in higher profits in the form of dividends. Since domestic households are risk averse ($\sigma > 0$) they accumulate assets when they observe a positive temporary domestic shock. In other words, the domestic economy runs a current account surplus, which translates into a capital account outflow. Panel (c) in Figure 2.3 plots this optimal response of foreign shares holdings. Panel (d) shows the response of domestic agents' holdings of foreign shares to a foreign productivity shock. This mechanism is somehow different as foreign households can only hold foreign assets. When a positive temporary foreign supply shock occurs, foreign households' wealth increases via the dividends they perceive. foreign households optimally save some of this increase in wealth by buying shares, which pushes the price of foreign shares up.[21] Equilibrium in foreign equity markets implies that domestic investors become net sellers of foreign shares when a positive supply shock occurs in the foreign economy.

Additionally, an increase in productivity in the home country creates an excess demand for domestic equities, which pushes their price up as observed in panel (e).

2.4.3 Cross-country Correlation

To empirically motivate our analysis, a summary of statistics for international stock returns is provided in Table 2.1 before presenting the model predictions on cross-country correlations. Data is quarterly and corresponds to the period 1973:Q1-2002:Q3. All series were obtained from IMF International Financial Statistics apart from stock market returns and stock market indexes, which were obtained from Datastream. The quarterly nominal returns series are constructed from stock price indices (dividend reinvested). Real stock returns are constructed by substracting

[21]Notice that the model does not predict that foreign households only buy shares when they experience an increase in wealth. The market clearing conditions together with the arbitrage equation determine the changes in holdings of shares and bonds.

Table 2.1: Summary of statistics for real quarterly returns

	U.S.	France	Germany	Italy	Spain	U.K.	Average
Mean	3.01	2.51	2.80	1.68	2.28	3.29	2.59
Std. Dev.	3.8	6.0	5.4	6.7	6.3	5.1	5.6
Correlation matrix:							
U.S.	1	0.73	0.67	0.59	0.71	0.84	
France		1	0.84	0.66	0.74	0.81	
Germany			1	0.62	0.59	0.62	
Italy				1	0.67	0.73	
Spain					1	0.72	
U.K.						1	

Note: all the returns are quarterly and are expressed in percentage terms. Source: Datastream.

CPI inflation rates from nominal returns.[22] The top row of Table 2.1 records the mean returns in percent per quarter over the sample period.

The mean average is 2.59 percent per quarter, or 10.4 percent at an annual rate. The second row in Table 2.1 provides the standard deviations of the quarterly returns. The quarterly standard deviation ranges between 3.8 percent for the U.S. sample to 6.7 percent for the Italian sample, which corresponds to annualised standard deviations for real stock returns ranging between 15.2 and 26.8 percent, indicating that real stock returns are very volatile. Additionally, Table 2.1 reports the contemporaneous correlation matrix for a group of selected countries. The evidence shows that the correlations between domestic and foreign returns range between 0.59 and 0.84. The average correlation turns out to be 0.72.

In this subsection, we analyse to what extent we can reproduce the stock market spillovers observed in the data with an open economy theoretical framework. As in the rest of the chapter, the role of supply shocks as the source of international stock

[22] For a more extended analysis of stylised facts on international stock market data see Campbell (2003).

market co-movements is stressed.

Model predictions of cross-country correlations, conditional on uncorrelated shocks, are reported in Table 2.2 Panel A. The model statistics pertain to Hodrick Prescott filtered variables. All variables with exception of equity returns were expressed in logs prior to filtering. Table 2.2 Panel A shows that the model does not reproduce the cross-country correlations of the real variables observed in the data. The negative output cross-correlation is a common finding among the NOEM models that introduce the expenditure switching effect and can only be reversed by allowing for a positive correlation between technology shocks (see, for instance, Gali and Monacelli (2002) or Chari, Kehoe and McGrattan (2002)). Another common feature among these models is that they predict a high cross-country consumption correlation. As outlined by Lewis (1999), in a general equilibrium framework that integrates consumption and equity prices, consumption growth rates will tend to commove across countries, even when output growth rates do not. Empirically, however, consumption growth rates tend to have a much lower correlation than output growth. This phenomenon is called *"consumption home bias"*.

Remark 3. *When stock markets are perfectly integrated, namely, when there is no cost of investing in foreign shares in our framework, the model predicts that the stock market cross-correlation is equal to one. The introduction of adjustment costs in the model dramatically reduces the international stock market returns correlation predicted by our model.*

When transaction costs are zero, uncovered interest parity holds, which equates the expected real rates of stock returns and predicts the correlation of stock returns approximately equal to one. The introduction of the cost function, even with a cost as small as $\psi = 0.0001$, significantly reduces the international stock returns cross-correlation and our model predicts this cross-correlation equal to 0.72.

Remark 4. *When shocks are not correlated, our model is only able to reproduce correlations between domestic and foreign stock returns of a magnitude of 0.72.*

When shocks are correlated, our model reproduces the stock exchange correlations observed in the data.

Table 2.2 Panel B records the cross-country correlations of stock returns for different types of productivity shocks; asymmetric, symmetric, uncorrelated and correlated. Correlation between domestic and foreign productivity shocks needs to be introduced in our model in order to reproduce the levels of international stock market correlation observed in reality.

This finding can be explained as follows. The dynamic path of domestic stock returns in our model is affected by three variables: domestic profits, demand of domestic shares and the arbitrage condition with bond interest rates. As shown in Appendix A, the main driver of stock returns is domestic profits, which are significantly driven by domestic shocks. Introducing correlation between domestic and foreign shocks, introduces correlation between domestic and foreign profits and thus, domestic and foreign returns.

Evidence on positive correlation on productivity shocks an its effects on international economy has been recently analysed by Ghironi, Iscan and Rebucci (2003).

Table 2.2: Model predictions. Cross-country correlations.

Panel A: Uncorrelated shocks	Data	Model prediction
$Cor(\widehat{Y},\widehat{Y}^*)$	0.69	-0.10
$Cor(\widehat{C},\widehat{C}^*)$	0.39	0.99
$Cor(\widehat{q},\widehat{q}^*)$	0.68	0.87
$Cor(\widehat{R}_s,\widehat{R}_s^*)$	0.72	0.52
Panel B: Correlated shocks		$Cor(\widehat{R}_t,\widehat{R}_t^*)$
$Cor(\varepsilon_t,\varepsilon_t^*)=0.10$		0.59
$Cor(\varepsilon_t,\varepsilon_t^*)=0.25$		0.70
$Cor(\varepsilon_t,\varepsilon_t^*)=0.35$		0.78
$Cor(\varepsilon_t,\varepsilon_t^*)=0.50$		0.84
Asymmetric shocks		0.56

Note: The second column in Panel A records the baseline model predictions. The historical statistics correspond to the period 1973:Q1-2002:Q3.

2.4.4 Robustness Analysis

Table 2.3 presents the sensitivity analysis of our model to the parameters b and θ; b measures the degree of openness of the economy and θ measures both, the elasticity of substitution between domestic and foreign consumption bundles and the index of monopoly distortion. Columns two and three of Table 2.3 show model predictions of the second moments and correlations for different variables when the parameter b is varied between $b = 0.1$, namely, a relatively closed economy and $b = 0.4$, i.e., a relatively open economy. The main feature of this table is that the results of our model are mostly robust with regards to changes in the degree of openness of both economies.[23] For the purpose of this chapter, it is interesting to note that the model

[23]Remeber that in all the scenarios $b = b^*$. This means that the degree of openess is the same in the home country as in the foreign country.

does not predict a direct relationship between the degree of economic openness and the amount which agents trade in foreign shares when responding to supply shocks. Intuitively, this finding suggests that there is no clear link between the amount of goods an economy imports (as a percentage of GDP) and the holdings of foreign shares. Additionally, our model predicts that stock market co-movements do not depend on the economy's degree of openness. While changes in prices and in total consumption affect the domestic and foreign consumption bundles, stock market comovements are affected by changes in profits and in the demand for shares.

However, it needs to be acknowledged the limited definition of trade openness in this chapter. Models that explicitly include trade frictions in goods markets (e.g. Obstfeld and Rogoff (2001)) do find a link between trade openness and the level of foreign equity trade. From an empirical point of view, Lane and Milesi-Ferretti (2003) have identified growth in goods trade as a key co-variate of the growth in the scale of international balance sheets.

Additionally, it is revealed that the volatility of exchange rate decreases as the economy becomes more open. This result is in line with the results of other authors, like Gali et al. (2002) who conclude that exchange rates are not intrinsically more volatile in more open economies.

With respect to the parameter θ, columns four and five of Table 2.3 show the model's predictions when θ takes values of 3 and 6. It can be seen that the greater the value of θ, the larger the size of the fluctuations when supply shocks occur.

Table 2.3: Sensitivity analysis to b and θ

	Benchmark case	Sensitivity to b		Sensitivity to θ		Data
	$b = 0.27$					
	$\theta = 1.5$	$b = 0.1$	$b = 0.4$	$\theta = 3$	$\theta = 6$	
Standard Deviation (in %):						
$S = e$	2.58	6.64	1.80	1.79	1.43	4.80
x_F	0.02	0.02	0.02	0.26	2.23	6.9
q	1.77	1.81	1.77	2.45	8.03	7.83
π	0.66	0.66	0.71	0.55	0.41	1.35
Y	1.38	1.52	1.45	1.56	1.91	1.41
C	0.96	0.99	0.96	1.18	1.38	1.23
R_s	1.49	1.51	1.51	2.32	7.55	7.80
Cross-country Correlations:						
$Cov(\widehat{Y}, \widehat{Y}^*)$	−0.10	−0.05	−0.15	−0.36	−0.68	0.63
$Cov(\widehat{C}, \widehat{C}^*)$	0.99	0.99	0.99	0.98	0.57	0.39
$Cov(\widehat{R}_s, \widehat{R}_s^*)$	0.70	0.67	0.69	0.62	0.46	0.72
$Cov(\widehat{q}, \widehat{q}^*)$	0.87	0.85	0.84	0.76	0.48	0.78

Notes: Columns one to five detail the model predictions under different assumptions. Column six shows the empirical statistics. Supply shocks are correlated.

The standard deviations of π_H and π_F are not presented because given the monetary policy rule specification they are zero. At the same time, the monetary policy rules imply $\widehat{S}_t = \hat{e}_t$.

This result is due to the fact that any departure by the parameter θ from a unitary value creates inefficient fluctuations in the variables. The size of these fluctuations depends on the value of θ. An interesting result is that the model predicts volatility of stock market variables closer to that observed in reality when $\theta = 6$. In this scenario, standard deviation of q_t increases to 8.03 and standard deviation of $R_{s,t}$ becomes 7.55. Intuitively, as θ increases, the markup of the firms increases and thus the benefits the firms distribute, i.e., the dividends, also increase. This, in turn, pushes the stock returns and the share prices up, creating additional variability in these variables.

It is noted that in general our model does not match the standard deviation of the holdings of foreign shares observed in the data. Further work can focus on this direction: which changes do need to be introduced in the model in order to increase the variability of the stock exchanges' variables?

2.5 Imperfect Integrated Stock Markets

In this section we analyse how the predictions of our model depend on the cost of investing in foreign shares. In other words, we investigate the relationship between stock market integration and the international transmission of shocks.

2.5.1 Theoretical Implication One: Stock Return Co-movements and Consumption Gap

Remark 5. *The expected relationship between domestic and foreign stock returns depends on the cost of investing in the international portfolio.*

Taking the difference between the log-linear approximation of equations (A.11) and (A.12) and using PPP the following equation is obtained

$$E_t \left\{ \widehat{r}_{s,t+1} - \widehat{r}^*_{s,t+1} \right\} = E_t \left\{ \Delta \widehat{e}_{t+1} \right\} + \widehat{\Psi}_t \tag{2.19}$$

Equation (2.19) indicates that uncovered interest parity does not hold when transaction costs are different from zero. Our model predicts the spread between the nominal stock market returns reflects a premium on top of the expected exchange rate depreciation. If $\widehat{x}_{F,t} > 0$, which indicates that the home country is a net lender in the market of the international asset, the premium will be negative and domestic investors will receive lower remuneration for their foreign assets than the foreign stock return. As a consequence, investments in the foreign country become less attractive. The opposite occurs when $\widehat{x}_{F,t} < 0$. In this situation, the home investor is a net borrower in the market of the international asset, the premium is positive in order to give investors incentives to invest in the foreign assets.

Remark 6. *The consumption gap between countries depends on the degree of stock market integration.*

Additionally, taking the difference between the log-linear approximation of equations (A.12) and (A.14), it is shown that the consumption gaps are not necessarily equalised across countries. More precisely, our model predicts that the consumption gap also depends on the degree of imperfect market integration

$$E_t \left\{ \widehat{C}_{t+1} - \widehat{C}^*_{t+1} \right\} = \widehat{C}_t - \widehat{C}^*_t + \widehat{\Psi}_t / \sigma \tag{2.20}$$

Equation (2.20) indicates that the relationship between domestic and foreign consumption depends on the stock market structure and the cost affects consumers' optimal decisions, which affects international consumption risk sharing allocations.

It is interesting to point out that when there are no costs of investing in foreign stocks, i.e., $\widehat{\Psi}_t = 0$, our model yields the same predictions as a model with complete asset markets structure. In that case, equation (2.19) is the uncovered interest parity equation and equation (2.20) reveals that the consumption gap is equalised across countries. Therefore, the introduction of the investment costs is crucial to understanding the departure of our model from the framework of complete asset markets.

2.5.2 Theoretical Implication Two: Stock Prices

In this subsection we first examine the scenario where there are no costs of investing in foreign shares. If we solve forward the FOC for each consumer (equations (2.7) and (2.11)) and we rule out the possibility of self-fulfilling speculative asset-price bubbles, i.e., we use the non-Ponzi game condition, we obtain the expressions for domestic and foreign real equity prices in the home and the foreign country:

$$\frac{q_t}{P_t} = E_t \left\{ \sum_{\tau=1}^{\infty} \beta^{\tau} \frac{U'_{C_{t+\tau}}}{U'_{C_t}} \frac{\Omega_{t+\tau}}{P_{t+\tau}} \right\}$$

$$\frac{q_t^*}{P_t^*} = E_t \left\{ \sum_{\tau=1}^{\infty} \beta^{\tau} \frac{U'_{C^*_{t+\tau}}}{U'_{C^*_t}} \frac{\Omega^*_{t+\tau}}{P^*_{t+\tau}} \right\} \tag{2.21}$$

The above equations show that the firm's market value in each country on date t is the present discounted value of all the dividends the firm, starting on date $t+1$, will pay to shareholders over the future.

When a temporary domestic productivity shock in period t takes place, i.e., $z_t \neq 0$, $z_{t+1} = z_{t+2}... = 0$, an increase in current period profits, $\Delta\Omega_t > 0$, does not have a direct effect on current share prices since these are only influenced by the expectations of future profits, $\Omega_{t+1}, \Omega_{t+2}...$ and not by Ω_t. Note however, that actually q_t/P_t is indirectly affected since any temporary shock influences the intertemporal consumption patterns, which changes $\frac{U'_{C_{t+\tau}}}{U'_{C_t}}$.

Furthermore, perfect risk sharing implies $\frac{U'_{C_{t+\tau}}}{U'_{C_t}} = \frac{U'_{C^*_{t+\tau}}}{U'_{C^*_t}}$. With $E_t z_{t+\tau} = E_t z^*_{t+\tau} = 0$, our model predicts that the correlation between domestic share prices and foreign share prices is similar to the correlation between domestic and foreign real profits.

The scenario with costs of investing in foreign shares is next to be analysed.

Remark 7. *Costs of investing in the international portfolio affect share prices.*

When the costs of investing in the foreign market are taken into account, the correlation between domestic and foreign equity prices depends on such costs. Domestic equity prices are characterised in the same way as in the previous scenario in equation (2.21). However, in this scenario, it needs to be remembered that there is no perfect risk sharing and that $\frac{U'_{C_{t+1}}}{U'_{C_t}} * \Psi(x_{F,t}) = \frac{U'_{C^*_{t+1}}}{U'_{C^*_t}}$. If the difference between domestic and foreign real stock prices is log-linearised we obtain

$$\widehat{q}_t^* - \widehat{q}_t = -\widehat{\Psi}_t - \pi_1(\widehat{z}_t^* - \widehat{z}_t) - \pi_5(\widehat{C}_t^* - \widehat{C}_t) \tag{2.22}$$

where $\pi_1 = (1-\beta)(\theta-1)^2(1+\phi)$ and $\pi_5 = (1-\phi(\theta-1))(1-2b)-(\theta-1)\sigma$. Equation (2.22) predicts that an increase in the cost of investing in foreign shares, i.e., an increase in ψ makes investing in the foreign country less attractive, which decreases the domestic demand of foreign shares and consequently, also decreases the price of foreign shares.

2.5.3 Simulation Results

This subsection presents the graphs corresponding to the simulation results for the above theoretical predictions. We present different scenarios to analyse how the cost of investing in foreign shares affects the relationship between variables. We repeat the simulations allowing the parameter ψ, which measures the cost of intermediation in the foreign market, to take the values $0.0001, 0.001, 0.01$ and 0.03.[24] Figure 2.4 plots the impulse response functions of foreign shares, foreign stock returns, foreign share prices and foreign consumption to a one percent positive temporary shock in home productivity.

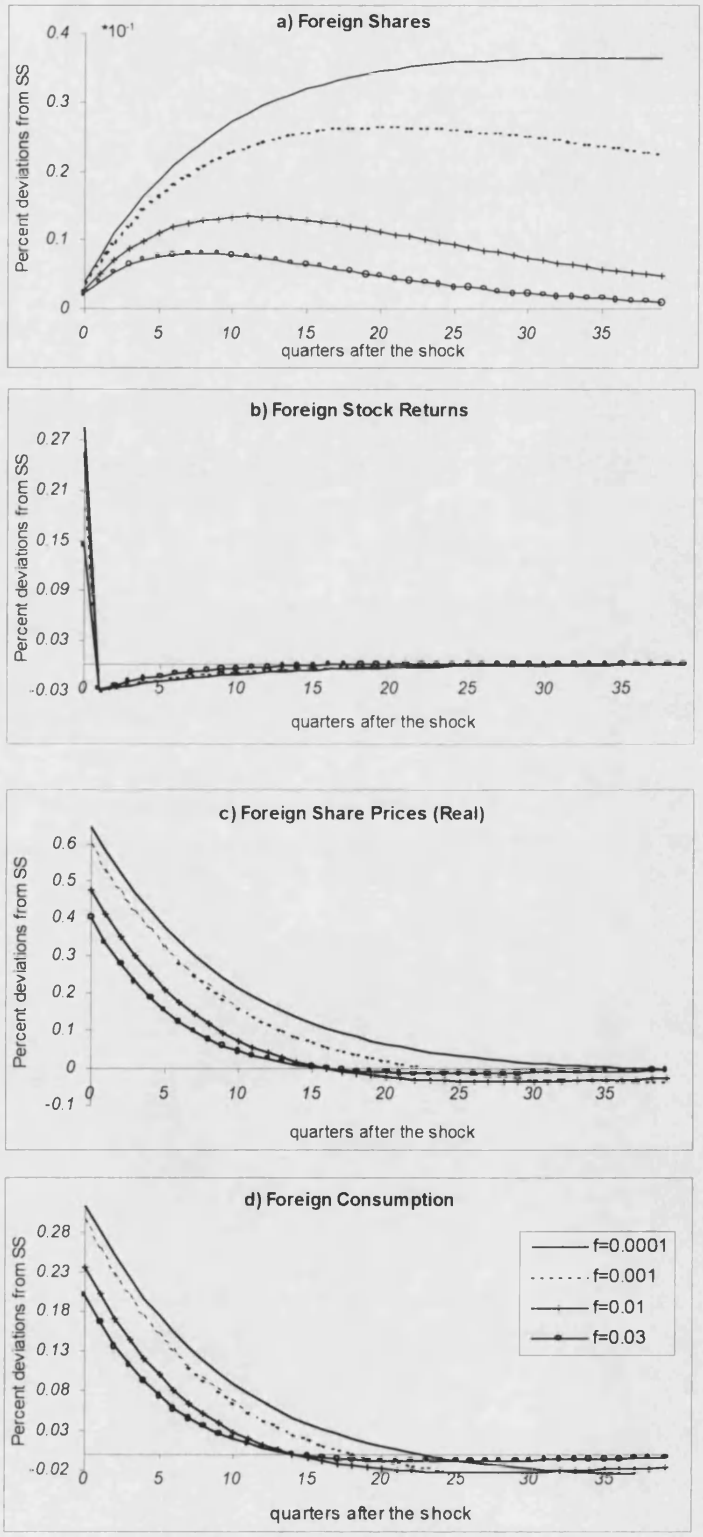
The main feature in Figure 2.4 is that varying the degree of stock market integration does not change the model's dynamics but it does alter the magnitude of the response of the different variables to a shock in z_t.

With respect to foreign asset holdings, as far as the cost is different from zero, domestic and foreign shares are not perfect substitutes for the domestic investors. In panel (a) in Figure 2.4, it is noted that the magnitude of the cost function affects the optimal portfolio allocation. In other words, the degree of stock market integration affects the optimal portfolio decisions. As anticipated, an increase in the costs of investing abroad reduces the optimal amount of foreign shares the domestic household chooses to hold.

The response of foreign stock returns to a positive temporary shock in z_t is plotted in panel (b). The magnitude of the initial increase in foreign stock returns

[24]Remeber that an increase in the adjustment costs, i.e., an increase in ψ, indicates that international equity markets are less integrated.

Figure 2.4: Impulse response functions. Various degrees of stock market integration



when ψ increases from 0.0001 to 0.001, 0.01 and 0.03 is $0.28, 0.25, 0.18$ and 0.14 respectively. This offers evidence on the theoretical implication one presented in Subsection 2.5.1; equation (2.19) predicted that the relationship between domestic and foreign stock returns depends on the magnitude of the cost.

Regarding the response of real foreign share prices, panel (c) in Figure 2.4 shows that the responsiveness of foreign share prices to domestic productivity shocks decreases when the magnitude of the transaction costs is higher. Equation (2.22) in the theoretical implication number two in Subsection 2.5.2 already pointed out that the magnitude of the cost affects the relationship between domestic and foreign share prices. Interestingly, it is also noteworthy that the time of the adjustment of foreign consumption towards the initial steady state depends on the parameter ψ.[25]

Finally, panel (d) in Figure 2.4 plots the dynamic response of foreign consumption to a shock in domestic productivity. This diagram illustrates that, as financial transaction costs increase, the initial response of foreign consumption to a shock in z_t decreases. Our model predicts that the more integrated financial markets are, the more opportunities they provide for consumption smoothing, predicting high correlation between domestic and foreign consumption.

Table 2.4 reports the model predictions with different values for the parameter ψ. As Figure 2.4 and Table 2.4 show, the introduction of costs to model imperfect integrated financial markets helps to decrease the cross-country correlation of consumption predicted by these models.

To summarise, as the cost of investing in foreign equities is reduced, namely, as stock markets become internationally more integrated, our model predicts that the rates of return in equity markets, share prices and consumption become more correlated across countries. Finally, the model predicts international consumption risk sharing; agents respond to adverse shocks originated both in the home and the

[25]Obviously, the time of adjustment also depends on the degree of persistence of shocks. In all scenarios presented in this subsection, the degree of persistence of shocks is the same and it is set at $\rho = 0.9$.

foreign country in order to reduce consumption variability.

Table 2.4: Model predictions. Different degrees of stock market integration

	$\psi = 0.0001$	$\psi = 0.001$	$\psi = 0.01$	$\psi = 0.03$
Standard Deviation (in %):				
$S = e$	2.49	2.36	2.06	1.86
x_F	0.022	0.021	0.016	0.012
q	1.74	1.76	1.83	1.89
π	0.67	0.64	0.62	0.47
Y	1.40	1.38	1.34	1.31
C	0.96	0.97	1.00	1.03
R_s	1.46	1.48	1.53	1.56
Cross-country Correlations:				
$Cov(\widehat{Y}, \widehat{Y}^*)$	−0.07	−0.06	0.02	0.09
$Cov(\widehat{C}, \widehat{C}^*)$	0.99	0.91	0.85	0.79
$Cov(\widehat{R}_s, \widehat{R}_s^*)$	0.73	0.65	0.61	0.57
$Cov(\widehat{q}, \widehat{q}^*)$	0.82	0.83	0.76	0.72

Note: see note for Table 2.3.

2.6 Asymmetric Holdings of Foreign Shares

In this section we investigate whether the simulation results of our model are robust to a scenario in which there are asymmetries in the initial holdings of foreign assets across countries. As Lane and Milesi-Ferretti (2001) document, net foreign assets over GDP vary across countries and are different from zero.

To introduce a non-zero steady state holding of foreign shares, the function $\Psi(.)$ needs to be appropriately modified. In particular, the new functional form of the cost function becomes

$$\Psi(x_{F,t}) = e^{-\psi(x_{F,t}-\overline{x})} \tag{2.23}$$

This cost function assumes the value of one if, and only if, $x_{F,t}$ equals $\overline{x}$, which is the steady state level of holdings of foreign shares.

A description of the calculation of the new steady state and the changes in the log-linear system can be found in Appendix C. In this scenario, the initial steady state equilibrium is asymmetric across countries. Table 2.5 shows the initial steady state equilibrium under different values of $\overline{x}$. When $\overline{x} > 0$, home investors hold foreign shares in equilibrium, namely they are net lenders in the international shares market. As a consequence, not all the goods produced in the foreign economy must be consumed abroad in a steady state equilibrium. Home agents also receive a fraction $\overline{x}$ of the dividends generated by foreign companies, which they can use to increase their consumption expenditure. As a result, in steady state $\overline{C} > \overline{Y\frac{P_H}{P}}$. Not surprisingly, equation (C.1) and Table 2.5 demonstrates that the larger $\overline{x}$ is, the greater the divergence between the consumption and the output levels in steady state equilibrium.

Table 2.5: Steady state equilibrium

	$\overline{x}=0$	$\overline{x}=0.1$	$\overline{x}=0.2$	$\overline{x}=0.3$	$\overline{x}=0.5$
$\overline{C}$	0.69	0.16	0.17	0.21	0.28
$\overline{Y\frac{P_H}{P}}$	0.69	0.15	0.16	0.18	0.23
$\overline{C}^*$	0.69	0.10	0.11	0.10	0.09
$\overline{Y^*\frac{P_F^*}{P^*}}$	0.69	0.12	0.13	0.13	0.14
$\overline{s}$	1	0.21	0.21	0.20	0.18

Next, the focus is on the description of the critical novelties. Figure 2.5 presents the impulse response functions of the stock returns and the holdings of foreign shares to both home and foreign supply shocks. The steady state value of foreign shares is allowed to vary between 0.1 and 0.5. Consideration is not given to the case $\overline{x} < 0$ in steady state. Basically, as only foreign companies can issue foreign shares, it would not be realistic that domestic investors are net sellers of foreign share in steady state equilibrium. However, the possibility that home investors short sell foreign shares in the dynamic adjustment to a new equilibrium is not ruled out. To clarify, we do not consider negative values for $\overline{x}$ but $\widehat{x}_{F,t} - \overline{x}$ can be negative. Additionally, with respect to the magnitude of $\overline{x}$, for instance $\overline{x} = 0.2$ implies that home investors place 83 percent of their equity portfolio in domestic shares and 16 percent in foreign shares. Similarly, $\overline{x} = 0.5$ indicates that home investors place 66 percent of their portfolio in domestic shares and 33 percent in foreign shares.[26, 27]

A common feature among the four panels in Figure 2.5 is that the fact that domestic investors hold foreign shares in equilibrium amplifies the response of stock returns to supply shocks. Interestingly, a positive domestic supply shock has a longer, positive effect in domestic stock returns. This pattern is robust across different levels of $\overline{x}$ in equilibrium.

Panels (a) and (b) in Figure 2.5 plot the impulse response function of home and foreign stock returns to supply shocks. Two points are worth noting. First, introducing asymmetric holdings of foreign shares significantly affects the dynamic response of stock returns to supply shocks. In all cases, the response of stock returns does not vanish after the first period, which implies that supply shocks have not only an immediate effect on stock markets. Second, the shape of the response of stock returns to supply shocks does not depend on the initial steady state equilibrium of holdings of foreign assets.

Panel (c) plots the dynamic response of foreign shares to a positive temporary home supply shock for different levels of $\overline{x}$. There are two main points to observe. First, domestic households experience a temporary increase in wealth when a domes-

[26] At the end of 2000, foreign equities comprised roughly 12 percent of U.S. equity holdings and 30 percent of U.K. equity holdings (Warnock (2001)).

[27] Due to the fact that there is no international market for domestic shares and the share markets clear each period, domestic investors always invest one unity in domestic shares. Therefore, the proportion domestic investors invest in foreign shares is given by $\frac{\overline{x}}{1+\overline{x}}$.

tic supply shock happens. As their consumption is already higher that their income, they optimally buy extra foreign shares to postpone the increases in consumption over time. In other words, as households are risk averse, they optimally decide to smooth consumption over time and accordingly, the model predicts an increase in domestic savings when a positive temporary domestic shock occurs. In our model this is equivalent to increasing their holdings of foreign shares. Second, the larger the amount of foreign shares domestic investors hold in equilibrium, the less the amount changes as a response to domestic technology shocks. Intuitively, even if diversification is optimal, domestic investors have to pay costs in order to invest in the international portfolio, which limits the amount of foreign shares domestic investors optimally want to trade.

Nevertheless, note that the magnitude of the response of foreign shares to technology shocks is minimal. Comparing these results with the dynamic response of foreign shares to shocks in the simulations in Section 2.5, the model here predicts that changes in domestic holdings of foreign shares are more sensitive to the level of transaction costs than to the initial holdings. In other words, the dynamic pattern of holdings of foreign shares depends on the transaction costs in the international financial market, but it barely depends on the initial level of holdings of foreign shares.

The standard deviations and the cross-country correlations predicted under the different scenarios are also shown in Table 2.6. We observe that the standard deviations and the correlations predicted by the new scenarios do not change so much as compared with those of the original model. The main difference is that allowing for asymmetric holdings of foreign shares reduces the variability of foreign shares holdings, which suggests that due to the costs of transferring foreign shares, domestic investors will never gain excessive exposure to foreign shocks.

Figure 2.5: Impulse response functions. Asymmetric holdings of Foreign shares

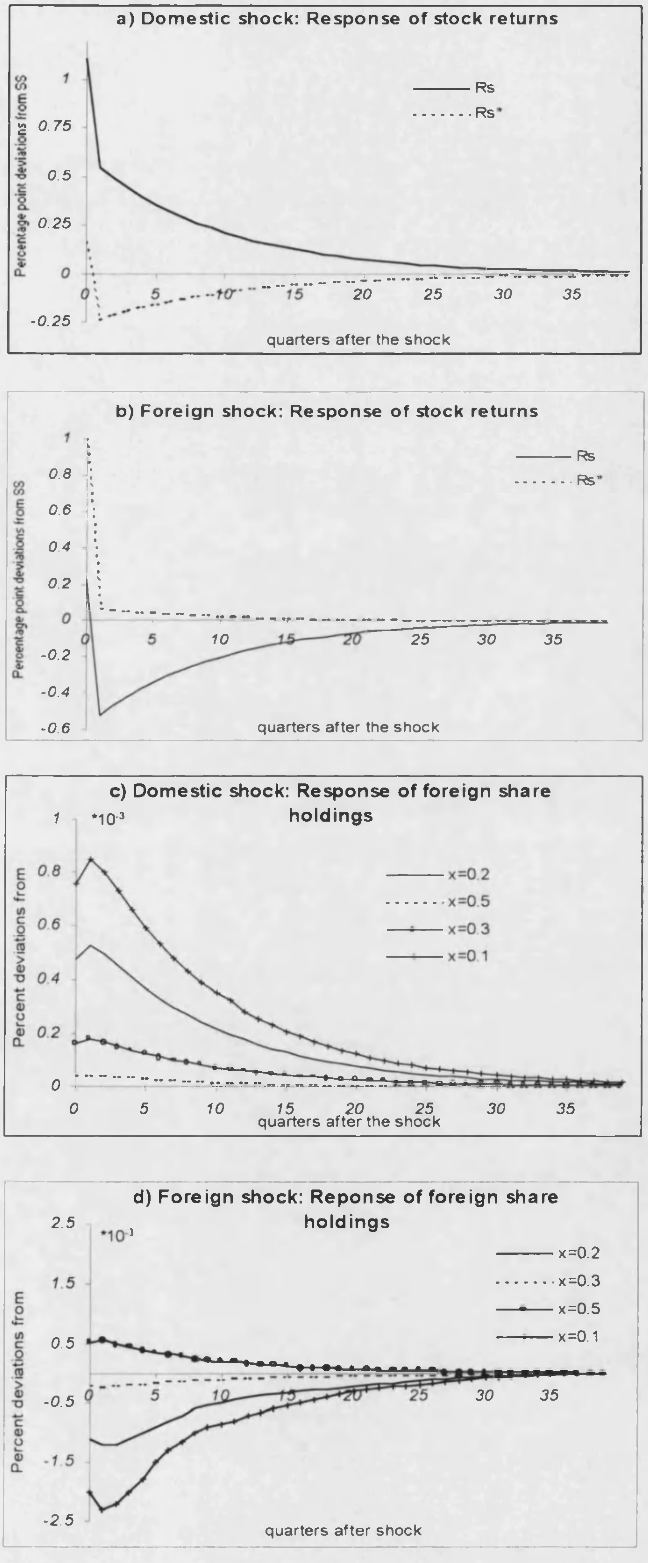


Table 2.6: Model predictions with asymmetric holdings of foreign shares

	Benchmark case	$\overline{x} = 0.1$	$\overline{x} = 0.2$	$\overline{x} = 0.3$	$\overline{x} = 0.5$
Standard Deviation (in %):					
$S = e$	2.58	2.59	2.61	2.44	2.55
x_F	0.02	0.004	0.002	0.001	0.001
q	1.77	1.75	1.70	1.76	1.76
π	0.66	1.10	1.14	1.09	1.17
Y	1.38	1.48	1.46	1.41	1.46
C	0.96	0.99	0.83	0.81	0.86
R_s	1.49	1.87	1.72	1.66	1.79
Cross-country Correlations:					
$Cov(\widehat{Y}, \widehat{Y}^*)$	−0.10	−0.11	−0.16	−0.09	−0.12
$Cov(\widehat{C}, \widehat{C}^*)$	0.99	0.95	0.95	0.96	0.95
$Cov(\widehat{R}_s, \widehat{R}_s^*)$	0.70	0.56	0.52	0.48	0.57
$Cov(\widehat{q}, \widehat{q}^*)$	0.87	0.92	0.88	0.84	0.81

Note: see note for Table 2.3.

2.7 Summary and Conclusions

This chapter is the first attempt at introducing stock market integration into a theoretical New Open Economy Model. We have explicitly introduced shares in the model and stock market integration has been modelled by introducing concave transaction costs on the holdings of foreign shares. We have devoted special attention to studying to what extent international stock market co-movements are attributable to supply shocks and to exploring the role of foreign profits and dividends as an extra channel of international shocks spillovers. The model has been log-linearised around an initial steady state equilibrium. Three different scenarios have been simulated. The first one (results presented in Section 2.4) is the benchmark model with transaction costs. The second scenario (presented in Section 2.5) has analysed the effects of various degrees of stock market integration on stock return comovements and on stock prices. The third scenario (analysis presented in Section 2.6) has introduced asymmetric holding of foreign shares in the initial equilibrium to investigate the effects on international transmission of supply shocks.

The main conclusion of this chapter is that the model predicts a bi-directional relationship between international stock market dynamics and economic activity. International dynamic spillovers and the correlations of stock returns are affected by the fact that domestic investors can gain exposure to international shocks by buying foreign shares. Dividends and profits act as an extra channel of international transmission of shocks.

The focus is on the effect of supply shocks on stock markets as this is the contribution of our model to this branch of literature. With respect to the response of the other real variables to supply shocks (consumption, output, prices, exchange rate, etc.) the model's predictions are essentially the same as those published in the NOEM literature. Next, the main predictions of our model regarding stock market cross-correlation are summarised:

- In our benchmark scenario, the model predicts positive correlation between home and foreign stock returns when stock exchanges respond to supply shocks. Intuitively, a domestic productivity shock increases the dividends domestic shares pay and thus, it increases domestic stock returns. Consequently, domestic agents experience a temporary increase in wealth and they optimally decide to increase the demand of foreign shares, pushing the price of foreign shares and foreign returns up and signifying positive international spillovers between stock exchanges. This result has two main implications. First, it draws attention to the role of supply shocks in helping to explain the dynamic behaviour of international stock market returns. Second, it indicates that dividends act as channels of the international transmission of shocks.

- Bringing imperfect international stock market integration through adjustment costs into the model dramatically reduces international stock returns correlations. Our model predicts that when stock markets are not perfectly integrated, imperfect capital mobility and barriers to portfolio diversification limit the ability of agents to take optimal decisions; thus, affecting the dynamic response of variables to technology shocks and the international spillovers. Not surprisingly, the contemporaneous correlations of stock returns, share prices and consumption decrease when transaction costs of investing in foreign shares increase.

- Regarding the introduction of various degrees of stock market integration, our model predicts that the expected relationship between home and foreign stock returns depends on the level of the cost of investing in the international portfolio. At the same time, this transaction cost also affects share prices.

- When introducing initial asymmetric holdings of foreign shares, the duration of the dynamic response of the stock returns to supply shocks changes dramatically. The shocks turn out to affect stock returns longer. Apart from this, the dynamic response of real variables to supply shocks does not depend on the initial level of foreign assets.

- Finally, the dynamic response of holdings of foreign shares is significantly reliant upon the level of transaction costs in the international stock market, but it hardly depends on the initial level of holdings of those foreign shares.

Extensions:

Several issues remain however. The model presented in this chapter is a first attempt at introducing stock market integration within a NOEM framework. As such, it puts forth a limited case and further analysis should be undertaken to make the model's assumptions more general and realistic:

Among the limitations of the model, it does not contemplate capital accumulation, which limits the role of stock markets in the transmission mechanism.

In addition, we acknowledge that policy issues are barely discussed in the chapter. Given the growing interest on the role of monetary policy on asset prices bubbles, both in the empirical literature (Rigobon and Sack (2002), Smets (1999))) and the theoretical literature (Ghironi, Lee and Rebucci (2004)), it would be desirable to analysis the role of monetary policy and its relationship to asset price movements in the model. Further analysis should be focussed on this direction.

Finally, further analysis with respect to the predictions of the model would need to be carried out in order to examine the factors that affect and would increase the variability in stock market variables.

Nonetheless, we believe that the profit channel documented in this chapter is significant and gives some insight on additional mechanisms of international transmission of shocks.

One of the aims of this thesis is to investigate possible sources of stock market comovements across countries. In addition to new theoretical articles on the New Open Economy literature, empirical implementation of these models is also getting started. Most of these empirical studies are at a macroeconometric level using Vector Autoregressive analysis (see for instance Ghironi (1999) and Smets and Wouters (2002)). As Lane and Ganelli (2002) point out, more microeconomic evidence on international financial trade is also highly desirable. The next two chapters of this thesis focus on this last point. The objective in the next chapters is to better understand which factors affect international stock market spillovers from an empirical perspective.

Part II

EMPIRICAL STUDIES

Chapter 3

Intra-day Spillovers between the FTSE 100 and the Dow Jones Industrial Average Returns

3.1 Introduction

Does Wall Street lead the FTSE 100 Index returns? If so, why? This chapter empirically investigates the intraday transmission of stock prices and volatility between the FTSE 100 index and the Dow Jones Industrial Average index returns.

Given the increasing international economic integration, the deregulation and globalisation of financial markets, corporate and economic news released in one country may not reveal information only about that particular country, but may contain "global factors" affecting the world economy. This chapter investigates the extent to which international stock market spillovers are due to the fact that news released in one country contains "global information". We call this hypothesis "global factor hypothesis". Our econometric specification uses an aggregate shock model to describe how domestic traders extract these global factors from stock price movements observed in foreign exchanges.

Section 3.3 contains the description of the intra-day FTSE 100 and Dow Jones

100 and the Dow Jones Industrial Average index in a novel manner: We use intra-day prices to test how information is transmitted from one market to the other. With our intra-day data set we can identify time spans and calculate intra-day returns depending on whether both stock exchanges are open for trade or only one of them is open. With this unique data set, we specify and separately estimate the stock market spillovers in three cases:

- Case 1: effects of New York stock prices on next morning London stock prices. This case takes into account that New York Stock Exchange closes later than London Stock Exchange. Thus, the afternoon price movements in New York may partially reflect "global" news that London investors incorporate into the prices next morning.

- Case 2: effects of London stock prices on New York stock prices. This case takes into account that London Stock Exchange opens earlier than New York Stock Exchange. Thus, New York traders may learn information from FTSE 100 morning movements.

- Case 3: simultaneous trading hours between the New York and the London Stock Exchanges. In this case news is incorporated simultaneously in both stock prices.

As the preliminary statistical analysis shows that stock returns data presents conditional heteroskedasticity and volatility clustering, we propose to model stock's behaviour using the General Autoregressive Conditional Heteroskedasticity (GARCH) family of models. In addition, as this thesis focuses on asymmetries on stock price co-movements, we propose an Exponential GARCH (EGARCH) model for each of the cases. The EGARCH models allow for asymmetric responses of volatility to good and bad news.

Finally, it is commonly stated that the FTSE returns respond to the movements in the New York stock prices. Examples are *'following the decline in Wall Street yesterday, the FTSE 100 lost 27.5 points to 6,176'* (Financial Times, 15-Feb-03) or Masih and Masih (1999), who conclude that *'our findings tend to confirm the widely held view of the leadership of the US equity market over the long and the short term'*.

These analysis use daily stock returns. Given that the U.S. market closes later, news released in the afternoon (London time) is first incorporated into New York stock prices and it is included into next day London returns. As a consequence, it is statistically observed that the New York returns lead the FTSE returns but not vice versa. The main contribution of this chapter is the use of intra-day stock prices to identify the dynamic spillovers between the FTSE and the Dow Jones indices during the different time regimes. Furthermore, we investigate whether the FTSE returns also contain global information relevant for American investors and assess whether the findings of previous studies are mainly due to the fact that daily data is used.

The rest of the chapter is organised as follows. After summarising the related literature in Section 3.2, the different time spans are defined in Section 3.3. This section also provides a description of the dataset used in the chapter and presents a preliminary correlation analysis. Section 3.4 sets up the econometric specification for each of the cases. Section 3.5 presents the model estimations and Section 3.6 checks the robustness of the results. Finally, Section 3.7 presents this chapter's summary and conclusions.

3.2 Related Literature

While it is generally accepted that stock markets tend to move together, there is no consensus as to why they move together. There are hardly any theoretical models available on why stock markets co-move. The answer to this open question lies somewhere between two extreme explanations: global news and investors' sentiment.

In an efficient equity market environment, stock prices should adjust instantaneously to the flow of incoming information so that stock prices reflect at any point in time all relevant information affecting them (Fama 1991). One possible source of information influencing stock prices in one country is the movement of stock prices in other markets around the world.

The empirical literature on interdependencies among the national stock markets has taken two approaches. The first group of studies examines the contagion effects across several countries following a crises (e.g. the October 1987 stock market crash or the East Asian financial crises). ARCH / GARCH models are usually employed to analyse the spillovers and contagion effects of a shock from one country on another. The second approach involves testing the interdependence directly using cointegration, or vector autoregressive techniques.

In this section the studies belonging to the first approach are reviewed as the econometric techniques used in this chapter are similar to theirs. In Chapter 4 the second branch of empirical studies will be reviewed.

It is often empirically observed that large (small) changes in returns during one period tend to be followed by large (small) changes during subsequent periods. This phenomenon is often called volatility clustering. The Autoregressive Conditional Heteroskedasticity (ARCH) class of models introduced by Engle (1982) has proven to be successful in capturing volatility clustering. This model has been generalised to the General Autoregressive Conditional Heteroskedasticity (GARCH) by Bollerslev (1986).[1] To account for asymmetric effects of good and bad news on volatility, Nelson (1991) developed the Exponential GARCH (EGARCH) model.

As mentioned above, the nature of the international transmission of stock returns and volatility was a focus of extensive studies after the equity crash of 1987: Bennett and Keleher (1988), von Fustenberg and Jeon (1989), Eun and Shim (1989), Hamao, Masulis and Ng (1990), King and Wadhwani (1990) are to name but a few. These articles report several empirical regularities. First, lagged spillovers of price changes and price volatility are found between major markets. Second, correlations in volatility and stock prices appear to be asymmetric in causality between the U.S. and other countries. In particular, Von Furstenberg and Jeon (1989), Eun and Shim (1090) and Hamao et al. (1990) report evidence that the U.S. innovations are rapidly

[1] A discussion of the econometric properties of the estimates of the GARCH models can be found in Bollerslev, Engle and Nelson (1993). An extensive review of theory and empirical evidence in ARCH modelling in finance can be found in Bolleslev, Chou and Kroner (1993).

transmitted to other markets but not in the other direction. Gerits and Yuce (1999) also conclude that *'the U.S. market exerts a significant impact on the European stock exchanges, but not vice versa'.*

Among the first studies trying to explain the documented international linkages by so-called "global factors", King and Wadhwani (1990) use a signal extraction model to separate the "global factors" in foreign price changes from the "local factors". They construct a model in which "contagion" between markets occurs as a result of attempts by rational agents to infer information from price changes in other markets. Their model is based in the fact that, because investors have access to different sets of information, they can infer valuable news from price changes in other markets. However, King et al. (1990) use close-to-close returns, so that the returns in one country have overlapping hours with returns in the other country.

To overcome the problem of overlapping trading hours, Lin, Engle and Ito (1994) analyse the interrelationship between New York and Tokyo equity markets, which do not share any common trading period. They propose and estimate a signal extraction model with GARCH processes to identify the global factor from the daytime returns of one market. They demonstrate that information revealed during the trading hours of the Tokyo market (New York market) has a global impact on the returns of the New York (Tokyo) market. Lin et al. (1994) improved upon the King and Wadhwani (1990) approach by breaking down close-to-close returns into daytime and overnight returns and by allowing time-varying volatility in performing the signal extraction.

We adapt Lin et al. (1994) econometric specification to our intra-day framework. Given the increasing availability of high frequency data on stock prices, we use intra-day prices for the Dow Jones Industrial Average and the FTSE 100 indices to adapt the Lin et al. (1994) framework to common and non-common trading hours returns for the New York and the London Stock Exchanges. A series of EGARCH models are specified to characterise investors behaviour in each of the four regimes previously defined and to analyse how stock price movements across the London and New York markets influence each other.

The analysis in this chapter is related to Connolly and Wang (2003). They explain return co-movements for the U.S., U.K. and Japanese equity markets with an imperfect learning theoretical model. They split close-to-close time spans between intraday and overnight returns. In their model, domestic investors try to extract unobservable global factors from foreign market returns and use this information in subsequent domestic trading. Their empirical results suggest that foreign intraday returns significantly influence subsequent domestic market returns. They conclude that their evidence supports the imperfect signal extraction hypothesis suggested by King et al. (1990).

On the one hand, this chapter is related to these studies by the way we model the behaviour of investors, namely the way we describe how domestic traders extract global factors from stock price movements observed in foreign markets. On the other hand, we improve these analysis by using more refined intra-day time spans and by modelling in a novel manner how intra-day stock prices influence each other. For each of the intra-day cases defined, our econometric specification explicitly incorporates the fact that both stock exchanges are open for trading or only one of them is open. In addition, we use an EGARCH model to estimate each of the cases to account for the asymmetric effect of good and bad news on volatility.

3.3 Data and Preliminary Correlation Analysis

3.3.1 Stock Market Indices

We adopt the FTSE 100 (FTSE) and the Dow Jones Industrial Average (DJ) as the stock price indices for the London Stock Exchange and the New York Stock Exchange respectively. The FTSE 100 index is a capitalisation-weighted index of the 100 largest companies traded on the London Stock Exchange. The Dow Jones Industrial Average is a price-weighted average of 30 blue-chip stocks that are generally the leaders and most liquid names in their industry.[2] Intra-day data for the indices has been obtained from Deutsche Bank equity derivatives data set. Deutsche Bank has a direct connection with Bloomberg and, on a daily basis, downloads minute by minute stock index prices observations into a spread sheet. This unique data set allows us to calculate intra-day stock indices returns.[3]

From 20 September 1999 the London Stock Exchange has opened its trading at 08:00h and has continued trading until 16:30h (London time or 03:00h-11:30h New York time).[4] The Dow Jones trades between 09:30h and 16:00h (New York time or 14:30h-21:00h London time).[5] Therefore, both exchanges typically share two hours overlap on each trading day. The common trading hours correspond to the first two trading hours on the New York Stock Exchange and the last two trading hours on the London Stock Exchange.

The sample period in this chapter corresponds to 4 January 1999 through 28 March 2003. The sample consists of 1,104 observations. When national stock exchanges are closed due to national holidays, bank holidays or unpublished data, the index level is assumed to remain the same as that of the previous trading day.

Our sample period includes transitions to daylight saving time and winter time. Consequently, adjustments have to be made for potential differences in the exact time of the transition. In the U.K. this transition to daylight saving time takes place on the last Sunday of March, while in the U.S. it takes place on the first Sunday of April. This implies that in the week 28 March to 4 April 1999 the exchanges had 1.5 hours of daily common trading. In the weeks 26 March to 2 April 2000, 25 March to 1 April 2001 and 31 March to 7 April 2002 the overlap period becomes only one

[2]During the sample period used, two out of the thirty company members of the Dow Jones Industrial Index trade on the Nasdaq: Intel Corp. and Microsoft Corp. The rest of the DJ members trade on the New York Stock Exchange.

[3]The same data source is used to calculate returns in Chapters 4 and 5 of this thesis.

[4]Before the 20 September 1999 the London Stock Exchange trading hours were between 09:00-17:00h.

[5]Unless otherwise stated, the time notation throughout the chapter refers to London time.

hour every day. The transition to winter time takes place both in the U.K. and in the U.S. on the last Sunday of October. Thus, no adjustments need to be made regarding winter transition. Due to the 11 September 2001 terrorist attacks. The week of 10-14 September 2001 is not included in our analysis.

Stock returns are measured as the change in the stock price index's logarithm. FTSE 100 Index returns are denoted as $FTSE$ and Dow Jones returns as DJ. Both the FTSE and the Dow Jones daytime (open-to-close) returns are divided into non-common trading hours returns and common trading hours returns. London daytime returns are divided into morning trading returns $-FTSE_{m,t}-$, which comprise changes in FTSE prices between 08:00h and 14:30h and common trading hours returns $-FTSE_{c,t}-$, which contain the changes in FTSE prices between 14:30h and 16:30h. Similarly, New York daytime returns are divided between common trading hours returns $-DJ_{c,t}-$, which include the changes in DJ price between the opening and 1130h and afternoon trading returns $-DJ_{a,t}-$, which include the trading period between 11:30h to 16:00h New York time.[6] The definitions of the intra-day returns are as follows[7]

$$\begin{aligned} FTSE_{m,t} &= \ln(FTSE_{14:30,t}) - \ln(FTSE_{open,t}) \\ FTSE_{m,t} &= \ln(FTSE_{close,t}) - \ln(FTSE_{14:30,t}) \end{aligned} \tag{3.1}$$

$$\begin{aligned} DJ_{c,t} &= \ln(DJ_{11:30,t}) - \ln(DJ_{open,t}) \\ DJ_{a,t} &= \ln(DJ_{close,t}) - \ln(DJ_{11:30,t}) \end{aligned} \tag{3.2}$$

Using the above intra-day prices, the three cases analysed in this chapter can be described as follows:

- Case 1: effects of Dow Jones stock prices on FTSE prices. As on a daily basis, New York Stock Exchange closes later than London stock exchange, there is

[6]Remember that 14:30h London time is the time the New York Stock Exchange opens (09:30h in New York time). 11:30h New York time is the time the London Stock Exchange closes (16:30h in London time).

[7]FTSE subscripts correspond to London time and DJ subscripts correspond to New York time.

a time span when DJ is still open for trading meanwhile FTSE is closed for trading. Information released during this time is immediately incorporated in DJ prices but it can not be incorporated in FTSE prices until the following morning. In practice, to study how London traders learn from previous price movements in New York, we analyse the effects of $DJ_{a,t}$ on the following morning's FTSE prices, namely, on $FTSE_{m,t+1}$.

- Case 2: effects of FTSE returns on DJ returns. As on a daily basis, London Stock Exchange opens earlier than New York Stock Exchange, there is a time span when FTSE trades meanwhile DJ is still closed. Information released during this time is immediately incorporated in FTSE prices but it can only be incorporated in DJ prices later on, when New York Stock Exchange opens for trading. In practice, we analyse the effects of $FTSE_{m,t}$ on $DJ_{c,t}$.

- Case 3: simultaneous trading hours between the New York and the London Stock Exchanges. This takes place between 14:30h and 16:30h London time and 09:30h to 11:30h New York time and both stock prices incorporate news simultaneously.

Figure 3.1 shows the timing of trading in the two markets and the periods corresponding to the time spans in each market used in this chapter.

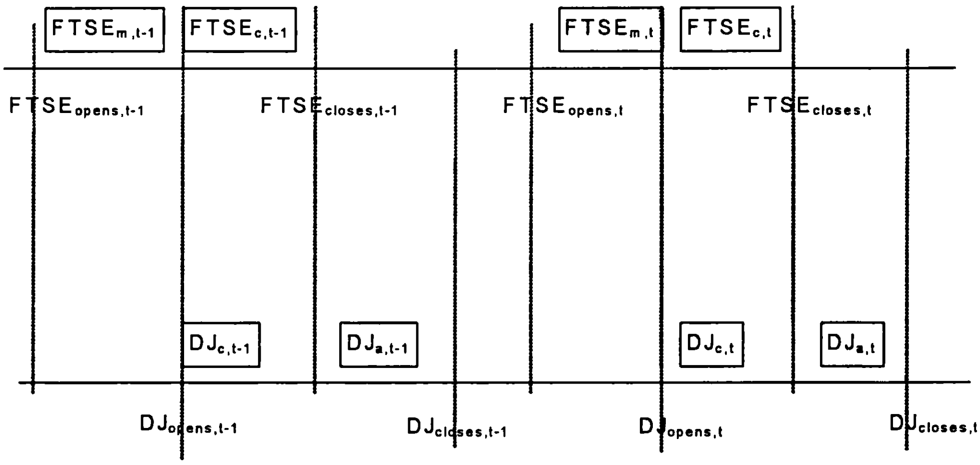


Figure 3.1: time conventions for intra-day index returns

3.3.2 Autocorrelation of Domestic Returns

Table 3.1 reports the data summary for the FTSE 100 and DJ returns series. The mean, the standard deviation, the skewness, the kurtosis and the Jarque-Bera statistic are reported.

Comparing the returns volatility among the different time spans, the summary statistics in Table 3.1 indicate that we can not conclude the one index is more volatile than the other as the standard deviations reported are not significantly different statistically. The kurtosis measure reveals that the empirical distribution of all the returns has fat tails compared to a normal distribution. The Jarque-Bera statistic to test the null hypothesis of a normal distribution is rejected for all the series, supporting the general view that financial data does not follow a normal distribution. The bottom part of Table 3.1 reports the autocorrelation coefficients regarding the different time spans for the Dow Jones returns and the FTSE 100 returns. Notice that all the autocorrelation coefficients are negative, which indicates that stock returns tend to reverse the movements of the previous day's domestic market returns. Finally, the Ljung-Box statistics indicate that the returns and the squared returns series exhibit significant autocorrelation.

Figure 3.2 plots the FTSE and Dow Jones intra-day returns. Volatility clustering is apparent in Figure 3.2. The implication of volatility clustering is that volatility shocks today influence the expectation of volatility many periods in the future. Overall, the descriptive statistics from Table 3.1 point out the presence of conditional heteroskedasticity in the series and Figure 3.2 reveals volatility clustering, suggesting GARCH specifications to model the conditional variances.

Table 3.1: Descriptive statistics and autocorrelation of returns

	$FTSE_{m,t}$	$FTSE_{c,t}$	$DJ_{c,t}$	$DJ_{a,t}$
Average (/10)	-0.006	-0.000	-0.002	0.002
Std. Dev.	0.010	0.007	0.009	0.008
Skew	-0.047	-0.042	0.083	0.029
Kurtosis	4.532	5.761	5.781	4.171
Jarque-Bera Statistic	81.33	336.4	341.9	61.26
Probability	0.000	0.000	0.000	0.000
Autocorrelation:				
ρ_{t-1}	-0.038	-0.022	-0.040	-0.042
p-value	0.242	0.465	0.190	0.176
ρ_{t-2}	-0.016	-0.002	-0.008	-0.044
p-value	0.293	0.764	0.411	0.143
ρ_{t-3}	-0.023	-0.061	-0.029	-0.031
p-value	0.129	0.208	0.447	0.176
Ljung-Box(10)	32.04	9.621	13.82	13.99
Ljung-Box^2 (10)	259.2	430.2	83.05	84.35

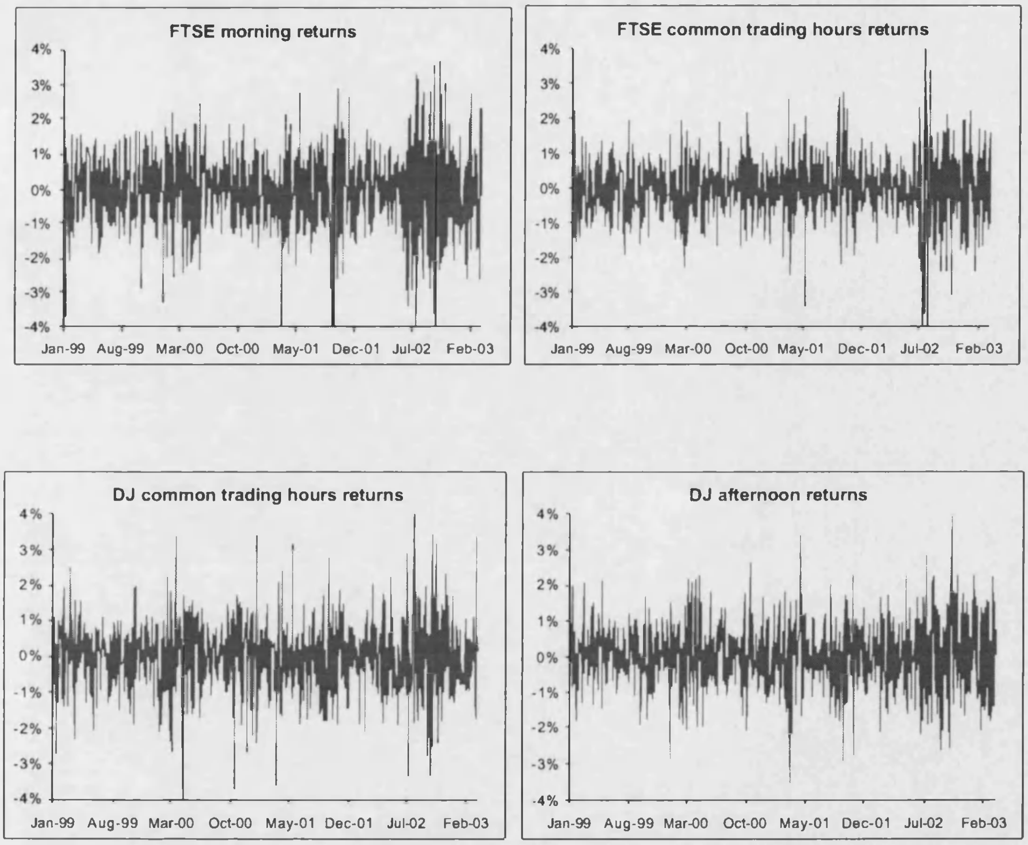
Notes: the sample period is 4 January 1999 through 20 March 2003.

Jarque-Bera statistic tests whether the series is normally distributed. Under the null hypothesis the series follows a normal distribution.

The coefficient ρ_{t-k} stands for the autocorrelation coefficient at lag k.

The p-value correspond to that of the Ljung-Box Q-statistic at lag k. The statistical test for tenth order serial correlation and returns and the squared returns, respectively. Both tests are distributed as $\chi^2(10)$ under the null. All the Ljung-Box Q-statistic are significant at 1 percent level.

Figure 3.2: Intra-day FTSE and DJ returns



3.3.3 Cross-Market Correlations

The descriptive analysis in this subsection places emphasis on investigating two types of correlation across the stock returns in London and New York: cross-market correlation and lagged spillovers. While cross-market correlations capture the contemporaneous co-movements between stock returns, lagged spillovers measure the co-movements between foreign returns and the subsequent domestic returns.

Table 3.2 reports intra-day cross-market correlations. The statistics in this table show that all the correlation coefficients are positive, which indicates that the FTSE and the DJ returns tend to move in the same direction. The key feature to highlight is that the highest contemporaneous correlation of 0.255 corresponds to that between $FTSE_{c,t}$ and $DJ_{c,t}$, i.e., the FTSE and the Dow Jones returns between the overlapping trading period of both markets. This correlation coefficient presents evidence that during the common trading period both stock prices tend to move on a more synchronous way, indicating that information revealed during that time span tends to affect stock prices in a similar direction on both sides of the Atlantic.

Even if the correlation coefficients do not shed any light upon which market affects which, they suggest that it is interesting to use intra-day stock market data to study the nature of the transmission of returns between the London and the New York Stock Exchanges. The econometric estimation presented in Section 3.5 will investigate the direction of the transmission of stock price movements.

Table 3.2: Intra-day cross-market correlation

	$FTSE_{m,t}$	$FTSE_{c,t}$	$DJ_{c,t}$	$DJ_{a,t}$
$FTSE_{m,t}$	1	0.003	0.309	0.082
$FTSE_{c,t}$		1	0.255	0.189
$DJ_{c,t}$			1	0.042
$DJ_{a,t}$				1

Next, Table 3.3 reports the lead-lag cross-country correlations between the FTSE and the DJ stock returns. In the table, column one shows whether FTSE morning trading returns lead subsequent FTSE and Dow Jones returns. Similarly, column two reveals whether returns during FTSE common hours lead subsequent FTSE and Dow Jones returns and so forth. The correlation coefficients in the Table 3.3 present evidence of bi-directional dynamic spillovers between the London Stock Exchange and the New York Stock Exchange. In particular, the FTSE morning returns significantly affect the subsequent Dow Jones morning returns as the correlation coefficient $\rho = 0.095$ shows. Similarly, the Dow Jones afternoon returns significantly influence the following morning FTSE returns, $\rho = 0.135$. The fact that these correlation coefficients are positive and significant suggest that domestic investors extract information from previous foreign stock prices movements.[8]

Next sections will model in detail and further investigate the nature of these stock returns spillovers.

Table 3.3: Lead-lag cross-correlation

	$FTSE_{m,t}$ leads	$FTSE_{c,t}$ leads	$DJ_{c,t}$ leads	$DJ_{a,t}$ leads
$FTSE_{m,t}$	-0.038	0.106**	0.107**	0.135**
$FTSE_{c,t}$	0.036	-0.022	0.004	0.084**
$DJ_{c,t}$	0.095**	0.082**	-0.040	0.005
$DJ_{a,t}$	-0.015	0.031	0.002	-0.042

Notes: Bartlett's standard errors can be approximated by the square root of the number of observations. The number of observations is 1,052 and the corresponding standard error is 0.031.

** indicates that the null of zero correlation can be rejected at a 5 percent significance level.

[8]Spectral analysis could be used to address the issues of leads and lags more systematically.

3.4 Model and Econometric Specification

3.4.1 Econometric Framework

The approach presented in this chapter is based on the Lin, Engle and Ito (1994) aggregate shock model. The econometric framework is designed to separate the global factor that affects stock returns globally from a local factor that influences stock returns nationally. There are two crucial differences between their specification and the one used in this chapter. First, they use the aggregate shock approach to model the international transmission mechanism between the Tokyo and the New York stock markets. Neither market shares any overlapping trading hours, which is not the case for the FTSE and DJ indices. We adapt their approach to our intra-day data set and we specify different econometric set ups for each of the cases identified in Section 3.3. Second, Lin et al. (1994) estimate a GARCH(1,1) model. As the focus of this thesis is on asymmetries on stock prices, we choose an Exponential GARCH (EGARCH) specification that allows market volatility to respond asymmetrically to positive and negative market innovations, namely to good and bad news. These so called "leverage effects" refer to the tendency for changes in stock prices to be negatively correlated with changes in stock volatility.

Case 1. Effects of New York stock prices on London stock prices

We use the fact that on a daily basis New York Stock Exchange closes later than the London Stock Exchange to study the effects of the former on the FTSE prices and volatility. More specifically, we propose to analyse the effects of the Dow Jones afternoon returns, $DJ_{a,t-1}$, on the following morning's FTSE prices, $FTSE_{m,t}$. Equation (3.3) represents the price change in the Dow Jones index during the New York afternoon trading, namely, when the London market is already closed for trading. This price change depends on that morning trading in New York, the morning trading in London and a dummy variable to control for Monday and post-holiday effects.[9]

$$DJ_{a,t-1} = \alpha_0 + \alpha_1 DJ_{c,t-1} + \alpha_2 FTSE_{c,t-1} + \alpha_3 Dm_t + u_t \tag{3.3}$$

where u_t denotes the part of the information that cannot be predicted based upon public information during Dow Jones afternoon trading span.

Next morning, when the London market opens, the information on the previous Dow Jones price changes may be incorporated into the FTSE prices. Part of this information most likely reflects news on fundamentals and part is noise caused by New York traders. To model how London investors process this foreign information we use the aggregate shock model. In this approach, London investors use the unexpected returns of the New York market to infer "global factors" from the Dow Jones yesterday's afternoon trading and to predict the current FTSE returns.

Consequently, we specify FTSE next morning returns as a function of the preceding FTSE returns, the Monday and post-holiday dummy variable and the influences of the unexpected DJ returns.

$$FTSE_{m,t} = \beta_0 + \beta_1 FTSE_{c,t-1} + \beta_2 Dm_t + \beta_3 u_t + v_t \tag{3.4}$$

To test the "global information hypothesis", our coefficient of interest is β_3. A positive and significant β_3 coefficient indicates that London traders infer "global" information from previous innovations in the New York market.

The information set containing domestic and foreign returns up to the point j is denoted by $\Omega(j)$. Shocks u_t and v_t are assumed to be serially uncorrected and mutually independent

$$u_t/\Omega(j) \sim N(0, q_t) \qquad j \in \{FTSE_{m,t}, DJ_{opening,t}\} \tag{3.5a}$$

$$v_t/\Omega(j) \sim N(0, s_t) \qquad j \in \{FTSE_{m,t}, DJ_{opening,t}\} \tag{3.6a}$$

[9]The Monday dummy is equal to one for the returns from the Friday close to the Monday opening ans the returns during the national holidays. See, for instance, French (1980) for an explanation of the introduction of the Monday and post-holiday dummy.

where $N(0, \sigma_t)$ denotes a normal distribution with the first element being the mean and the second element being the variance conditional on $\Omega(j)$ and $\sigma_t = \{q_t, s_t\}$.

Further, we assume that the conditional variances, q_t and s_t, follow an EGARCH process as outlined by Nelson (1991). The GARCH family of models incorporates the familiar phenomenon of volatility clustering which is evident in financial returns data. These models also display the fact that large returns are more likely to be followed by large returns of either sign rather than by small returns. In addition, the EGARCH specification captures the phenomenon that downward movements in the market are followed by higher volatilities than upward movements of the same magnitude. The specification of the conditional variances for the EGARCH models are:

$$\log(q_t) = \gamma_{oq} + \gamma_{1q} \log(q_{t-1}) + \delta_q \left| \frac{u_{t-1}}{q_{t-1}^{1/2}} \right| + \phi_q \frac{u_{t-1}}{q_{t-1}^{1/2}} \tag{3.5b}$$

$$\log(s_t) = \gamma_{os} + \gamma_{1s} \log(s_{t-1}) + \delta_s \left| \frac{v_{t-1}}{s_{t-1}^{1/2}} \right| + \phi_s \frac{v_{t-1}}{s_{t-1}^{1/2}} \tag{3.6b}$$

If we focus on equation (3.5b), the coefficient γ_{1q} represents the market volatility clustering. The δ_q term investigates the magnitude effect; if δ_q is positive, the conditional variance, q_t, rises when the market movements are large. The $\phi_q \frac{u_{t-1}}{q_{t-1}^{1/2}}$ term allows for "leverage effects". Recall that the surprise component of returns has the same sign as u_{t-1}, so when ϕ_q is negative, a negative innovation (bad news) increases the volatility more than a positive innovation (good news) of the same magnitude. Taken together, the $\phi_q \frac{u_{t-1}}{q_{t-1}^{1/2}}$ and $\delta_q \left| \frac{u_{t-1}}{q_{t-1}^{1/2}} \right|$ terms allow the market's conditional variance to respond asymmetrically to positive and negative returns. The impact is asymmetric if $\phi_q \neq 0$.

The aggregate shock model for case 1 with EGARCH processes can be formulated as equations (3.3)-(3.6).

Case 2. Effects of the FTSE returns on the DJ returns

The intuition behind this case is exactly the same as in case 1. We use the fact that on a daily basis the London Stock Exchange opens earlier than the New York Stock Exchange to analyse the effects of the FTSE returns on DJ returns.

In particular, we propose to investigate the effects of the FTSE morning returns, $FTSE_{m,t}$, on the posterior DJ returns, $DJ_{c,t}$. Equation (3.7) specifies the price change in London when the New York market is still closed

$$FTSE_{m,t} = \alpha_0 + \alpha_1 DJ_{c,t-1} + \alpha_2 FTSE_{c,t-1} + \alpha_3 Dm_t + u_t \tag{3.7}$$

where u_t is the unexpected return of the FTSE morning trading. The investors' behaviour is modelled in a similar way to that in case1: New York traders use the FTSE innovations to learn from the previous price movements in the London market. In other words, they used the unexpected return to infer the factor that affects stock markets globally. Consequently, Dow Jones morning trading returns can be modelled as a function of the previous day London and New York returns, the Monday and post-holiday dummy and the inferred influences from the unexpected returns of that day FTSE morning trading.

$$DJ_{c,t} = \beta_0 + \beta_1 FTSE_{c,t-1} + \beta_2 DJ_{c,t-1} + \beta_3 u_t + \beta_4 Dm_t + v_t \tag{3.8}$$

As in the previous case, our coefficient of interest to test the "global factor hypothesis" is the coefficient β_3. A positive and significant β_3 coefficient indicates that New York traders infer "global" information from previous innovations in the London market.

Exactly as in case 1, shocks u_t and v_t are assumed to be serially uncorrelated and mutually independent. The conditional variances follow EGARCH processes as described by equations (3.5)-(3.6).

The aggregate shock model for case 2 can be formulated as equations (3.5)-(3.8).

Case 3. Simultaneous trading in the London and New York stock markets

In this instance, stock price changes in both countries are simultaneously determined. The process that generates changes in stock prices is assumed to be a function of the news released in both countries

$$DJ_{c,t} = w_{DJ,t} + \tau_{DJ} E_{DJ}(w_{FTSE,t}) \tag{3.9}$$

$$FTSE_{c,t} = w_{FTSE,t} + \tau_{FTSE} E_{FTSE}(w_{DJ,t}) \tag{3.10}$$

where w_{DJ} is information released in New York and $w_{FTSE,t}$ is information released in London. E_{DJ} and E_{FTSE} denote the expectations operators conditional upon information observed in New York and London respectively. By introducing the expectations, it is assumed that information is not fully observable.

The main difference between this case and the previous ones is the simultaneous trading period. In this specification, τ_{FTSE} directly reveals the effects of the information extracted from the New York Stock Exchange on the FTSE returns. In practice, as $DJ_{c,t}$ and $FTSE_{c,t}$ trade simultaneously, the best way London investors can infer information from the New York market is observing the price changes in the Dow Jones index. Equally, the best way New York investors can gather relevant information from London is noting the price changes in the FTSE. Therefore, the mean equations are modelled to take into account possible domestic autocorrelations as well as the influence of one market on another. The system (3.9)-(3.10) becomes

$$DJ_{c,t} = \tau_0^{DJ} + \tau_1^{DJ} DJ_{a,t-1} + \tau_2^{DJ} FTSE_{m,t} + \tau_3^{DJ} Dm_t + w_{DJ,t} \tag{3.11}$$

$$FTSE_{c,t} = \tau_0^{FTSE} + \tau_1^{FTSE} FTSE_{m,t} + \tau_2^{FTSE} DJ_{a,t-1} + \tau_3^{FTSE} Dm_t + w_{FTSE,t} \tag{3.12}$$

The terms τ_1^{DJ} and τ_1^{FTSE} measure the interactions between past and present domestic market returns. The terms τ_2^{DJ} and τ_2^{FTSE} determine the international return spillovers.

To investigate the volatility spillovers, we model the conditional variance processes following Braun, Nelson and Sunier (1995) approach. These authors provide a method for estimating time-varying conditional betas (in a CAPM model) based on a bi-variate version of the EGARCH model of Nelson (1991). Applying their approach, we modify the univariate EGARCH model for the Dow Jones conditional variance, $\sigma^2_{DJ,t}$, as follow

$$\begin{aligned} \log(\sigma^2_{DJ,t}) &= \gamma_0^{DJ} + \gamma_1^{DJ} \log(\sigma^2_{DJ,t-1}) + \delta_{DJ}^{DJ} \left| \frac{w_{DJ,t-1}}{\sigma_{DJ,t}} \right| + \phi_{DJ}^{DJ} \frac{w_{DJ,t-1}}{\sigma_{DJ,t}} + \\ &\quad + \delta_{FTSE}^{DJ} \left| \frac{w_{FTSE,t-1}}{\sigma_{FTSE,t}} \right| + \phi_{FTSE}^{DJ} \frac{w_{FTSE,t-1}}{\sigma_{FTSE,t}} \end{aligned} \tag{3.13}$$

This specification allows for both Dow Jones and FTSE "leverage effects". In particular, the coefficients δ_{DJ}^{DJ} and ϕ_{DJ}^{DJ} in (3.13) account for domestic news effects. The coefficients δ_{FTSE}^{DJ} and ϕ_{FTSE}^{DJ} describe the volatility spillovers from the FTSE market to the DJ market. If the coefficients estimate δ_{FTSE}^{DJ} is negative and ϕ_{FTSE}^{DJ} is positive, then (3.13) indicates that the DJ volatility increases in response to FTSE negative innovations and it drops in response to FTSE positive innovations. In other words, the coefficients δ_{FTSE}^{DJ} and ϕ_{FTSE}^{DJ} capture the effects of FTSE innovations on DJ volatility.

Similarly, the FTSE conditional variance $\sigma_{FTSE,t}^2$ can be modelled as

$$\begin{aligned}\log(\sigma_{FTSE,t}^2) &= \gamma_0^{FTSE} + \gamma_1^{FTSE}\log(\sigma_{FTSE,t-1}^2) + \delta_{DJ}^{FTSE}\left|\frac{w_{DJ,t-1}}{\sigma_{DJ,t}}\right| + \phi_{DJ}^{FTSE}\frac{w_{DJ,t-1}}{\sigma_{DJ,t}} + \\ &\quad + \delta_{FTSE}^{FTSE}\left|\frac{w_{FTSE,t-1}}{\sigma_{FTSE,t}}\right| + \phi_{FTSE}^{FTSE}\frac{w_{FTSE,t-1}}{\sigma_{FTSE,t}} \qquad (3.14)\end{aligned}$$

In equation (3.14), the coefficients δ_{DJ}^{FTSE} and ϕ_{DJ}^{FTSE} capture the "leverage effects" of Dow Jones innovations on FTSE volatility.

A detailed discussion of properties of the estimated conditional variance matrix and ergodicity of the bi-variate EGARCH model can be found in Braun et al. (1995).

3.4.2 Model Estimation

This subsection describes the practical issues regarding the estimation.

Case 1 and case 2.

To estimate the aggregate shock model for case 1 formulated in equations (3.3)-(3.6) we employ a two-stage EGARCH approach. In the first stage, we apply the EGARCH method to estimate $DJ_{a,t-1}$ in equations (3.3) and (3.5) and obtain the fitted values of the unexpected returns, $\widehat{u}_t$. Then, the estimated residuals are substituted into the equation of the $FTSE_{m,t}$ returns and we estimate equations (3.4) and (3.6) with the EGARCH process again.

Econometric implications arise when generated variables appear in a regression equation. In our case, this applies to the inclusion of the estimated residuals $\widehat{u}_t$ as a regressor in equation (3.4). Pagan (1984) addresses the issue of the econometric implications of generated regressors. He demonstrates that Ordinary Least Squares provide the correct variance values for the α coefficients in the first stage of our estimations (equation 3.3). Then, two-Stage Least Square estimates provide the correct residual variance estimators for the β coefficients on the second stage of our estimations (equation 3.4). Pagan (1984) also shows that if the extra regressors in equation (3.4) also appear among the regressors in equation (3.3), then the second step estimators are perfecto efficient. These points have been taken into account when estimating our models. The main difference between his suggestion and our estimation is that at each stage of our estimation, we maximise a log likelihood function instead of a standard likelihood function.

In addition, as the standardised residuals resulting form the estimations have frequently shown to be non-normal for financial data, the robust standard errors of Bollerslev and Wooldridge (1992) are reported. These authors show that the maximisation with respect to a conditional normal distribution, even if the real underlying distribution is non-normal, yields efficient estimates.

When estimating the coefficients in case 2, a similar procedure to the one described above is applied to the $FTSE_{m,t}$ and $DJ_{c,t}$ returns in equations (3.5)-(3.8).

3.5 Econometric Results

3.5.1 Case 1. The Effects of New York Returns on London Returns

This subsection investigates whether the unexpected returns of the Dow Jones contain any global information and thus, have any impact on the subsequent FTSE returns. To test the "global information hypothesis", the sensitivity coefficient that measures the effects of Dow Jones afternoon returns on the following morning FTSE returns is the coefficient β_3 in the second stage of our estimation. The results of the estimation are presented in Table 3.4. For each stage, the upper part of the table provides the standard output for the mean equation, while the lower part contains the coefficients and standard errors for the variance equation.

Regarding the return equations, the significant t-statistic of $\beta_3 = 7.9 \cdot 10^{-4}$ in stage 2 of the estimation highlights the significant existence of spillovers from the DJ afternoon returns to the following morning FTSE returns. This evidence supports the "global factor hypothesis", as the information revealed during the trading hours of the Dow Jones market has a global impact on the posterior FTSE returns. In other words, when news is released during the time span corresponding to DJ afternoon trading, New York traders incorporate the news into the DJ prices. London Stock Exchange is already closed during this time span.[10] Next morning, when London Stock Exchange opens, FTSE traders use the DJ return surprises to extract global information, which they will incorporate into FTSE prices. The coefficient β_3 quantifies how much of the FTSE returns can be explained by innovations in the Dow Jones market. However, notice that the magnitude of the coefficient β_3 is very small, indicating that the influence of "global factors" on FTSE prices is tiny.

In addition, the significant coefficient $\alpha_2 = 0.267$ in stage 1 presents evidence that previous foreign returns tend to significantly affect posterior domestic returns.

Regarding the variance equations, all the variance terms corresponding both stages of the estimation in Table 3.4 are significantly different from zero, suggesting that it is appropriate to model stock returns volatility with an EGARCH process. After fitting the EGARCH model in stage 1, the Ljung-Box statistic tests the 5-th order autocorrelations of the squared returns rejects additional autoregressive heteroskedasticity. The reported skewness, kurtosis and Jarque-Bera statistic of the standardised residuals in stage 1 are still too large to accept the null hypothesis of a normal distribution. Therefore, we include the robust standard errors as

[10] News can refer to companies reporting results or trading statements, announcements of macroeconomic figures, the president of the Federal Reserve or the finance ministers speaking, etc...

Table 3.4: Estimation of stock returns. Case 1

Stage 1:	Coefficient	Standard Error
α_0	$-3.1 \cdot 10^{-5}$	$2.0 \cdot 10^{-4}$
α_1	-0.045^{*}	0.024
α_2	0.267^{***}	0.044
α_3	$-3.1 \cdot 10^{-4}$	$5.3 \cdot 10^{-4}$
$\gamma_{0,q}$	-0.309^{***}	0.128
$\gamma_{2,q}$ $(EGARCH\ term)$	0.977^{***}	0.011
$\delta_q \left(\left\| \frac{u_{t-1}}{q_{t-1}^{1/2}} \right\| term \right)$	0.107^{***}	0.027
$\phi_q \left(\frac{u_{t-1}}{q_{t-1}^{1/2}}\ term \right)$	-0.087^{***}	0.026
F-Statistic	4.539	$Prob = 0.000$
Skewness	-0.127	
Kurtosis	3.889	
Jarque-Bera	37.51	$Prob = 0.000$
Ljung-Box^2 (5)	6.057	$Prob = 0.310$
Stage 2:		
β_0	-0.001^{***}	$3.1 \cdot 10^{-4}$
β_1	0.105^{**}	0.051
β_2	0.002^{**}	$6.0 \cdot 10^{-4}$
β_3	$7.9 \cdot 10^{-4,***}$	$2.4 \cdot 10^{-4}$
$\gamma_{0,s}$	-0.564^{***}	0.152
$\gamma_{2,s}$ $(EGARCH\ term)$	0.952^{***}	0.014
$\delta_s \left(\left\| \frac{v_{t-1}}{s_{t-1}^{1/2}} \right\| term \right)$	0.160^{**}	0.050
$\phi_s \left(\frac{v_{t-1}}{s_{t-1}^{1/2}}\ term \right)$	-0.096^{***}	0.037
F-Statistic	3.44	$Prob = 0.000$

Notes for Table 3.4: the model is stage 1: $DJ_{a,t-1} = \alpha_0 + \alpha_1 DJ_{c,t-1} + \alpha_2 FTSE_{c,t-1} + \alpha_3 Dm_t + u_t$;
$u_t/\Omega(j) \sim N(0, q_t)$; $\log(q_t) = \gamma_{0,q} + \gamma_{1,q}\log(q_{t-1}) + \delta_q \left|\frac{u_{t-1}}{q_{t-1}^{1/2}}\right| + \phi_q \frac{u_{t-1}}{q_{t-1}^{1/2}}$

Stage 2: $FTSE_{m,t} = \beta_0 + \beta_1 FTSE_{c,t-1} + \beta_2 Dm_t + \beta_3 u_t + v_t$;

$v_t/\Omega(j) \sim N(0, s_t)$; $log(s_t) = \gamma_{0,s} + \gamma_{1,s} log(s_{t-1}) + \delta_s \left|\frac{v_{t-1}}{s_{t-1}^{1/2}}\right| + \phi_s \frac{v_{t-1}}{s_{t-1}^{1/2}}$

*, ** and *** indicate significance at 10, 5 and 1 percent levels respectively.

described by Bollerslev and Wooldridge (1992) in the second stage of the EGARCH estimation as mentioned in Section 3.4.2. To add to the non-normality of the residuals, Figure 3.3 plots the one step ahead conditional standard deviation of the residuals for each observation in the sample. The observation at period t is the forecast for t made using information available in $t-1$. This graph emphasised that the Dow Jones residual series are not i.i.d. and thus, contain extra information; the London traders extract global factors from this information and incorporate it later on in their price information set as modelled in equation (3.4) on the second stage of our estimation.

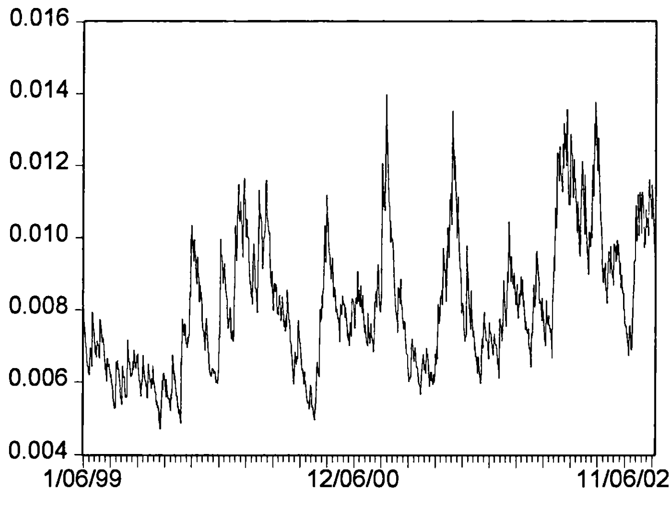


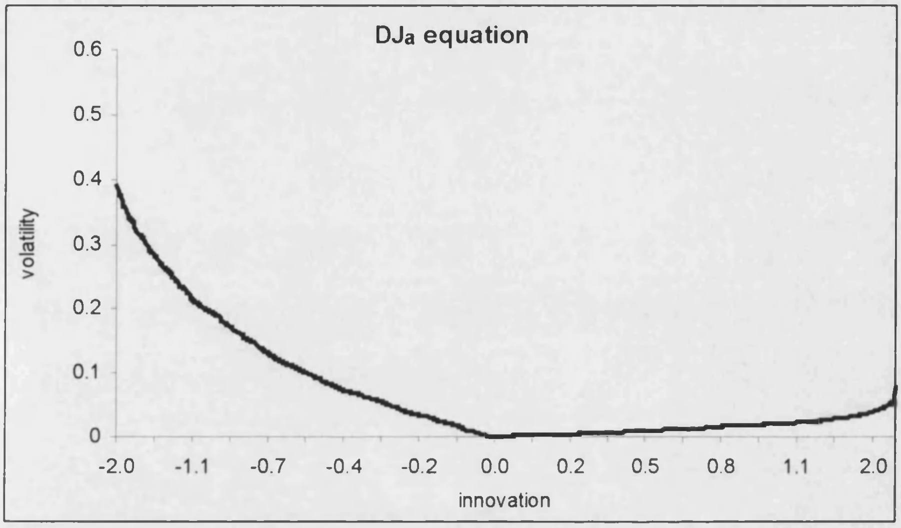
Figure 3.3: conditional standard deviation graph. Case 1, stage 1.

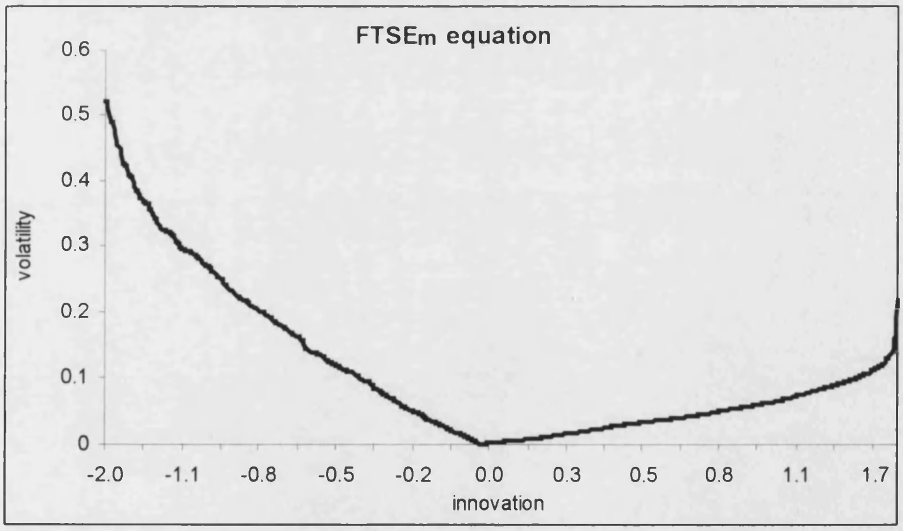
Next, we highlight some results from the variance equations. First, the EGARCH term is significant in both stages of the estimation, $\gamma_{2,q} = 0.977$ and $\gamma_{2,s} = 0.952$. The fact that the magnitude of these coefficients is close to one indicates that the volatility shocks are quite persistent. Second, in both stages, the coefficient δ is positive and significant, $\delta_q = 0.107$ and $\delta_s = 0.160$. These coefficients indicate that the magnitude of previous domestic market movements positively affects the variance. Third, the coefficient ϕ is negative and significant in both stages, $\phi_q = -0.087$ and $\phi_s = -0.096$. These coefficients present evidence on the "leverage effect" in both markets. Namely, both the FTSE and the DJ returns exhibit asymmetric volatility effects with domestic bad news having a greater impact on volatility than good news.

Given the estimated parameters, the news impact curve measures how information is incorporated into volatility estimates. Figure 3.4 plots the news impact curves for the system $DJ_{a,t-1}$ and $FTSE_{m,t}$ respectively. These graphs plot the effect of the news impact curve on volatility. In particular, the upper graph corresponding to equation (3.6) plots the standardised errors (the news), $\frac{v_{t-1}}{s_{t-1}^{1/2}}$, in the x-axis against the impact curve, $\delta_q \left| \frac{v_{t-1}}{s_{t-1}^{1/2}} \right| + \phi_q \frac{v_{t-1}}{s_{t-1}^{1/2}}$, in the y-axis. Equally, the bottom graph corresponding to equation (3.7) plots the standardised errors, $\frac{u_{t-1}}{q_{t-1}^{1/2}}$, in the x-axis against the impact curve $\delta_s \left| \frac{u_{t-1}}{q_{t-1}^{1/2}} \right| + \phi_s \frac{u_{t-1}}{q_{t-1}^{1/2}}$. Both figures graphically show the "leverage effects" as negative innovations have a clear larger impact on volatility than positive innovations. The graphs show that the "leverage effects" are larger in the FTSE equation than in the DJ equation. The Wald test applied to the coefficients also confirms that $|\phi_s| > |\phi_q|$, $Chi - square = 5.25$, $probability = 0.000$.

Overall, the variance equations indicate that an EGARCH is an appropriate model specification for the returns volatility processes.

Figure 3.4: News Impact Curve in case 1 estimations





3.5.2 Case 2. Effects of London Stock Returns on New York Stock Returns

This subsection investigates whether the unexpected returns of the FTSE 100 index contain any global information and thus, have any impact on the subsequent Dow Jones returns. The results of the estimation are presented in Table 3.5.

Regarding the return equations, the main feature of Table 3.5 is the evidence of return spillovers from London to New York stock market as suggested by the significant t-statistic of $\beta_3 = 0.002$. This result supports the "global factor hypothesis", presenting evidence that New York traders learn from previous innovations in the FTSE stock price movements. Notice that in this case, there is a time span when London Stock Exchange is open but New York Stock Exchange is not open yet. When news is released during this time span, London traders incorporate the news into the FTSE prices. Later on, American traders observe price movements in the FTSE market and interpret the unexpected part of those movements contain global information. The coefficient β_3 quantifies how much of the New York returns can be explained by innovations in the London market.

In addition, our results present evidence that previous foreign returns tend to significantly affect posterior domestic returns. This finding holds in both markets as the significant t-statistics of coefficients $\alpha_2 = 0.086$ in stage 1 and $\beta_1 = 0.066$ in stage 2 demonstrate. Furthermore, the sign of the statistically significant coefficient $\beta_2 = -0.074$ is negative, indicating that the Dow Jones returns tend to reverse the previous domestic stock price movements. These results are consistent with previous empirical findings on international equity market co-movements; see, for instance, Connolly et al. (2003) and Dickinson (2003).

Regarding the variance equations, all the variance terms corresponding both stages of the estimation in Table 3.5 are significantly different from zero, suggesting that it is appropriate to model stock returns volatility with an EGARCH process. As in case 1, the analysis of the residuals of the first stage of the estimation indicates

Table 3.5: Estimation of stock returns. Case 2

Stage 1:	Coefficient	Standard Error
α_0	-0.001^{***}	$3.0 \cdot 10^{-4}$
α_1	0.074	0.054
α_2	0.086^{**}	0.038
$\gamma_{0,q}$	-0.557^{***}	0.014
$\gamma_{2,q}$ $(EGARCH\ term)$	0.954^{***}	0.014
$\delta_q \left(\left\| \frac{u_{t-1}}{q_{t-1}^{1/2}} \right\| term \right)$	0.165^{***}	0.048
$\phi_q \left(\frac{u_{t-1}}{q_{t-1}^{1/2}} term \right)$	-0.102^{***}	0.038
F-Statistic	4.539	$Prob = 0.000$
Skewness	-0.283	
Kurtosis	3.843	
Jarque-Bera	45.42	$Prob = 0.000$
Ljung-Box^2 (5)	5.966	$Prob = 0.318$
Stage 2:		
β_0	$-5.0 \cdot 10^{-4,**}$	$2.4 \cdot 10^{-4}$
β_1	0.066^{**}	0.040
β_2	-0.074^{**}	0.035
β_3	0.002^{***}	$2.8 \cdot 10^{-4}$
$\gamma_{0,s}$	-0.350^{**}	0.168
$\gamma_{2,s}$ $(EGARCH\ term)$	0.971^{***}	0.015
$\delta_s \left(\left\| \frac{v_{t-1}}{s_{t-1}^{1/2}} \right\| term \right)$	0.121^{***}	0.039
$\phi_s \left(\frac{v_{t-1}}{s_{t-1}^{1/2}} term \right)$	-0.073^{***}	0.025
F-Statistic	14.4	$Prob = 0.000$

Notes for Table 3.5: the model is stage 1: $FTSE_{m,t} = \alpha_0 + \alpha_1 FTSE_{c,t-1} + \alpha_2 DJ_{c,t-1} + u_t$; $u_t/\Omega(j) \sim N(0, q_t)$; $\log(q_t) = \gamma_{0,q} + \gamma_{1,q}\log(q_{t-1}) + \delta_q \left|\frac{u_{t-1}}{q_{t-1}^{1/2}}\right| + \phi_q \frac{u_{t-1}}{q_{t-1}^{1/2}}$

Stage 2: $DJ_{c,t} = \beta_0 + \beta_1 FTSE_{c,t-1} + \beta_1 DJ_{c,t-1} + \beta_3 u_t + v_t$;

$v_t/\Omega(j) \sim N(0, s_t)$; $log(s_t) = \gamma_{0,s} + \gamma_{1,s} log(s_{t-1}) + \delta_s \left|\frac{v_{t-1}}{s_{t-1}^{1/2}}\right| + \phi_s \frac{v_{t-1}}{s_{t-1}^{1/2}}$

*, ** and *** indicate significance at 10, 5 and 1 percent levels respectively.

that the residuals are not i.i.d. To add to the structure of the residuals, Figure 3.5 plots the one step ahead conditional standard deviation of the residuals. This graph highlights that the residual series of the first stage of the estimation contain extra information, which the New York traders will incorporate later on in their price information set. as modelled in equation (3.8) in the second stage of our estimation.

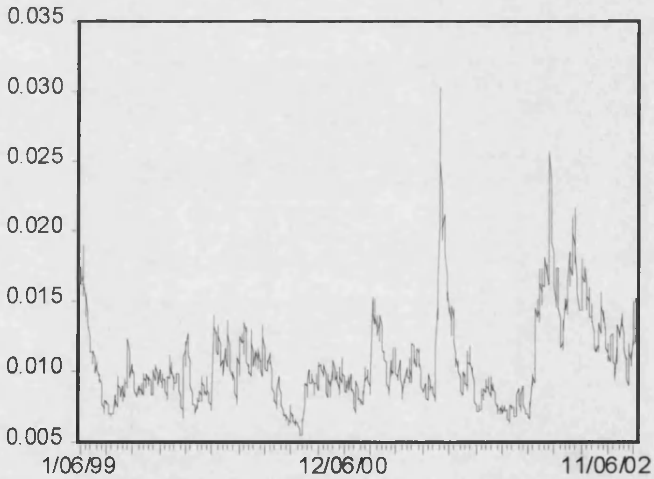


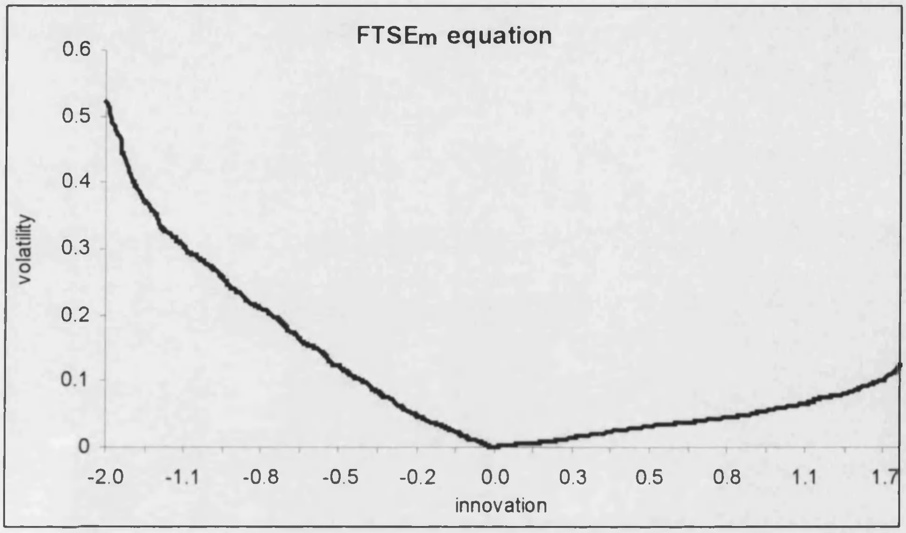
Figure 3.5: conditional standard deviation graph. Case 2, stage 1.

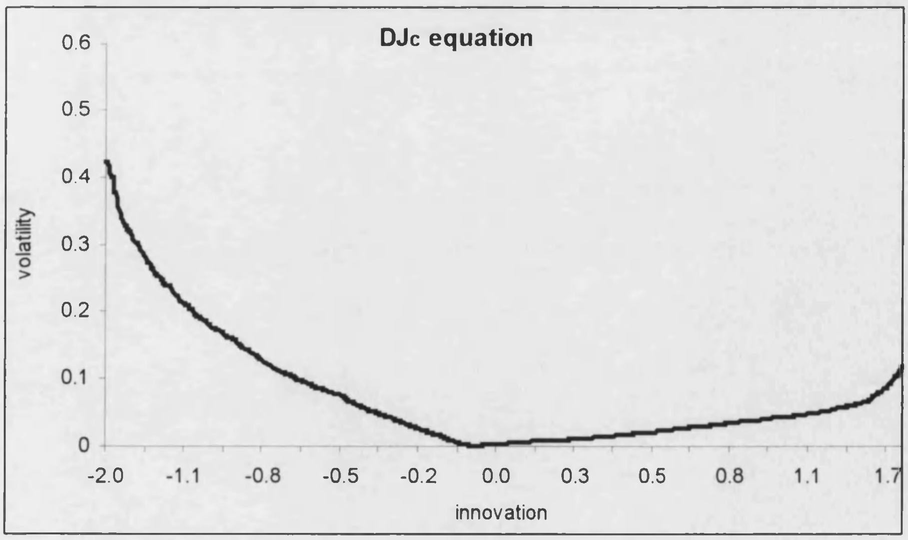
Some other results to highlight from the variance equations are: First, the EGARCH term is significant in both stages, $\gamma_{2,q} = 0.954$ and $\gamma_{2,s} = 0.971$. The fact that the magnitude of these coefficients is close to one indicates that the volatility shocks are quite persistent. Second, in both stages, the coefficient δ is positive and significant, $\delta_q = 0.165$ and $\delta_s = 0.121$. These coefficients indicate that the magnitude of previous market movements positively affects the variance. Third, the coefficient ϕ is negative and significant in both equations, $\phi_q = -0.102$ and $\phi_s = -0.073$. These coefficients present evidence on the "leverage effect" in both markets. Namely, both the FTSE and the DJ returns exhibit asymmetric volatility effects with domestic bad news having a greater impact on volatility than good news.

Given the estimated parameters, Figure 3.6 plots the news impact curves for the equations (3.7) and (3.8). These graphs plot the effects of news on volatility. The graphs confirm the finding in case 1 that the impact of negative news on volatility is larger on the FTSE market than on the DJ market. The Wald test applied to the coefficients also confirms that $|\phi_q| > |\phi_s|$, $Chi-square = 9.16, probability = 0.000$.

To summarise the findings from case 1 and case 2, even though we can not directly compare the magnitude of the estimated coefficients because they analyse different time spans, several common features arise in both estimations. First, regarding the volatility spillovers, all the estimated coefficients turn out to be significant in the volatility equations, indicating that the EGARCH models provide reasonable representations of the return volatility processes. Our results support the "leverage effect"; they confirm the tendency for changes in stock prices to be negatively correlated with changes in stock volatility. Our findings support evidence that bad news have larger effects on volatility than good news. Second, regarding the return spillovers, our estimations show that foreign returns significantly affect posterior domestic returns. Finally, both estimations present evidence in favour of the "global factor hypothesis" as a possible source of international stock returns correlations. The significant estimated coefficients β_3 indicate that movements in stock markets can be partially explained by innovations in foreign stock exchanges, namely, domestic traders learn from foreign returns innovations. Our results present evidence on increasing international stock market spillovers between the London and the New York Stock Exchanges, supporting the globalisation of financial markets around the world.

Figure 3.6: News Impact Curve in case 2 estimations





3.5.3 Regime 3. Common Trading Hours

Table 3.6 reports the coefficient estimates of the bi-variate EGARCH model in equations (3.11)-(3.13). The table captures the interactions of returns as well as the volatility spillovers between the FTSE and the DJ returns during the common trading hours of both stock exchanges. Note that all the test statistics presented on Table 3.6 are correlated and hence, once must draw an overall conclusion from this table with caution.

Regarding the return interactions, first, Table 3.6 confirms the results of previous cases indicating that foreign returns exert significant influence on posterior domestic returns. In our estimations, this can be seen by the fact that the coefficients τ_1^i $(i = FTSE, DJ)$ are not significant while the coefficients τ_2^i $(i = FTSE, DJ)$ are positive and significant. Second, the significant coefficient $\tau_2^{FTSE} = 0.063$, which measures the influence of DJ returns on posterior FTSE returns, and $\tau_2^{DJ} = 0.265$, which measure the influence of the previous FTSE returns on the posterior DJ returns, present evidence on bi-directional return spillovers during the common trading hours span between the London and New York Stock returns. Third, when comparing both coefficients, the smaller magnitude of τ_2^{FTSE} highlights the importance of the definition of the time spans when analysing international stock market spillovers. As the trading time sequence is $DJ_{a,t-1}$, $FTSE_{m,t}$ and $FTSE_{c,t}$, DJ afternoon returns, $DJ_{a,t-1}$, have larger direct impact on $FTSE_{m,t}$, not on $FTSE_{c,t}$.

Regarding the volatility spillovers, Table 3.6 shows that the estimated coefficients of the DJ to the FTSE volatility spillovers, $\delta_{DJ}^{FTSE} = 0.106$ and that of the FTSE to DJ volatility spillover $\delta_{FTSE}^{DJ} = 0.139$ are significant, suggesting significant bi-directional volatility spillovers during the common trading hours of both markets. Table 3.6 also shows that the asymmetric volatility coefficients ares significant for both markets ($\phi_{DJ}^{FTSE} = -0.092$ and $\phi_{FTSE}^{DJ} = -0.061$). These coefficients indicate that both markets experience a greater impact form negative foreign innovations on volatility than from positive foreign innovations. It is interesting to note that the asymmetric volatility coefficient of the FTSE on the domestic (FTSE) market

Table 3.6: Estimation of stock returns. Case 3

	$FTSE_{c,t}$		$DJ_{c,t}$	
	Coef.	Std. Error	Coef..	Std. Error
Mean equations:				
τ_0	$-1.2 \cdot 10^{-4}$	$2.2 \cdot 10^{-4}$	$1.1 \cdot 10^{-4}$	$2.7 \cdot 10^{-4}$
τ_1	-0.013	0.021	-0.053	0.034
τ_2	0.063**	0.025	0.265***	0.028
τ_3	$-2.6 \cdot 10^{-4}$	$5.3 \cdot 10^{-4}$	$2.9 \cdot 10^{-4}$	$5.6 \cdot 10^{-4}$
Variance Equations:				
γ_0	-0.513***	0.029	-0.513***	0.162
γ_1	0.951***	0.019	0.954***	0.014
δ_{FTSE}	0.192***	0.052	0.139***	0.037
ϕ_{FTSE}	-0.053	0.035	-0.066***	0.023
δ_{DJ}	0.106**	0.041	0.090**	0.035
ϕ_{DJ}	-0.092***	0.031	-0.024***	0.014
$Ljung-Box(5)$	4.68	$Prob = 0.455$	5.99	$Prob = 0.307$
$Ljung-Box^2(5)$	5.25	$Prob = 0.354$	2.47	$Prob = 0.780$

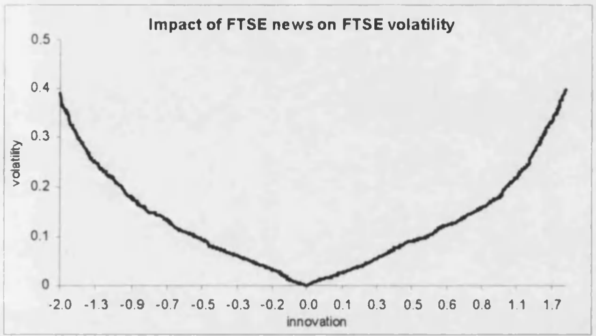
Notes: the model estimated is equations (3.11)-(3.13). *, ** and *** indicate that the null hypothesis can be rejected at the 10, 5 and 1 percent levels respectively.

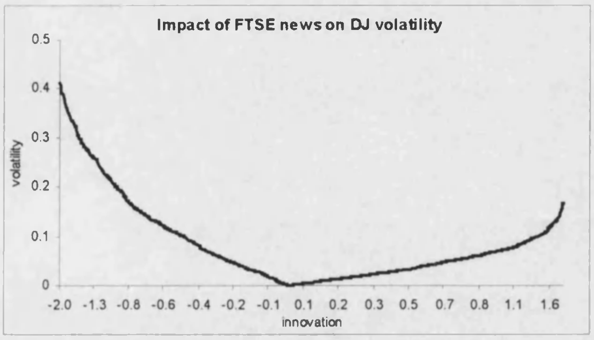
ϕ_{FTSE}^{FTSE} is not significant. This result indicates that during the common trading hours span, negative DJ innovations have larger impact on the FTSE volatility than negative FTSE innovations.

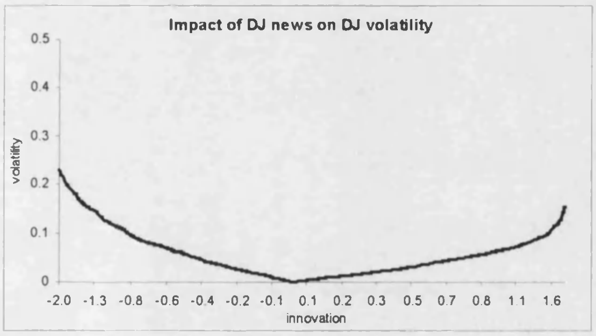
Figure 3.7 graphically shows the variance spillovers between the London and New York market. The top left panel plots the impact of FTSE news on FTSE volatility. This panel shows the no existence of asymmetric effects in this case; namely, positive and negative FTSE news affect FTSE volatility on the same way. The shape of the news impact curve on the rest of the panels present evidence of the "leverage effect". Notice that the bottom right panel clearly plots that DJ negative innovations exert a greater effect on FTSE volatility than DJ positive innovations.

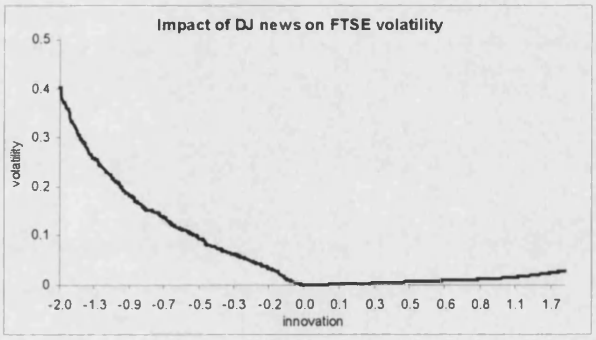
Overall, the results of this subsection show a clear bi-directional relation between the London and the New York Stock Exchanges in terms of returns interactions and volatility spillovers during the common trading hours period. Unlike previous studies, our results do not show that the DJ returns exert greater influence on the FTSE returns than the other way around. This finding is due to the fact that we use more refined intra-day data. Our findings draw attention to the importance of choosing the time spans when analysing stock market spillovers.

Figure 3.7: News Impact Curve in case 3 estimations









3.6 Robustness Analysis

In this Section we present an exercise to compare our findings with those of previous empirical studies. From the examination of the general links between the stock exchanges, several patterns are reported in the empirical literature: first, foreign daily returns affect domestic returns in a significant and positive way. Second, foreign market returns influence overnight returns. Third, the London market tends to reverse returns realised in the preceding overnight domestic market. However, evidence on the influence of other stock exchanges on the U.S. market is mixed. On the one hand, authors like Lin et al. (1994), Masih et al. (1999) and Connolly et al. (2003) find evidence of bi-directional cross-market interdependencies between the U.S., London and Tokyo equity markets. For instance, Connolly et al. (2003) investigate return co-movements between the U.S., U.K. and Japan equity markets during the period 1985-1995. They find that in general, foreign market returns exert a dominant influence over subsequent domestic returns. On the other hand, Becker et al. (1995) and Gerrits et al. (1999) conclude that the U.S. equity market exerts significant influence on the London market but not vice versa. However, it is worth noting that various authors use different sample periods, U.S. indices (S&P 500 instead of Dow Jones) and specifications. The diverse results may be due to these differences.

When comparing this chapter results with those of other analysis, all the empirical studies of spillovers between international stock prices indexes present cross-market returns analysis with daily and overnight returns. Our estimations support these previous empirical findings. Additionally, with a finer break-down of time spans, the influences of one stock exchange to the other can be further measured and compared.

This Section presents an exercise to compare our findings with those from previous studies. To this aim, we redefine the time spans and we repeat the empirical analysis using daily (open-to-close) returns. We model the mean equations as a

VAR specification with only one lag with the FTSE and DJ daily returns as dependent variables. The error terms are assumed to follow a bi-variate EGARCH model. Results of the estimation are presented in Table 3.7.

As for the international return spillovers, the upper part of Table 3.7 reports that all the coefficient estimates for the FTSE equation are significant; previous day FTSE returns negatively affect next day FTSE returns ($\tau_1 = -0.081$ and significant) indicating that the FTSE index tends to reverse previous day price changes. The previous developments on the DJ market positively affect FTSE daily returns ($\tau_2 = 0.143$ and significant).Comparing the magnitude of these two coefficients our results indicate that the FTSE returns are mostly affected by previous day DJ returns.

None of the coefficient estimates of the DJ return equation turns out to be significant; previous day developments in both sides of the Atlantic do not affect posterior DJ stock prices.

To summarise the results of the return spillovers using daily data, Table 3.7 reports that DJ returns exert significant influence on FTSE returns but not vice-versa. These findings are in line with Gerrit et al. (1999) who estate that the U.S. returns are not significantly affected by foreign stock returns.

Table 3.7: Bi-variate EGARCH using daily returns

	$FTSE_{d,t}$		$DJ_{d,t}$	
	Coef.	Std. Error	Coef..	Std. Error
Mean equations:				
τ_0	$-1.7 \cdot 10^{-4,***}$	$3.1 \cdot 10^{-4}$	$5.1 \cdot 10^{-4}$	$3.0 \cdot 10^{-4}$
τ_1	-0.081^{**}	0.021	0.001	0.034
τ_2	0.147^{**}	0.034	0.014	0.029
τ_3	$7.6 \cdot 10^{-4}$	$8.0 \cdot 10^{-4}$	0.001	$8.4 \cdot 10^{-4}$
Variance Equations:				
γ_0	-0.600^{***}	0.015	-0.391^{***}	0.091
γ_1	0.956^{***}	0.013	0.964^{***}	0.008
δ_{FTSE}	0.147^{***}	0.048	0.069^{**}	0.035
ϕ_{FTSE}	-0.047	0.035	-0.025	0.028
δ_{DJ}	0.114^{***}	0.039	0.028^{**}	0.017
ϕ_{DJ}	-0.098^{***}	0.031	-0.101^{***}	0.022
$Ljung-Box(5)$	4.68	$Prob = 0.455$	5.99	$Prob = 0.307$
$Ljung-Box^2(5)$	5.25	$Prob = 0.354$	2.47	$Prob = 0.780$

Notes: *, ** and *** indicate that the null hypothesis can be rejected at the 10, 5 and 1 percent levels respectively. LR is the likelihood ratio test of the hypothesis that there is no variance spillover.

As for the international volatility spillovers, if we concentrate on the FTSE equation, the significant coefficients $\phi_{DJ} = -0.098$ and $\delta_{DJ} = 0.114$ demonstrate that the DJ innovations have significant influence on FTSE volatility. In the same equation, the significant coefficients $\phi_{FTSE} = -0.047$ and $\phi_{DJ} = -0.098$ present evidence on the asymmetric effects, such that bad news generated in either the FTSE or the DJ markets affect FTSE volatility more than good news generated in either market.

As for the Dow Jones equation, the coefficient $\delta_{FTSE} = 0.069$ is significant, which presents evidence of volatility spillovers from the FTSE tot the DJ stock markets. However, the coefficient $\phi_{FTSE} = -0.025$ is not significant, which indicates that the FTSE leverage effect is not present, namely, that the FTSE negative innovations do not have greater impact on DJ volatility than the FTSE positive innovations.

Overall, the coefficient estimates in Table 3.7 report significant influence of the DJ daily returns on the FTSE daily returns and weak influence on volatility spillovers from the FTSE to the DJ stock prices. These results are in line with Becker et al. (1995) and Gerrit et al. (1999) who suggest that U.S. stock market is not affected by international developments.

Nevertheless, when comparing the results presented in Table 3.7 with those presented in Table 3.6, we observe that the picture changes dramatically. The conclusions of our analysis depend greatly on the time spans used to perform the analysis. As mentioned in Section 3.5, using more refined intra-day time spans, we observe significant bi-directional returns and volatility spillovers between the FTSE and the DJ stock prices. The main difference is that in Section 3.5 we defined the time spans such that the FTSE returns can be identified during the hours when the New York Stock Exchange is closed. The empirical results in Section 3.5 provide evidence that the FTSE price changes are incorporated into posterior DJ returns. Results in Section 3.5 are consistent with the view of Connolly et al. (2003). Like these authors, we claim that the immediately preceding foreign market returns may contain more new information and thus, exert a significant influence on the subsequent domestic market returns.

To understand why the empirical results show that the U.S. market leads the London market when using daily data, consider a typical calendar day: the U.K. market closes before the U.S. market. Thus, the U.K. market is not able to respond to all the shocks in the same day. Instead, it responds to U.S. shocks with a one-day lag. On the other hand, if the U.S. market is influenced by the developments in the U.K. market, the former should respond to a U.K. shock in the same day. As a consequence, a leading relationship from London to New York is not observed in the empirical analyses.

3.7 Summary and Conclusions

This chapter has analysed the dynamic interactions between the FTSE 100 and the Dow Jones Industrial Average returns. In particular, we have investigated how much of the movements in one stock market can be explained by innovations in the foreign stock market.

While many studies focus on daily international market spillovers, a problem with their conclusions arises because there are non-synchronous trading periods for different markets around the globe. This chapter avoids this problem in a novel way: instead of focussing on daily returns or daily and overnight returns, we use intraday data to analyse the lead-lag relationship between the FTSE 100 and the Dow Jones returns, allowing the returns of the two countries to reflect information revealed over different time intervals.

Accordingly, to investigate the return and volatility interactions between both stock exchanges, we have defined three different cases depending on whether both exchanges are open or only one of them is open. As empirical tests of the data show that the returns series present conditional heteroskedasticity and as the focus of this thesis is on asymmetries on stock price co-movements, we have estimates a series of EGARCH models for each of the cases analysed.

Overall, the results of this chapter show significant bi-directional returns and volatility spillovers between the London and New York stock indices. We conclude that the availability of higher frequency datasets helps to better understand the nature of international market spillovers. The globalisation of industries and international portfolio diversifications are increasing the interdependencies between national stock exchanges, reducing the role of the U.S. as the only producer of information that may affect international stock prices.

The main empirical findings of this chapter are hereby summarised:

- The significant coefficient estimates of the EGARCH equations indicate that EGARCH processes provide a reasonable representation of the return processes. All the estimations support evidence of the "leverage effects", indicating an asymmetric response of volatility to good news and bad news. In particular, negative innovations exert a larger influence on volatility than positive innovations.

- Evidence from the estimations of cases 1 and 2 supports the "global factor hypothesis". This hypothesis states that a part of the movements of the foreign stock returns is attributed to containing global information and thus, domestic investors learn from stock price innovations in foreign markets. Domestic market traders infer the unobservable information from the previous foreign market returns and incorporate valuation information into their subsequent domestic trading. If there is a global factor in equity pricing, investors may follow price changes in foreign markets because they reveal information about this global pricing factor. Our findings reflect the financial globalisation process around the globe, highlighting the importance of foreign stock exchange developments when taking domestic investment decisions.

- As for the stock market spillovers between the common trading hours span, our results show significant bidirectional relationship between the London and the New York Stock Exchange in terms of returns interactions and volatility spillovers. Unlike previous studies, our results do not show that the DJ returns exert greater influence on the FTSE returns than the other way around.

- However, when repeating the exercise with daily observations, our estimates deliver very different results. In line with previous empirical findings, the new results show that the influence of DJ returns on FTSE returns in greater than the other way around. Our findings draw attention to the importance of choosing the time spans when analysing international stock market spillovers

Chapter 4

Stock Market Interactions and Macroeconomic News. An Exercise with High Frequency Data

4.1 Introduction

The increasing availability of high frequency data sets has stimulated numerous research on the financial market microstructure. Empirical analysis of high frequency data on financial markets has yielded interesting results on, for instance, the volatility distribution of asset prices, dynamic relationships between stock indices and their corresponding futures contracts and the impact of news on asset markets. However, a still unresolved empirical question is how European stock markets respond to movements on other stock exchanges in the short-term. As far as we know, this chapter is the first empirical attempt to characterise price interactions in three important European futures markets: the German, the Pan-European and the British using high frequency data.

After presenting the data and the descriptive statistics in Section 4.3, the main empirical question in this research is addressed in Section 4.5:

- Question one: What are the short-term dynamic spillovers between the futures returns on the DAX, the DJ Eurostoxx 50 and the FTSE 100?

The analysis is extended in Section 4.6 by examining if economic news is one source of international stock return co-movements. In particular, we test whether stock market interdependencies are attributable to reactions of foreign traders to public economic information. To the extent that there are common factors in business cycles, macroeconomic news in one country may reveal information about futures cash flows or discount rates in many countries, not just in the home country. This suggests that one source of market return co-movements may be macroeconomic announcements. Connolly and Wang (2003) and MacQueen and Roley (1993) present evidence to test this "public information hypothesis". In order to evaluate this view, we address a further question:

- Question two: How do the stock indices react to economic information emanating from Germany, the Euro-Zone and U.K.?

Furthermore, Section 4.7 investigates how the intermarket relationships change at the time of economic releases. The question addressed in this section is:

- Question three: Do cross-market linkages remain the same or do they increase during periods in which economic news is released in one of the countries?

Investigation of the above issues can test the efficiency of European futures markets and the existence of a lead-lag relationship between European stock indices. The results in this analysis give some insight into changes in stock market interactions at the time of economic announcements. If markets are informationally efficient, price adjustments to new information should be completed sufficiently quickly to avoid arbitrage windows. These points have crucial implications for investors' trading and hedging strategies.

The recent availability of high frequency datasets from different stock exchanges provides an enormous potential to investigate short-term international stock market interactions. The data used in this research consists on minute-by-minute futures prices for the FTSE 100, the DAX and the DJ Eurostoxx 50 indices. The richness of the dataset contributes to the international stock market interdependencies literature with investigating empirical interactions between the European futures markets. Among the empirical contributions of this chapter, this is the first empirical research that explores the short-term return spillovers between the Eurostoxx, the DAX and the FTSE futures returns. Second, regarding the role of economic news in explaining stock returns comovements, this research is the firs analysis that incorporates German and Pan-European news to investigate international returns spillovers.

The remainder of this chapter is structured as follows. The next section reviews previous studies. Section 4.3 introduces the data used in this study and some preliminary statistical analysis. Section 4.4 describes the methodology. Section 4.5 answers the first question and presents the results for the dynamic relationships among the European stock returns. Section 4.6 focuses on the second question and investigates how the news is transmitted across markets. Section 4.7 answers the third question by discussing how the cross-market relationships change in the minutes after the release of economic data. Finally, Section 4.8 offers a summary and the conclusions.

4.2 Related Literature

This chapter is in some aspects related to two principal themes in the empirical literature: lead-lag relationships between asset markets and the literature on event studies using high frequency data.

4.2.1 Lead-Lag Relationship Literature

Previous empirical studies of the dynamic relationship of the major world stock price indices use monthly, weekly or daily data to investigate the interdependence of stock markets. Eun and Shim (1989) use a Vector Autoregressive (VAR) model to report a substantial amount of interdependence among national stock markets. King and Wadhwani (1990), in a study of the period at the time of the 1987 stock market crash, document how price movements in one market are transmitted to other markets. More recent papers use Vector Error Correction (VECM) specifications to study the links between the European and the U.S. stock markets (Gerrits and Yuce (1999) and Bonfiglioli and Favero (2000)), between the Latin American markets (Cheng, Firth and Meng (2002)) or between Asian emerging markets (Masih and Masih (1999)). There is a lack of research on the lead-lag relationship between different European stock exchanges using high frequency data and macroeconomic information releases.

With regards to the literature on lead-lag relationships between markets for related assets using high frequency data, a large number of studies investigate the dynamic interactions between stock index and futures prices or between ADRs and stock prices. Most of this literature focuses on the U.S. or the U.K. financial markets. For instance, Hasbrouck (2003) empirically investigates the intra-day price discovery in the U.S. equity index markets. Arbitrage opportunities between the index and its futures contract imply that the price series are cointegrated, suggesting a VECM to study the price leadership in these markets. Abhyankar (1995) and Gwilym and Buckle (2001) also use a VECM to examine the lead-lag relationship between the FTSE 100 index and the derivatives contracts, which are based upon it. The aim of these papers is to determine how movements in prices are transmitted between markets for related assets. In this chapter, the temporal inter-relationships between different markets geographically associated are analysed. From an econometric perspective, this chapter's focus is similar to the one in this branch of literature and our analysis is linked to these papers through the econometric techniques used. In our analysis, after testing and rejecting any cointegration relationship between the DAX, the Eurostoxx 50 and the FTSE 100 futures contracts, a VAR approach is used to examine the intra-day interdependencies between the futures returns on the three indices.

4.2.2 Event Studies Literature

In recent years there has been a growing literature looking at the impact of macroeconomic announcements on U.S. and U.K. financial assets. The majority of these studies uses regression analysis where the announcements are included as exogenous variables in the Ordinary Least Square regressions. For example, Gwilym et al. (2001) investigate the impact of U.K. scheduled macroeconomic news announcements on the FTSE 100 and short sterling futures contracts. They find that the announcements on Retail, Producer Price Indices and Money variables have a significant impact on the FTSE 100 contracts. Clare and Courtenay (2001) also investigate the effects of U.K. macroeconomic news on selected futures contracts. They use a non-parametric test to document the initial reaction of London International Futures and Options Exchange contracts to a wide set of scheduled announcements. They find that announcements related to monetary policy decisions are the ones that produce the greatest effects on the contracts.

Nevertheless, it needs to be emphasised that the focus of this chapter is not to characterise the effects of a particular item of news on the stock returns, but to study whether the dynamic interactions between the DAX, the Eurostoxx 50 and the FTSE 100 futures returns change when macroeconomic data is released.

A large number of studies document the impact of economic news on exchange rate volatility or on the returns themselves. Examples are Almeida, Goodhart and Payne (1998) and Andersen, Bollerslev, Diebold and Vega (2003). These two papers compare the effects of pre-scheduled news (U.S. news in both cases) with the effects of non-scheduled releases (German news). Both studies report that the reaction of the exchange rates to the U.S. scheduled announcements is different from the reaction to the German non-scheduled announcements. In addition to their results, this chapter demonstrates that the announcement timing affects the intra-day co-movements between the different stock exchanges.

While previous research shows that home country macroeconomic surprises influence home country asset prices, few studies investigate the influence of domestic announcements on foreign stock prices. As far as we know, no study has concentrated on changes to the dynamic relationships between stock prices when economic data is released using high frequency data. This is one of the aims of this chapter.

Regarding this last point, two papers that investigate the sources of stock market co-movements need to be mentioned. Becker, Finnerty and Friedman (1995) attribute the interactions between the U.K. and the U.S. stock markets to U.S. economic information, namely to the "public information hypothesis". In particular, they study the response of U.K. equities during the half-hour following the U.S. economic announcements at 14:30h London time.[1] They find that the correlation between the FTSE 14:30h-15:30h and the U.S. overnight returns is higher on announcement days that on non-announcement days. Since the U.S. stock exchange is not open by then, they can not study the short-term interactions between both stock exchanges following the announcement minutes. Based upon on a different argument, Connolly and Wang (2003) explain the return comovements for the U.S., U.K. and Japanese equity markets with an imperfect learning theoretical model. They examine the return comovements in these equity markets with a focus on the distinction between economic fundamentals and contagion. Their results show that the bulk of observed co-movements in returns of the international equity markets cannot be attributed to public information about economic fundamentals.

This chapter is linked to these papers because it also studies the co-movements between different stock exchanges and we analyse if these co-movements can be attributed to public information flow, as measured by the news on macroeconomic fundamentals. Our analysis differs from theirs since we use a microstructure approach

[1] All times in this chapter refer to London time. Notation is of twenty four hours a day.

and our focus of attention is the short term effects exploiting the microstructure information contained in our high frequency data set.

4.3 Data and Descriptive Statistics

4.3.1 Stock Market Indices

The stock indexes futures contracts data covers the period July and August 2001. The intra-day data consists of equally spaced thirty seconds snapshots of the last transaction prices for the futures contracts published on the screens of Reuters information systems. The contracts included are the futures on the DJ Eurostoxx 50 , the DAX and the FTSE 100 index. The futures on these three indexes are the most liquid ones traded in Europe.

The Eurex Stock Exchange launched Futures on the Dow Jones and the Eurostoxx 50 Indices in June 1998. The DJ Eurostoxx Index comprises the 50 Euro-Zone (excluding U.K. and Switzerland) blue-chip companies with the largest free float market capitalization. During the months of the sample used the constituents of the index were: sixteen French companies, thirteen German, seven Italian, seven Dutch, five Spanish, one Belgium bank and one Finnish company. The trading hours are 08:00h until 16:30h London time.

The DAX is the German Stock Index, which comprises Germany's thirty largest market capitalisation companies. Its futures contracts are also traded on the Eurex Stock Exchange. The FTSE 100 Index Futures are traded on the London International Futures and Options Exchange between 08:00h and 17:30h. Between 16:30h-17:30h, the FTSE futures are traded but other contracts are not. As our interest relays upon studying the dynamic interactions between the different exchanges, only the common trading hours are included in our analysis, namely intra-day data between 08:00h and 16:30h.

We calculate returns over one minute intervals. This return is defined as the log of the last transaction price of the current minute interval, P_t, minus the log of the last transaction price of the previous minute interval, P_{t-1}, *i.e*, $R_t = \ln(P_t) - \ln(P_{t-1})$. The data was pre-filtered for errors. The data on 27 August was excluded since it was a bank holiday in England and the exchange was closed. Due to problems with the data collection, data on 27 July starts at 08:47h and data for the FTSE on 23 August starts at 09:15h.

Regarding the zero observations, those minutes with one or two of the index returns equal to zero are substituted by the corresponding thirty seconds returns. For instance, the original data set includes the transaction prices for the contracts on 2 July at 09:00:00h, at 09:00:30h, at 09:01:00h, etc.[2] If the DAX futures return between 09:00:00h and 09:01:00h is zero, the one minute return of the three series are substituted for the corresponding 30 seconds returns, i.e., the returns between 09:00:30h and 09:01:00h are calculated for each series. Otherwise, zero observations are left in the data set as they are information in our analysis, namely, no trades are crossed at that particular minute. In total 4.0 percent of the DAX returns, 9.1 percent of the Eurostoxx returns and 5.8 percent of the FTSE returns are equal to zero. After cleaning the data, the sample contains 21,790 one-minute observations for each of the futures on the DAX, Eurostoxx 50 and FTSE 100 indices.

4.3.2 Preliminary Analysis

4.3.2.1 Descriptive Statistics and Correlation Analysis

Descriptive statistics of the returns are reported in Table 4.1. R_{DAX} stands for DAX futures returns, R_{Eur} for Eurostoxx futures returns and R_{FTSE} for FTSE futures returns. The returns present typical features of high frequency data: the sample skewness is 0.0 for the three series, but the sample kurtoses are well above the normal value of 3, which indicates that the returns are symmetric but fat-tailed relative to the normal distribution. The FTSE 100 futures contracts are the only ones that yielded on average positive returns during the sample period studied.

[2] 09:00:00h stands for nine hours, zero minutes and zero seconds.

Panel B in Table 4.1 reports the sample autocorrelations of the futures price series and of the futures returns series for the DAX, the Eurostoxx 50 and the FTSE 100 stock indexes. The sample autocorrelations of all price series present very large values of first-order autocorrelation and die off very slowly, which indicates that futures prices are quite likely to be processes integrated of order one. The lower part of the table documents the autocorrelations of the futures returns. Only the FTSE 100 returns present negative first order autocorrelation. This empirical finding has been previously documented by Glosten and Milgrom (1985). If the transaction prices bounce between the bid and the ask levels, a negative serial dependence is noted in the time series. A likely explanation for the fact that no observation is made of a negative first order autocorrelation with the DAX and Eurostoxx 50 returns may be that in our sample the intra-day average bid-ask spread for the DAX futures contracts is 0.12 percent, for the Eurostoxx 50 futures contracts is 0.13 percent and for the FTSE 100 futures contracts the bid-ask spread is 0.23 percent, nearly twice as large as that on the previous contracts.

Table 4.1 Panel C provides the correlation matrix of the stock index futures between the three markets. As expected, there are strong positive correlations between the three markets. In particular, the correlation between the DAX and the Eurostoxx 50 futures is 0.718. This high correlation is due to the fact that, as pointed out before, by 1 July 2001, thirteen out of the fifty members of the Eurostoxx 50 index are German companies, which represents the 24 percent of the market capitalisation of the index. This fact makes it worth testing whether there are cointegration relationships between the future contracts in such a way that future prices movements are driven by the same components in the long-term.

Table 4.1A: Minute by minute returns distribution

	Mean	Std. Dev.	Skew	Kurtosis	Maximum	Minimum
R_{DAX}	$-3.5.10^{-5}$	0.0005	-0.012	8.293	0.0075	-0.0054
R_{Eur}	$-4.0.10^{-6}$	0.0005	0.0264	6.318	0.0049	-0.0041
R_{FTSE}	$1.5.10^{-7}$	0.0004	0.0418	7.565	0.0053	-0.0046

Table 4.1B: Autocorrelations

	$k=1$	$k=2$	$k=3$	$k=4$	$k=5$
P_{DAX}	1.000	1.000	0.999	0.999	0.998
P_{Eur}	1.000	0.999	0.999	0.999	0.998
P_{FTSE}	0.999	0.999	0.998	0.998	0.997
R_{DAX}	0.030*	0.016**	-0.009	-0.011	-0.002
R_{Eur}	0.035*	0.025*	0.008	-0.002	0.006
R_{FTSE}	-0.014**	0.017**	0.010	0.012	0.004

Notes: all of the autocorrelations of prices are significant at 1 percent level. For the returns autocorrelations, ** and * denote significance at 5 and 10 percent levels respectively.

Table 4.1C: Contemporaneous correlation

	R_{DAX}	R_{Eur}	R_{FTSE}
R_{DAX}	1	0.718	0.394
R_{Eur}		1	0.375
R_{FTSE}			1

4.3.2.2 Unit Root Test and Cointegration Test

We start this Subsection by testing whether the price series are stationary. We present two different tests. In the Augmented Dickey Fuller test the null hypothesis is the existence of a unit root in the series. In addition, we run a test with stationarity as the null. In particular, we run the following equation:

$$P_{i,t} = \alpha_i + \beta_i P_{i,t-1} + \varepsilon_t \qquad i = DAX,\ Eurostoxx,\ FTSE$$

The hypothesis of stationarity can be evaluated by testing whether the absolute value of is strictly less than one. Namely, for each of the three price series, H_0 : $|\beta_i| < 1$ or $P_{i,t}$ is stationary. The results are presented in Table 4.2, Panel A. The null hypothesis of stationarity is strongly rejected in the three price series.

To test if each series contains a unit root, namely if it is integrated of order one, i.e., I(1). Table 4.2 Panel B details the ADF unit root tests of stationarity in the levels and first differences of the futures price series (in natural log form) of the DAX, the Eurostoxx 50 and the FTSE 100. The test equations include both intercept and trend. The lag length in the ADF regression is set to three, four and two respectively in accordance to the Akaike Information Criteria. The test results reported in Panel A show that the null hypothesis that futures prices levels are non-stationary is not rejected for all the markets. The null hypothesis that first log differences in these futures indexes are non-stationary is strongly rejected. These results indicate that the price series of the futures on the DAX, the Eurostoxx and the FTSE follow an I(1) or non-stationary process and thus, should be differenced to achieve stationarity.

The Johansen Cointegration test for each pair of prices is recorded in Table 4.2 Panel C. To estimate the number of cointegration relations, Johansen (1988, 1991) proposes two methods: the trace test and the maximal eigenvalues test. The test statistic examines the hypothesis of zero cointegration relations against the alternative of that all the series are stationary. The maximum eigenvalue statistic tests the hypothesis of zero cointegration relations against the alternative of one cointegration relation. Table 4.2 Panel C notes that for each pair of prices the trace statistic in the first row and the maximum eigenvalue statistic in the second row. For each test, the maximum eigenvalue, the likelihood ratio test statistic and the five percent level critical values are detailed. The tests allow for linear trends in the original price series but not in the cointegration equations. At 5 percent significance level, the results in Table 4.2 indicate that all the tests reject the existence of a cointegration relationship between the stock markets included in our analysis. In other words, the DAX, the Eurostoxx 50 and the FTSE 100 future prices do not share a long-term equilibrium. As a consequence, the appropriate econometric specification to model the dynamic interactions between the three futures markets is a Vector Autoregressive Approach (VAR), not a Vector Error Correction Model.

This result may seem surprising. In the case of lower frequency data sets (daily, weekly or monthly prices), the different countries' stock prices may be cointegrated and exhibit stable long-term relations. The presence of strong economic ties and policy coordination between the relevant countries, the formation of common trading blocks (e.g., EU, MERCOSUR or NAFTA) and the development of integrated economic systems (e.g., EU and EMU) may produce a significant long-run relationship between different stock markets. However, in our case, the frequency of the data is minute by minute. The main drivers of this data are individual trades, news announcements, etc. There is too much noise in the data to identify a long term trend (a cointegration vector) at the international level.

It is worth to mention that cointegration does not imply efficiency. Market efficiency refers to the fact that news (whatever kind and origin) are immediately incorporated into prices while cointegration refers to the existence of a common long term trend among de three markets.

Table 4.2.A: stationarity of the price series

	P_{DAX}	P_{Eur}	P_{FTSE}
β	0.999	0.999	0.999
Chi square	$6.3 \cdot 10^{+6}$	$4.9 \cdot 10^{+6}$	$4.6 \cdot 10^{+6}$
Prob	0.000	0.000	0.000

Notes: null hypothesis is that the price series are stationary.

Table 4.2.B: Augmented Dickey Fuller unit root test

	P_{DAX}	P_{Eur}	P_{FTSE}
ADF levels	-2.43	-2.53	-2.67
ADF first differences	-67.4***	-67.0***	-65.2***

Notes: the 5 percent Mackinnon critical values for rejection of hypothesis of a unit root is -3.41.*** indicates significance at 1 percent level.

Table 4.2.C: Johansen cointegration test

Pair	Eigenvalues	Likelihood Ratio	Critical Value 5% level	H_0 No. of CE (r)	H_A
Eur-DAX	0.0004	9.33	15.41	$r = 0$	Stationary
	0.0004	9.32		$r = 0$	$r = 1$
Eur-FTSE	0.0004	10.82	15.41	$r = 0$	Stationary
	0.0004	8.94		$r = 0$	$r = 1$
DAX-FTSE	0.0003	7.34	15.41	$r = 0$	Stationary
	0.0003	7.34		$r = 0$	$r = 1$

Notes : all likelihood ratios reject any cointegration equation at 5 percent significant level.

4.3.3 Macroeconomic News

The other part of our data set consists of Euro-Zone, British and German macroeconomic announcements covering the same period plus a market expectations series for each type of announcement. The expectations series are obtained from Money Market Services International (MMS). MMS conducts a weekly survey among financial analysts on the expected magnitude of the macroeconomic data that will be released in the near future. MMS publishes the mean and the standard deviation of the results of the survey. This mean for each data release reflects the market expectations or the market consensus regarding that macroeconomic release. This survey is widely used in the finance literature to identify (ex-post) the surprise element of the news (see, for instance McQueen and Roley (1993) and Connolly and Wang (2003)). Notice that the expectation series are the result of a survey, they do not correspond to statistical estimates. These series can be obtained either directly from MMS or from Bloomberg.

The inclusion of the MMS survey series enables the announcements to be classified into the unexpected and the expected part of the announcement. The macroeconomic data series are supplemented with the inclusion of Monetary Policy Committee interest rates decisions by both the European Central Bank (ECB) and the Bank of England (BoE), including 'no change' decisions, the release of the weekly European Financial Statement of the ECB and the publication of the CIPS Service Reports and the Changes in Official Reserves for the U.K.

For the Euro-Zone and the British releases, the announcements reach the market at the official announcement time, which is generally at 11:00h for Euro-Zone macroeconomic data releases and 12:45h for the ECB interest rate decisions. British announcements are generally released at 09:30h and BoE interest rate decisions at 12:00h. On the other hand, German releases are not announced at regular prearranged times.

To include the macroeconomic news data in our analysis the series is classified according to the country of origin and their sign, i.e., if they represent good news for the market or bad news for the market.[3] The full set of macroeconomic announcements used in our study is presented in Appendix D along with the days and release times.

4.4 Methodology

The goal of this section is to study the dynamic interactions between the futures on the DAX, the Eurostoxx 50 and the FTSE 100 indices. Unfortunately, economic theory is not rich enough to provide a tight specification of the dynamic relationships between stock market returns. From an empirical point of view, the Vector Autoregressive (VAR) approach is suitable for the analysis of dynamic linkages among the markets since it can identify the main interactions and simulate the responses of a given exchange to innovations in the other markets.

The initial model specification in this section is an unrestricted VAR approach on the returns of the three futures contracts. Each return is affected by its own lagged returns and the past movements on the other stock exchanges. The general form of the unrestricted VAR system is

$$R_{j,t} = \alpha_j + \sum_{j=1}^{3}\sum_{\tau=1}^{K}\beta_{j,\tau}R_{j,t-\tau} + u_{j,t} \quad t = 1, 2, ..., T \tag{4.1}$$

where $R_{j,t}$ is the return of the index j at time t. j = DAX, Eurostoxx and FTSE indices. The $\beta_{j,\tau}$ measure the spillovers between markets j and j' captured by lagged returns. $u_{j,t}$ is a vector white noise process with $E(u_t u_t^{'}) = \Omega$ for all t. Notice that in absence of market restrictions and cost of capital, the constant term α_j should be zero. This initial VAR specification will be used to answer the first question addressed in this chapter on stock market spillovers.

[3] Any economic activity that changes the cash flows and/or the discount rates affects stock prices. Good news causes a theoretical increase in the stock prices. For instance, a higher than expected value for the Industrial Output. On the opposite, a lower than expected sentiment index is included as bad news.

Next, to answer the second question on the effect of news on stock market returns, the series of macroeconomic releases are introduced as exogenous variables in the VAR specification. The new VAR system is

$$R_{j,t} = \alpha_j + \sum_{j=1}^{3}\sum_{\tau=1}^{K}\beta_{j,\tau}R_{j,t-\tau} + \sum_{i=0}^{6}\sum_{s=0}^{S}\theta_{i,s}x_{i,t-s}^{ne} + u_{j,t} \quad t = 1, 2, ..., T \tag{4.2}$$

for j = DAX, Eurostoxx and FTSE. Each category of news i is allowed to affect futures indices up to S minutes after the news is released. According to the efficient markets hypothesis, only the unexpected part of the announcements should have an impact on stock returns. If we denote x_t as the actual announced economic figure at moment t and x_t^e as its correspondent expected value, then $x_t^{ne} = x_t - x_t^e$ represents the unexpected part of the release or the "news" contained in the announcements, which is included in our regression. The news is classified into different categories i depending on its country of origin and its sign, i.e., positive news vs. negative news. The coefficients $\theta_{i,s}$ measure the impact of news on stock returns. Evidence supporting the "public information hypothesis" is collected by domestic news affecting foreign stock returns, namely if the coefficients $\theta_{i,s}$ are significant in the $R_{j,t}$ equation.

Market efficiency requires that price adjustments to new information are completed sufficiently quickly to avoid unnecessary arbitrage windows, and so the speed of market adjustment to news may be used to judge the degree of market efficiency.

Finally, to answer the third question addressed in this chapter and to assess whether the dynamic spillovers between the domestic and the foreign returns change during periods in which macroeconomic data is released, an interaction coefficient is introduced. Formally, we impose the following constraint on β in equation (4.1)

$$\beta = \beta^0 + \beta^1 x_t^{ne}$$

Thus, we conjecture that the interactions between the international futures returns have some linear relation with the macroeconomic announcements measured by the variable x_t^{ne}. The coefficient β^1 captures the incremental impact of information releases on the lead-lag relationship between returns. To test if dynamic spillovers between futures returns change during the minutes after the announcements, we can directly test if $\beta^1 = 0$. Equation (4.1) can be rewritten as follows

$$R_{j,t} = \alpha_j + \sum_{j=1}^{3} \sum_{\tau=1}^{K} \left(\beta^0_{j,\tau} + \beta^1_{j,\tau} x^{ne}_t\right) R_{j,t-\tau} + u_{j,t} \quad t = 1, 2, ..., T \tag{4.3}$$

As in the previous equations $R_{j,t}$ corresponds to the return of market j in minute t. A positive and significant coefficient β^1 indicates that the lead of the domestic market strengthens in the wake of local macroeconomic news releases. On the other hand, a negative and significant coefficient β^1 provides evidence of a weakening in the lead of domestic returns at the time of domestic announcements.

One of the criticisms of the unrestricted VAR models is that the Impulse Response Function and the Decomposition of the Variance are sensitive to the assumed origin of shocks and to the order in which they are transmitted to other markets. This is overcome in this chapter by using the Generalised Impulse Response and Variance Decomposition described by Pesaran and Shin (1998). The generalised functions are invariant to the reordering of the variables in the VAR. The generalised impulse responses from an innovation to the j^{th} variable are derived by applying a variable specific Cholesky factor computed with the j^{th} variable at the top of the Cholesky ordering.

As the system is just identified, we estimate the unrestricted VAR in equation (4.1) by applying OLS equation by equation. All the tests in the chapter are computed using heteroskedasticity and serial correlation consistent standard errors (HAC), which perform heteroskedasticity-robust inference about the coefficients and are asymptotically robust to residual heteroskedasticity unknown form.

4.5 Results: Spillovers between European Stock Exchanges

This section answers the first question addressed in this chapter: what are the dynamic spillovers between the futures returns on the DAX, the Eurostoxx 50 and the FTSE 100? Furthermore, it also investigates whether the transmission of price movements is symmetric or asymmetric with the London Stock Exchange. In particular we discuss the results of the estimation of our baseline VAR model in equation (4.1). The number of lags K=9 is chosen based on the Akaike Information Criteria.

The VAR estimates capture important cross market linkages. For sake of space, the estimated coefficients of the VAR system are not reported. Instead, the Wald test is noted in order to examine whether the lagged domestic returns are jointly significant in the foreign returns equations and the generalised impulse response functions of the system and its variance decomposition are examined. Table 4.3 reports the F-statistics of the Granger Causality Tests.

Remark 1. *There are clear short term international dynamic interactions among the European stock futures markets.*

The significant F-statistics in Table 4.3 show the existence of cross-market interactions between the DAX, the Eurostoxx 50 and the FTSE 100 futures returns. This finding indicates that past returns in the foreign markets influence subsequent domestic returns.

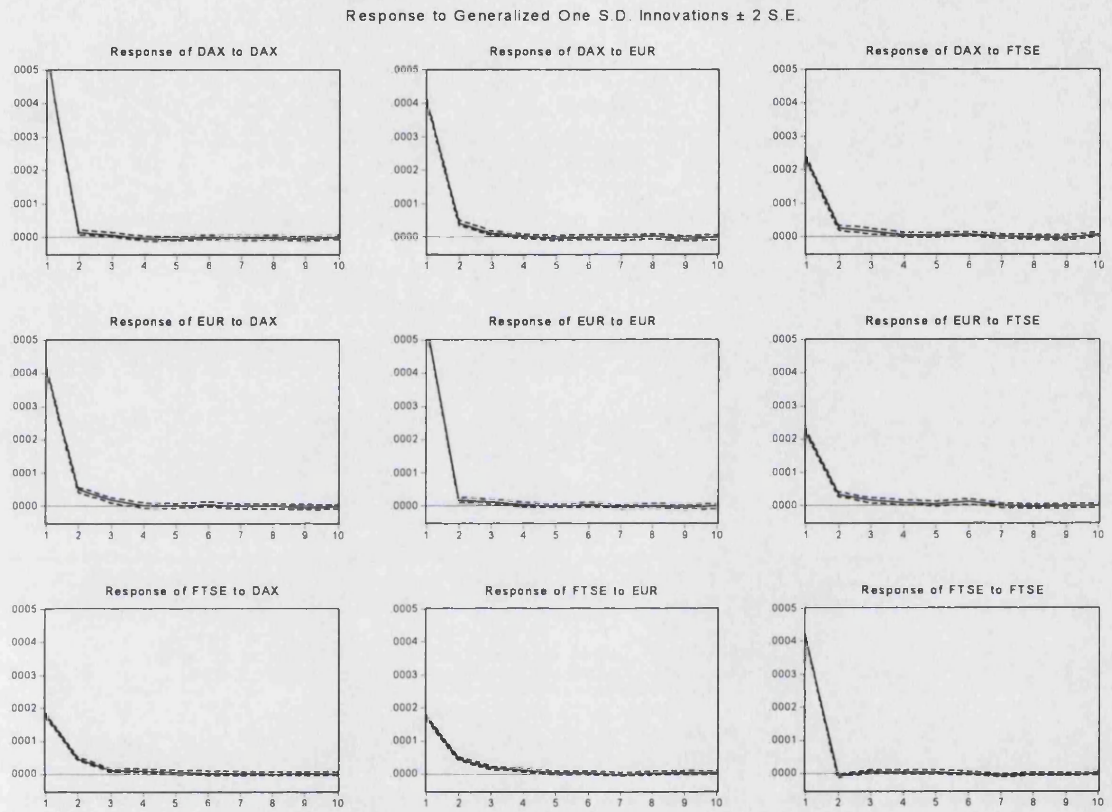
Table 4.3: Granger causality tests

Hypothesis:	F-Statistic	Probability
R_{DAX} does not Granger cause R_{Eur}	26.25	0.000
R_{DAX} does not Granger cause R_{FTSE}	46.58	0.000
R_{Eur} does not Granger cause R_{DAX}	20.65	0.000
R_{Eur} does not Granger cause R_{FTSE}	49.08	0.000
R_{FTSE} does not Granger cause R_{DAX}	7.55	0.000
R_{FTSE} does not Granger cause R_{Eur}	10.07	0.000

Notes: it is tested as to whether returns in market i are jointly significant in the equation for returns in market j, which is equivalent to test if all the past coefficients in the VAR equations are jointly significant or not.

The impulse response functions dynamically simulate the model. Figure 4.1, column 1 draws the adjustment paths of the three markets when the DAX futures increase by one standard deviation. The second column depicts the response of each market when the Eurostoxx futures increase by one standard deviation and in the third column, a one-standard deviation shock is introduced in the FTSE equation. In each graph, the centre line represents the impulse response and the two dashed lines depict the two-standard deviation confidence bands.

Figure 4.1: Generalised Impulse Response Functions to one standard deviation shocks



Notes: in the x axis, minutes after the shock are drawn.

Several interesting patterns of market returns interactions emerge when analysing the graphs. First, innovations in the domestic stock exchange are transmitted to foreign stock exchanges. Second, all the markets attain the maximum response one minute after a shock in any foreign stock exchange has been introduced. Third, the three futures react up to four or five minutes after the shock in one of the foreign markets has been introduced. This finding shows that the DAX and the Eurostoxx futures adjust to movements in the FTSE futures prices as fast as the FTSE adjusts to movements in continental European futures prices. Nevertheless, it is interesting to note that the magnitude of the initial response of the Eurostoxx to a shock in the FTSE 100 is not larger than the initial response of the FTSE 100 to a shock in the Eurostoxx 50, as the coefficients $2.25 \cdot 10^{-4}$ and. $1.73 \cdot 10^{-4}$ turn out not to be statistically different (Chi square of the Wald test is 0.490, probability = 0.483). Our findings reveal that, even though the cross-market spillovers are asymmetric with the FTSE 100 price movements, the FTSE 100 futures prices are not isolated from other futures prices movements. Finally, domestic returns tend to reverse returns realised in the preceding minutes and the effect of a shock upon the domestic market is internalised within the same minute as the introduction of the shock..

The variance decomposition is an attempt to gauge to what extent the variance of certain markets are explained by other markets. Variance decomposition of a one-standard deviation shock to each market is listed in Table 4.4. The forecasting horizons are given for one to five minutes, ten and fifteen minutes ahead. Each row displays the forecasted error variance explained by the market in the column heading. The last column, labelled *'Foreign markets'*, shows the percentage of forecast error variance of the market in the first column explained by all other markets except the market's own innovations. The results in Table 4.4 demonstrate that most of the decomposition of the forecast error variance is picked up by the first minute after the shock has been introduced. The results also indicate that the DAX and the Eurostoxx 50 futures affect each other in a very similar way. Furthermore, the British futures market appears to be the most exogenous one, as most of its variance

Table 4.4: Generalised variance decomposition

Decomp.	Period	Std. Error	Due to a shock in:			*Foreign*
of:		*1,000	$R_{DAX,t}$(%)	$R_{Eur,t}$(%)	$R_{FTSE,t}$(%)	$markets_t$(%)
σ_{DAX}	$t+1$	0.535	56.6	32.4	10.8	43.8
	$t+2$	0.538	56.4	32.6	10.9	43.5
	$t+3$	0.538	56.3	32.6	10.9	43.6
	$t+4$	0.538	56.3	32.6	10.9	43.6
	$t+5$	0.538	56.3	32.6	10.9	43.6
	$t+10$	0.539	56.3	32.6	10.9	43.6
	$t+15$	0.539	56.3	32.6	10.9	43.6
σ_{Eur}	$t+1$	0.540	32.8	57.2	9.9	42.7
	$t+2$	0.544	33.0	56.8	10.1	43.1
	$t+3$	0.544	33.0	56.8	10.1	43.1
	$t+4$	0.544	33.0	56.8	10.1	43.1
	$t+5$	0.544	33.0	56.8	10.1	43.1
	$t+10$	0.545	33.0	56.8	10.1	43.2
	$t+15$	0.545	33.0	56.8	10.1	43.2
σ_{FTSE}	$t+1$	0.415	14.0	12.7	73.2	26.7
	$t+2$	0.419	14.6	13.4	71.9	28.0
	$t+3$	0.419	14.6	13.5	71.8	28.1
	$t+4$	0.419	14.6	13.5	71.7	28.2
	$t+5$	0.420	14.6	13.5	71.7	28.2
	$t+10$	0.420	14.6	13.5	71.7	28.2
	$t+15$	0.420	14.6	13.5	71.7	28.2

Notes: variance decomposition of one standard deviation shock to each market is listed.

is explained by its own innovations. Five minutes after the shock, 71.8 percent of the FTSE variance is explained by its own shocks, unlike the variances of 56.4 percent and 56.8 percent respectively of the DAX and the Eurostoxx 50 which are explained by their own innovations.

These findings with regards to interdependencies between different stock exchanges could superficially appear to be inconsistent with market efficiency. A couple of observations concerning these results need to be made. First, the minute-by-minute average return changes are small. Thus, even if some predictive ability can be achieved, it may still not offset the transaction costs. Second, the extent to which the minute-by-minute fluctuations in stock markets can be explained by their immediately preceding time path is not large. The R^2 values of the three VAR equations fall into the range 0.012 to 0.024.

To summarise, the results in this section show significant short-term dynamic spillovers between the LIFFE and the Eurex futures markets. The empirical evidence suggests that the FTSE 100 futures are the most influential ones. However, our results do not show a clear lead-lag relationship pattern between the European stock exchanges in which, for instance, the FTSE 100 index leads the price evolution and continental European futures follow its movements. Furthermore, we find that the spillovers vanish within the next five minutes after a change in any of the futures prices, which indicates that markets are efficient when responding to movements on other stock exchanges.

4.6 Macroeconomic News and Stock Market Returns

In this section, the second question addressed in this chapter is answered: how do the stock indices react to economic information originating in Germany, the Euro-Zone and the U.K.? To test for systematic effects of news on the stock market returns, we repeat the analysis of the previous section but we include the effect of the economic news in the VAR system as specified in equation (4.2). In particular, we introduce the exogenous dummy variables in the VAR equations to account for the macroeconomic news. Each dummy variable is a series of zeros with observations equal to one on the minutes in which economic data is released. The Money Market Services expectations series are used to identify the group to which the news belong, namely if the macroeconomic releases represent positive surprises (if they were better than expected) or negative surprises (if they were worse than expected).

According to our classification of news, i.e., country of origin and sign of the surprises, we introduce six new dummy variables $x_{i,t}^{ne}$, where i stands for positive and negative surprises emanating from British, Euro-Zone and German announcements. In the estimation, the news is allowed to affect the evolution of stock prices up to ten minutes after the announcement has been released.[4,5]

The results of the estimation of the system (4.2) are presented in Table 4.5. The first two columns of this table refer to the DAX equation. Columns three and four pertain to the Eurostoxx 50 equation and columns five and six relate to the FTSE 100 equation. For sake of space not all the coefficients of the new estimations are reported.[6] Instead, the table is divided into two panels. In the upper part of Table 4.5 we report the cumulative effect of each category of news on the future prices. The F-statistics testing the null hypothesis that the sum of the lagging coefficients on the news variables is equal to zero are also given. In the lower part of Table 4.5 the effects of the news on stock returns at the same minute of the release and up to two minutes afterwards are reported. All the estimated coefficients not reported in the

[4]This means that in the VAR specification S=10 lags. Clare and Courtenay (2001) demonstrate that the abnormal activity for the FTSE 100 contracts lasts for around eight minutes after the British announcements. We tried the estimation with different lags orders up to thirty minutes and the news never affected stock returns more than two minutes after the announcement.

[5]A negative S is included before the official release times in the estimation to account for announcement leakage, but doing so proved unnecessary.

[6]Note that the news series are includd as *new* exogenous variables in the VAR system. As they are uncorrelated with the error and they are independent of the past, their inclussion does not change the $\beta_{j,\tau}$ coefficients estimated in the previous section.

table turn out not to be significant. For notational convenience, the subscripts i are replaced by each category of news, namely gp stands for positive German news, gn denotes negative German news, up represents positive British announcements and do forth. For instance, with this notation, $\theta_{ep,0}$ is the coefficient that corresponds to the positive Euro-Zone news dummy the minute when the news is released. In the same way, $\theta_{un,-2}$ is the coefficient that corresponds to the negative British news dummy two minutes after the releases. This notation is consistent in all the tables presented in the chapter.

Table 4.5: VAR estimates. Effects of the news on stock returns

All the coefficients and the standard deviations presented in this table are multiplied per 1,000.

Panel A: Cumulative coefficients and F-statistics

	$R_{DAX,t}$		$R_{Eur,t}$		$R_{FTSE,t}$	
	Coef.	F-Stat.	Coef.	F-Stat.	Coef.	F-Stat.
$\theta_{up,0\ldots-10}$	0.991^{**}	1.945	0.963^{*}	1.675^{*}	1.341^{***}	4.961
$\theta_{un,0\ldots-10}$	−0.095	0.849	−0.124	0.616	−0.151	1.531
$\theta_{ep,0\ldots-10}$	0.568	1.552	0.579^{***}	4.262	0.376	1.083
$\theta_{en,0\ldots-10}$	-0.640^{***}	3.889	-0.941^{***}	4.330	−0.819	1.432
$\theta_{gp,0\ldots-10}$	1.092^{***}	2.948	0.711^{***}	2.342	0.272^{***}	1.903
$\theta_{gn,0\ldots-10}$	-0.783^{**}	2.127	-0.342^{**}	2.187	−0.960	1.524

Table 4.5: Continues. Panel B: Effect of news on stock returns

	$R_{DAX,t}$		$R_{Eur,t}$		$R_{FTSE,t}$	
	Coef.	Std. Error	Coef.	Std. Error	Coef.	Std. Error
$\theta_{up,0}$	0.456**	0.192	0.438**	0.210	0.718**	0.370
$\theta_{up,-1}$	0.328**	0.123	−0.254**	0.135	0.205***	0.087
$\theta_{up,-2}$	−0.041	0.129	0.032	0.151	0.254	0.125
$\theta_{un,0}$	−0.281	0.210	−0.287*	0.183	−0.317***	0.116
$\theta_{un,-1}$	0.076	0.146	−0.042	0.159	0.151	0.139
$\theta_{un,-2}$	0.097	0.167	0.086	0.071	−0.082	0.081
$\theta_{ep,0}$	0.549***	0.141	0.938***	0.257	0.247***	0.078
$\theta_{ep,-1}$	−0.225	0.177	0.462*	0.261	−0.185	0.183
$\theta_{ep,-2}$	0.162	0.126	0.099	0.165	0.083	0.093
$\theta_{en,0}$	−0.952***	0.331	−1.092***	0.302	−0.046	0.295
$\theta_{en,-1}$	−0.137	0.242	−0.170	0.189	0.015	0.117
$\theta_{en,-2}$	−0.344*	0.209	0.087	0.171	−0.093	0.113
$\theta_{gp,0}$	0.297	0.215	0.274	0.235	0.243**	0.114
$\theta_{gp,-1}$	0.333*	0.173	0.301*	0.165	0.298**	0.121
$\theta_{gp,-2}$	0.156	0.193	0.232	0.163	0.932	0.154
$\theta_{gn,0}$	−0.472**	0.217	−0.494***	0.150	−0.395***	0.132
$\theta_{gn,-1}$	−0.406***	0.166	−0.382	0.238	0.041	0.129
$\theta_{gn,-2}$	−0.026	0.210	0.008	0.246	0.064	0.105

Notes: parameter estimates from regression (4.2)

$$R_{j,t}= \alpha_j+\sum_{j=1}^{3}\sum_{\tau=1}^{K}\beta_{j,\tau}R_{j,t-\tau}+\sum_{i=1}^{6}\sum_{s=0}^{10}\theta_{i,s}x^{ne}_{i,t-s}+u_{j,t}$$

x_i^{ne} stands for each category of news. HAC consistent standard errors are reported.

*,** and *** indicate significance at the 10, the 5 and the 1 percent levels respectively.

Remark 2. *Foreign economic news affects domestic returns.*

From the cumulative estimated coefficients and the F-statistics reported in the upper part of Table 4.5 few points are worth noting.[7] First, as expected, DAX returns are mostly affected by German releases, Eurostoxx 50 returns are mostly influenced by Euro-Zone releases and FTSE 100 returns are mostly influenced by British announcements. Second, news impacts the stock prices with the correct sign, namely, news designated as "good surprises" positively affects stock returns and news defined as "bad surprises" negatively affects stock returns. Third, news on domestic macroeconomic data significantly affects foreign futures returns. In particular, German news always affects Eurostoxx 50 returns (F-Statistic=2.341 and 2.187) and Euro-Zone negative news affects DAX returns (F-Statistic=3.889). Further, our results show that positive German news significantly affects the three futures returns. This finding suggests that British investors are also aware of news emanating from continental Europe. Finally, British positive news significantly affect DAX returns (F-Statistic=1.945) and Eurostoxx 50 futures returns (F-statistic=1.675). This last effect is mainly due to the response of the markets to the cut in U.K. interest rates on 2 August. This finding empirically supports the current literature on the effects of monetary policy on stock prices. Rigobon and Sack (2002) and Smets (1997) establish the links between monetary policy and stock prices. Both authors conclude that increases in short-term interest rates result in a decline in stock prices.

Remark 3. *Futures returns adjust to news immediately.*

In the lower part of Table 4.5 it is noted that the main effect of all the news on futures returns, except for positive German news, is within the same minute of the release. Moreover, the full response to the news occurs within two minutes of the release.

With respect to the British news, positive releases have a strong, significant effect

[7]If the vector of estimated coefficients $\underline{\widehat{\theta}}$ follows a Normal distribution $\underline{\widehat{\theta}}\tilde{}N(\theta,\sigma^2(X'X)^{-1})$, the cumulative coefficient $R\underline{\widehat{\theta}}$ follows a distribution $R\underline{\widehat{\theta}}\tilde{}N(R\theta,R\sigma^2(X'X)^{-1}R')$. R is a vector of one and zeros that picks the relevant category of news.

on the FTSE 100 futures, its initial impact on the FTSE 100 returns is $\theta_{up,0} = 0.718$. Positive announcements have a large and persistent effect not only on the FTSE contracts, but also on the Eurostoxx 50 ($\theta_{up,0} = 0.438$) and DAX ($\theta_{up,0} = 0.456$) indexes futures. Buckle, Gwilym, Thomas and Woodhams (1998) also study the effects of British news on the FTSE 100 future contracts. They include dummy variables to take news into account. Using five minute windows, their empirical analysis shows that none of the dummy variables turn out to be significant, which suggests that news does not affect the mean returns. On the contrary, our results indicate that British news does have an effect on stock prices but that the price adjustment to news takes less than five minutes. Regarding the timing of the adjustment, our results are in line with those of Clare and Courtenay (2001). For the FTSE contracts, they also illustrate that the mean returns peak in the first minute following the British announcements and then they decline sharply.

With regards to Euro-Zone news, as far as we know, no research has analysed its effects on stock prices. Our results suggest that Euro-Zone announcements have a larger explanatory power than news emanating from other countries on the Eurostoxx 50 futures price movements. Interestingly, we also find that Euro-Zone news immediately affects in a significant way the DAX ($\theta_{ep,0} = 0.549$ and $\theta_{en,0} = -0.952$) and the FTSE 100 futures returns ($\theta_{ep,0} = 0.247$). Curiously, we also discover that the positive Euro-Zone news has an effect on stock returns of the form ...0,0, +1, -1, +1..., i.e., the stock prices react positively within a minute of the release, there is a rebound after the initial news shock, but this rebound is then reversed. Other authors like Goodhart, Hall, Henry and Pesaran (1993) also document this initial overreaction of stock prices to macroeconomic news. However, it needs to be stressed that the initial effect of the news is always lower than 0.07 percent, the magnitude of this coefficient is not big enough to make systematic profits from the announcement release. Therefore, this finding is not contrary to the efficient market hypothesis.

Remark 4. *Announcement timing matters.*

The use of German announcement data makes it possible to examine a further interesting question: unlike the other announcements, German releases do not have pre-advertised release dates and times. Therefore, it is possible to examine how pre-scheduled announcements affect the response of stock exchanges to news. We would expect that futures returns response to non-scheduled announcements is completed more slowly than the response associated to scheduled releases. Table 4.5 shows that this is the case for positive German news. The markets do not react to news within the first minute of its release but they react one minute later. We may think that international investors wait for the DAX index's reaction and then respond as soon as the DAX index moves. However, the DAX's response to positive German news also peaks one minute after the releases ($\theta_{gp,-1} = 0.333$ *vs.* $\theta_{gp,0} = 0.297$), which indicates that foreign investors react to the news itself and not the DAX's response to the news. In the case of negative German news, a different story emerges and markets respond within a minute of the releases.[8]

Other authors have compared the effects of pre-scheduled versus non pre-scheduled news in the exchange rate DM/USD. Almeida et al. (1998) find longer lags in the exchange rate assimilating German information relative to American information. However, Andersen et al. (2003) illustrate that only a very few German macroeconomic indicators significantly affect the DM/USD exchange rates. They attribute their result to the inexact release time of German macroeconomic indicators; they argue that uncertain releases may result in less market liquidity around announcement times and, hence, less trading associated with announcements. The different results from these articles indicate that there is no clear consensus in the literature about the effect of non pre-scheduled German news on the DM/USD exchange rate. Nevertheless, it is important to point out that these studies analyse the effect of German announcements on exchange rates, not on stock markets.

[8]Due to the fact that the sample used covers only two months of data, our results may be affected by the inclusion (or exclusion) of a particular item of news. The IFO figure is the German news release that has most effect on the stock exchanges. We repeat the analysis excluding this release from the news data series. Results of this estimation are presented in Appendix E.

In general, it does not matter from which country the news emanates, the magnitude of the estimated coefficients is very small in comparison to the effect of foreign market returns. This implies that data on macroeconomic figures affects stock returns on an intra-day basis to a tiny level.

Overall, when the macroeconomic releases are included in our analysis, the news significantly affects not only the domestic futures returns but also the international futures returns. This evidence supports the "public information hypothesis" and demonstrates the importance of economic information in explaining international equity market linkages. Furthermore, we find that the general response of the stock returns to news is very quick, characterised by a jump within the same minute and the minute following the announcement and little movement thereafter. We can conclude that futures markets are efficient when adjusting to new international economic information.

4.7 Effects of News on Stock Market Interdependencies

This section answers the third question addressed in the chapter: do cross market linkages remain the same or do they increase in the minutes following the economic announcements? In other words, do investors follow the FTSE's response to British news or do they respond to the news itself? In the previous section the discussion focussed on how domestic news affects foreign futures returns. In this section we go one step further and we investigate how interactions between domestic and foreign futures returns change around periods when macroeconomic data is released. Subsection 4.7.1 analyses the changes in the lead-lag relationship between futures markets at the time of the announcements. Subsection 4.7.2 focuses on how the contemporaneous correlation between futures markets changes during the announcement periods.

4.7.1 Lead-lag Relationships between Futures Markets at the Time of Releases

To test the impact of macroeconomic releases on the lead-lag relationship between DAX, Eurostoxx 50 and FTSE 100 futures returns, interaction variables $x_i^{ne} * R_i$ are introduced into the system (4.3). These variables assume the value of one if observation t lies within five minutes prior to the news releases or ten minutes after the news releases and zero otherwise. As in the previous section we include ten lags in the new estimation. Table 4.6 reports the estimates of the interaction parameters β^1. The structure of Table 4.6 is exactly the same as that of Table 4.5; the first two columns refer to the DAX equation, the third and fourth column refer to the Eurostoxx 50 equation and the last two columns refer to the FTSE 100 equation. Panel A reports the cumulative coefficient and the F-statistics testing the null hypothesis that the sum of the lagging coefficients is equal to zero. Panel B reports the estimated coefficients $\beta^1_{i,-1}$ to $\beta^1_{i,-3}$ on the interaction variables for each category of news.

Table 4.6: Effects of news on the lead-lag relationship between futures returns

Panel A: Cumulative coefficients and F-statistics

	$R_{DAX,t}$		$R_{Eur,t}$		$R_{FTSE,t}$	
	Coef.	F-Stat.	Coef.	F-Stat.	Coef.	F-Stat.
$\beta^1_{up,-1...-10}$	0.135	1.180	0.076	1.010	-0.066*	1.660
$\beta^1_{un,-1...-10}$	-0.022	1.017	0.127	1.338	-0.010	1.396
$\beta^1_{ep,-1...-10}$	-0.281**	2.212	-0.422***	3.928	-0.195*	1.574
$\beta^1_{en,-1...-10}$	-0.126	1.096	-0.235	1.265	-0.038**	2.260
$\beta^1_{gp,-1...-10}$	-0.005	0.841	0.154*	1.570	-0.221*	1.652
$\beta^1_{gn,-1...-10}$	-0.072	1.165	-0.207	1.155	-0.245	0.437

Table 4.6: Continues. Panel B: Effect of news on stock returns spillovers

	$R_{DAX,t}$		$R_{Eur,t}$		$R_{FTSE,t}$	
	Coef.	Std. Error	Coef.	Std. Error	Coef.	Std. Error
$\beta^1_{up,-1}$	-0.002	0.083	-0.099	0.063		
$\beta^1_{up,-2}$	0.018	0.062	0.041	0.072		
$\beta^1_{up,-3}$	-0.040	0.081	-0.011	0.066		
$\beta^1_{un,-1}$	-0.024	0.081	0.004	0.079		
$\beta^1_{un,-2}$	0.002	0.066	-0.017	0.059		
$\beta^1_{un,-3}$	-0.053	0.068	-0.026	0.061		
$\beta^1_{ep,-1}$	0.068	0.086			0.002	0.063
$\beta^1_{ep,-2}$	0.009	0.095			0.022	0.058
$\beta^1_{ep,-3}$	-0.175	0.121			-0.116	0.080
$\beta^1_{en,-1}$	-0.029	0.103			0.066	0.047
$\beta^1_{en,-2}$	-0.017	0.083			-0.084	0.054
$\beta^1_{en,-3}$	-0.085	0.060			0.065	0.043
$\beta^1_{gp,-1}$			0.025	0.067	-0.052	0.048
$\beta^1_{gp,-2}$			-0.011	0.068	-0.024	0.044
$\beta^1_{gp,-3}$			-0.003	0.067	-0.074	0.046
$\beta^1_{gn,-1}$			-0.076	0.080	-0.047	0.057
$\beta^1_{gn,-2}$			-0.027	0.077	-0.077	0.066
$\beta^1_{gn,-3}$			-0.121	0.077	-0.071	0.050

Notes: parameter estimates from regression (4.3)

$$R_{j,t}= \alpha_j+\sum_{j=1}^{3}\sum_{\tau=1}^{K}(\beta^0_{j,\tau}+\beta^1_{j,\tau}x^{ne}_t)R_{j,t-\tau}+u_{j,t}$$

HAC consistent standard errors are reported. *,** and *** indicate significance at the 10, 5 and 1 percent levels respectively.

Remark 5. *Stock market dynamic interactions do not increase at the time of the release of economic news.*

Panel A in Table 4.6 shows mixed evidence regarding the effects of macroeconomic news on stock market spillovers. Regarding British news, the sum of the lagging interaction variable coefficient is insignificant in most instances. The F-Statistic does not reject the null hypothesis that the sum of the lagging coefficients on the interaction variables is equal to zero at 10 percent level. This implies that there are no significant changes in the lead-lag relationship between the FTSE 100 and the continental European futures at the time of British economic news releases.

Regarding the continental European news, several interesting patterns of market return co-movements emerge. First, for the FTSE 100 equation the sum of the lagging interaction variable coefficients is negative and significant for the Euro-Zone news ($\beta^1_{ep,-1\ldots-10} = -0.195$ and $\beta^1_{en,-1\ldots-10} = -0.038$) and the positive German releases ($\beta^1_{gp,-1\ldots-10} = -0.221$). This evidence implies that the lead of the Eurostoxx 50 futures over the FTSE 100 weakens around the time of Euro-Zone economic releases. Similarly, the lead of the DAX futures over the FTSE 100 returns weakens around the time of positive German news releases. This evidence suggests that British investors do not take into consideration the response of continental European investors to European news, at least in the next ten minutes following the releases. Second, the feedback of the Eurostoxx 50 returns to the DAX market also weakens around the release of positive Euro-Zone information ($\beta^1_{ep,-1\ldots-10} = -0.281$ and significant). Third, the lead of DAX returns over Eurostoxx 50 strengthens following the release of positive German news ($\beta^1_{gp,-1\ldots-10} = 0.154$ and significant). Finally, the rest of the cumulative coefficients are not significant, which shows no evidence of meaningful changes in the lead-lag relationship of the futures markets around the time of economic news releases.

Table 4.6 Panel B reports further evidence of the changes in the lead-lag returns relationship at the time of the economic releases. The individual lagged coefficients $\beta^1_{i,-1}$ to $\beta^1_{i,-2}$ are presented for each category of news. None of the individual estimated coefficients reported in this part of the table turn out to be significant at the 10 percent level.[9] Nevertheless, the negative signs of most of the coefficients confirm the previous result that the lead of the domestic market does not strengthen during periods when domestic economic news is released.

Remark 6. *Foreign investors react to the content of the news itself more than to the response of the domestic market to the national news.*

In Section 4.6 we concluded that domestic news affects foreign futures returns. Section 4.7 provides some evidence of a weakening in the lead of the domestic returns at the time of national macroeconomic news releases. If both findings are pooled together they suggest that in the short-term international investors do not wait to see the response of domestic markets to local news, but directly react to the information contained in the news itself.

4.7.2 Contemporaneous Cross-Correlations at the Time of Releases

Further analysis to study how the stock market interactions change at the time of the announcement periods is presented in this subsection. Table 4.7 presents changes in the contemporaneous correlations around announcement minutes. Panel A presents the contemporaneous correlation coefficients for the pairs FTSE-DAX and FTSE-Eurostoxx at about the time of the British announcement minutes.[10] The coefficient $\rho_{u,before}$ depicts the contemporaneous correlation between the pairs FTSE-DAX (column one) and FTSE-Eurostoxx (column two) five minutes before the news is released. Similarly, the coefficient $\rho_{u,after}$ describes the returns' contemporaneous correlation in the five minutes after the announcements are released. Additionally,

[9]We repeat the estimation allowing the interaction variable to afect foreign returns up to thirty minutes. Neither the qualitative results nor the conclusions are altered. All the coefficients not reported in Table 4.6 are not significant.

[10]Note that in this table no distinction is made between positive and negative news.

minute by minute contemporaneous correlation is also reported in this table. For instance, the coefficient $\rho_{u,0}$ describes the contemporaneous correlation in the exact minute the news is released. Similarly, the coefficient $\rho_{u,+1}$ is the contemporaneous correlation one minute before British releases and the coefficient $\rho_{u,-2}$ depicts the contemporaneous correlation two minutes after the British announcements. Table 4.7 Panel B presents the changes on contemporaneous correlations around Euro-Zone releases and Panel C presents the changes around German releases.

Remark 7. *Contemporaneous correlation between futures returns changes at the time of macroeconomic releases.*

Before examining the results in Table 4.7 we report the contemporaneous correlation between futures returns when there are no macroeconomic announcement releases: $\rho^n = 0.432$ for the pair FTSE-DAX, $\rho^n = 0.412$ for the pair FTSE-Eurostoxx and $\rho^n = 0.748$ between the DAX and the Eurostoxx 50 returns. Next, the salient feature in Table 4.7 Panel A is a significant increase in the contemporaneous correlation between the futures returns on the five minutes following the announcement. Specifically, the contemporaneous correlation increases from $\rho_{u,before} = 0.452$ to $\rho_{u,after} = 0.492$ for the pair FTSE-DAX and from $\rho_{u,before} = 0.315$ to $\rho_{u,after} = 0.7539$ for the pair FTSE-Eurostoxx. Having a closer look to the minute by minute return cross-correlation, we observe that the main increase in the contemporaneous correlation between the FTSE 100 and the continental European returns is not the minute when the news is released, but one minute before the announcements. The high co-movements one minute before the announcement ($\rho_{u,+1} = 0.776$ *vs.* $\rho^n = 0.432$ for the FTSE-DAX pair and $\rho_{u,+1} = 0.777$ *vs.* $\rho^n = 0.412$ for the FTSE-Eurostoxx pair) are due to the fact that British news is pre-scheduled, namely that all market participants know the exact minute in which the news is made public. One minute before the news releases investors do not trade but they wait for the actual announcement figure, as they know new information is about to arrive onto the market. The lower magnitude of the correlation during the announcement minute ($\rho_{u,0} = 0.459$ for the FTSE-DAX pair and $\rho_{u,0} = 0.505$ for the FTSE-Eurostoxx pair) may be explained by traders having diverging opinions about the impact of news on the direction of the prices and they respond to new information according to their own views. After the initial response, contemporaneous co-movements between the stock markets increase again, when investors extract the "common information" or common reaction of the market to the piece of news. The co-movements between the different stock exchanges remain higher in all the cases, up to twenty minutes after the news is released.

Table 4.7, Panel B displays the change in the contemporaneous correlation coefficients at the time of the Euro-Zone announcement periods. Our results do not show a significant increase in the co-movements between the Eurostoxx 50 and the DAX returns at the release of Euro-Zone news. However, as we pointed in Section 4.3, the contemporaneous correlation between both indices returns is very high for the whole subsample ($\rho = 0.718$), which indicates that these two indices tend to move in a similar way. In contrast, the evidence presented shows that the contemporaneous cross-dependences between the Eurostoxx 50 and the FTSE 100 futures more than double when there is Euro-Zone economic news ($\rho_{e,before} = 0.222$ *vs.* $\rho_{e,after} = 0.565$). The lower correlation between both indices before the announcement releases is due to the time schedule of Euro-Zone news, which is released at 11:00h, period in which the intra-day volatility and the liquidity of both markets is relatively low.

Table 4.7 Panel C characterises the contemporaneous correlation between the DAX and the other stock indices at the time of German news announcements.[11] As with news emanating from other countries, our results show that the contemporaneous correlation between indices returns increases just after the announcement releases ($\rho_{g,before} = 0.710$ *vs.* $\rho_{g,after} = 0.749$ for the pair DAX-Eurostoxx and $\rho_{g,before} = 0.466$ *vs.* $\rho_{g,after} = 0.504$ for the pair DAX-FTSE). When we focus on the minute by minute cross-country correlations, our results show that, in contrast to

[11] In this case, the German news series does not contain the IFO release. Further discussion and the estimation including this figure is presented in Appendix E.

Table 4.7: Contemporaneous cross-market correlations at the time of releases

Panel A: British news is released. Panel B: Euro-Zone news is released.

Panel C: German news is released

Panel A:	$R_{FTSE,t} - R_{DAX,t}$	$R_{FTSE,t} - R_{Eur,t}$
$\rho_{u,before}$	0.452	0.315
$\rho_{u,after}$	0.492	0.539
$\rho_{u,+1}$	0.776	0.777
$\rho_{u,0}$	0.459	0.505
$\rho_{u,-1}$	0.702	0.565
$\rho_{u,-2}$	0.525	0.536
Panel B:	$R_{Eur,t} - R_{DAX,t}$	$R_{Eur,t} - R_{FTSE,t}$
$\rho_{e,before}$	0.733	0.222^b
$\rho_{e,after}$	0.738	0.565
$\rho_{e,+1}$	0.748	0.289
$\rho_{e,0}$	0.584	0.387^b
$\rho_{e,-1}$	0.490	0.303
$\rho_{e,-2}$	0.793	0.181^b
Panel C:	$R_{DAX,t} - R_{Eur,t}$	$R_{DAX,t} - R_{FTSE,t}$
$\rho_{g,before}$	0.710	0.465
$\rho_{g,after}$	0.749	0.504
$\rho_{g,+1}$	0.582	0.381
$\rho_{g,0}$	0.646	0.354
$\rho_{g,-1}$	0.952	0.511
$\rho_{g,-2}$	0.757	0.389

Note: all coefficients are significant at 1 percent level. Only the coefficients with ^{b} are not significant at 1 percent level.

news emanating from other countries, neither in the minutes leading up to the release nor at the time it takes place do the linkages between the DAX and the Eurostoxx 50 increase ($\rho_{g,+1} = 0.582$, $\rho_{g,0} = 0.646$ *vs.* $\rho^n = 0.747$). This result is in line with our expectations as German news does not have pre-set release times and investors do not know the exact minute of the release. Interestingly, the coefficient that depicts the linkages between the DAX and the Eurostoxx 50 one minute after German releases increases to $\rho_{g,-1} = 0.953$, which implies that the bulk of the investors' common reaction to German news takes place in that minute.

4.7.3 Are the Impacts of British, Euro-Zone and German Announcements on Stock Market Co-movements Similar?

In this subsection the results obtained on the effects of British, Euro-Zone and German announcements on stock market co-movements are compared and some general conclusions are presented. The main feature is that the impacts of news emanating from different countries on stock markets are not similar. One main difference is worth noting: stock market interactions at the time of economic releases depend on whether the announcements have a pre-scheduled time, as is the case with British and Euro-Zone releases, or they do not have a pre-set release time, like the German announcements. On the one hand, the general pattern of co-movements when British and Euro-Zone economic data is released is an increase of contemporaneous cross-correlations the minute before the release, a lower correlation during the announcement minute and a new increase in stock market movements one or two minutes after the release. On the other hand, the co-movements between the stock exchanges the minutes prior to German releases do not increase due to the fact that investors do not know that economic data is about to be released.

4.8 Summary and Conclusions

This chapter has explored the short term dynamics between the returns on the DAX, the Eurostoxx 50 and the FTSE 100 futures and the role of public macroeconomic announcements as a source of international equity market linkages. In the first part of the chapter the spillovers between the European stock exchanges were analysed. The second part of the chapter studied the effects of macroeconomic news on stock market spillovers. A better understanding of the transmission mechanism and the market integration when new public information arrives onto the market may provide investors with more efficient strategies to speculate or hedge with stock indices.

The main interesting empirical patterns of international futures' return interactions found in this research are:

- Even though there are clear dynamic interactions between the DAX, the Eurostoxx 50 and the FTSE 100 futures, there are no profit opportunities when trading the futures on these indices. Our empirical analysis on the dynamic interactions between the futures returns does not identify a clear dynamic pattern in which, for instance, the FTSE index leads the futures movements and the continental indices futures follow its movements.

- Domestic macroeconomic surprises significantly affect the domestic and the foreign stock returns in the short-term. The general response of the returns to both, domestic and foreign news, is very quick, characterised by a jump in the same minute of the release and little movement thereafter. This result is consistent with the view that equity market linkages are partially attributable to common reactions to public economic information, namely with the "public information hypothesis".

- Dynamic cross-market linkages between the FTSE 100, the Eurostoxx 50 and the DAX futures do not strengthen at the time of economic announcements. Specifically, the lead of a market does not strengthen around domestic macroeconomic news releases. However, the contemporaneous correlation between the three futures returns increases in the minutes after macroeconomic data is released.

- Finally, the fact that official announcements have pre-scheduled times, as with British and Euro-Zone news announcements, or non pre-scheduled times, like German news releases, affects the short-term stock market interactions around announcement periods.

Overall, our results suggest that domestic investors directly react to the content of foreign news itself, they do not wait and follow the foreign market's response to the news. This evidence supports the "public information hypothesis" as a possible source of international stock market co-movements and demonstrates the importance of public economic information in explaining international equity market linkages. However, we also find that returns co-movements can not be only attributable to common reactions to economic information. The stock market spillovers are much stronger than the reaction of domestic stock returns to foreign economic news.

Generally, our results point out how important is the use of high frequency datasets to analyse and to better understand the dynamic interactions between different stock exchanges. The recent availability of new high frequency datasets from different stock exchanges provides an enormous potential for answering new questions on stock market interdependencies. As shown by the different results reported in this chapter, the information contained in these datasets is very rich.

Chapter 5

Non-Linear Dynamics between the FTSE 100 Cash and Futures Returns

5.1 Introduction

This chapter focuses on dynamic interactions of equity prices among theoretically related assets. In particular, we explore the dynamic spillovers between the minute-by-minute FTSE 100 futures and cash indices and investigate the effects of arbitrage activity on shaping the observed dynamic spillovers.

The cost of carry model is often assumed to describe the non-arbitrage relation between the futures and index prices.[1] From a theoretical perspective, transaction costs and arbitrage activity in stock markets motivate the use of non-linear specifications to model the lead-lag relationship between stock index and its futures markets. However, in the past five years, the introduction of electronic trading systems to replace the traditional floor trading in many markets, for instance, in Germany, U.K., Australia and U.S., has significantly reduced the transaction costs and has acce-

[1] See Brenner and Kronner (1995) and Dwyer, Locke and Yu (1996).

lerated the price discovery process in these markets.[2] As a consequence, we might expect screen trading to have importantly reduced or even eliminated the non-linear dynamics between stock and futures returns induced by the transaction costs. In the case of Australia, Anderson and Vahid (2001) find strong evidence of non-linearities in returns before the electronic trading in the futures market and weaker evidence of non-linearities after the online trading. Their analysis suggests that the automation of the markets has removed the non-linear properties of the basis.

This chapter explores the existence of intra-day non-linearities in the FTSE 100 cash and futures indices during the month of July 2001. We test if the introduction of the electronic trading systems in the London Stock Exchange in 1997 and in the London International Financial Futures and Options Exchange (LIFFE) in 1999 has eliminated the non-linear dynamic relationship in the FTSE 100 markets. Since the introduction of the screen trading in both exchanges, no study has analysed the non-linear dynamics of the FTSE 100 index and futures returns.

Section 5.3 introduces the theoretical cost of carry model that accounts for transaction costs and arbitrage activity and the econometric specification. The empirical analysis in Section 5.5 uses the Tsay (1998) multivariate test statistic applied to one minute frequency data to test the non-linear behaviour of the mispricing error series and of the system that includes the transaction prices of the FTSE 100 futures contract and its index value.

Further, Section 5.6 uses a discrete regime-switching model to examine the intraday dynamics of the basis or mispricing error. In practice, we often see that small deviations from the non-arbitrage relation stated by the cost of carry model are not arbitraged away immediately. This is caused by transaction costs, dividend risks and short-selling restrictions. In reality, what we observe is that the arbitrageurs only enter the market if the deviation from the non-arbitrage relation is sufficiently

[2]See Grunbilchler, Longstaff and Scwartz (1994), Franses, Lucas, Taylor and van Dijk (2000) and Anderson and Vahid (2001) for studies on the ways in which electronic trading might affect the lead-lag relationship between futures and cash prices.

large to compensate for the transaction costs. This implies that there is at least one threshold value which defines the different regimes. In other words, the basis or the mispricing error may follow a non-linear dynamic process. In particular, we assume that it follows a Self Exciting Threshold Autoregressive model. If this is the case, the feasibility of index arbitrage affects the speed of convergence of the basis to its equilibrium value.

Non-linearities in the dynamic behaviour of the basis imply non-linearities in the index and futures returns. Given that both prices are cointegrated, a Threshold Error Correction Specification to characterise the dynamic relation between the FTSE 100 cash and futures indices is estimated in Section 5.7. The model allows for non-linear adjustment processes of the asset prices towards their long-term equilibrium.

This chapter has two main contributions. First, as mentioned before, this is the first study that presents a discrete regime-switching model to analyse the index arbitrage in the FTSE 100 markets after the introduction of electronic trading systems. Second, from an econometric perspective, this study generalises previous models as we use an integrated approach suggested by Tsay (1998) in which the threshold values that define the different regimes are endogenously determined in the model.

The outline of the chapter is as follows. The next section reviews the existing literature on the relation between index futures and cash prices. Section 5.3 introduces the theoretical model of our work and describes the econometric model. Section 5.4 provides details on the dataset used in this study. Section 5.5 contains the empirical results of the non-linearity tests for the basis and the returns. Section 5.6 presents the estimation of the non-linear model for the basis. Section 5.7 elaborates upon the results of the Threshold Error Correction Model. Section 5.8 extends the analysis using different frequency subsamples. Finally, some concluding remarks are given in Section 5.9.

5.2 Related Literature

5.2.1 Stock Price Dynamics and Electronic Trading

With respect to the dynamic interactions between the FTSE 100 stock index and its futures contracts, Abhyankar (1998) provides an extensive survey of the empirical evidence on the lead-lag relationship between cash and futures prices. Additionally, several studies document the lead-lag relationship in the British context, for instance Gwilym, McMilland and Speight (1999) and Gwilym and Buckle (2001), but little work has been done on examining non-linearities in the U.K. markets. As our findings will show that non-linearities are important in explaining the short-term dynamics between the FTSE 100 futures and the cash index, the former studies fail to capture the effects of the arbitrage activity in these markets.

Two studies, as far as we know, study the non-linear intra-day dynamics in the FTSE 100 markets with regime-switching models: Garrett and Taylor (2001) and Franses, Lucas, Taylor and van Dijk (2000). Both studies find strong evidence of non-linearities in the U.K. markets. Garrett et al. (2001) examine the intra-day and interday dynamics of both the level of and changes in the FTSE 100 basis. In particular, they investigate if the first-order autocorrelation in basis changes is a result of arbitrage behaviour or a manifestation of market microstructure effects such as non-trading in the underlying stock index. In their analysis, they apply a Self Exciting Threshold Autoregressive model (SETAR) to the mispricing as it allows the mispricing to behave differently according to whether arbitrage opportunities are present or not. This chapter also analyses the dynamics of the basis using a SETAR specification. We extend Garrett et al. (2001) analysis because we additionally focus on the effects of the arbitrage opportunities on the futures and stock index returns dynamics.

Our work is closely related to Franses et al. (2000). They use a Smooth Transition Error Correction Model to study if the introduction of the new electronic trading system in the London Stock Exchange affected the arbitrage activity in the

U.K. markets. In their econometric specification, the threshold or 'border' between two regimes is not sharp but rather the transition between two regimes is gradual or smooth. We argue that as soon as arbitrage opportunities are present in the markets, arbitrageurs place their trades to take profit of such opportunities. Consequently, in our econometric specification there exists two threshold values that trigger arbitrage and define different regimes instead of the continuum of regimes as they postulate.

With respect to the motivation of this chapter, Grunbichler Longstaff and Schwartz (1994) extensively examine the effect of electronic screen trading on the lead-lag relation between futures and index levels. They highlight that the introduction of electronic trading lowers the trading costs for market participants. They also point out that price information is captured and disseminated more rapidly with screen trading, which accelerates the price discovery process. More recent studies also examine the effects of electronic trading in different markets. For instance, Hasbrouck (2003) analyses the effect of the introduction of the electronically-traded futures contracts in the U.S. equity indexes on price formation. Franses et al. (2000) examine the impact of the introduction of the electronic trading system in the London Stock Exchange on stock price dynamics. Anderson and Vahid (2001) use a very similar analysis to that of Franses et al. (2000) to characterise how the non-linear properties of the returns have changed due to the introduction of the electronic trading system in the Australian Stock Exchange. These last two studies find strong evidence of non-linearities before the introduction of the electronic trading systems and much weaker evidence of non-linearities with on-line trading. They suggest that the automation of markets may remove the non-linear properties of the basis.

Our chapter builds upon this last point. We investigate the existence of non-linearities in electronically trading markets. In particular, we extend Franses et al. (2000) analysis to examine the non-linear dynamic behaviour of the FTSE 100 index and its futures. They explore the non-linear dynamic relationship in the U.K. markets in 1997, at the time of the introduction of the electronic trading system in the London Stock Exchange. After the introduction of the automated trading system in the LIFFE exchange in 1999, we expect that the transaction costs faced by investors in the British markets are even lower. An interesting unanswered question that we investigate in this chapter is whether this further reduction in transaction costs has eliminated the non-linear dynamics between the FTSE 100 cash and futures returns.

5.2.2 Threshold Cointegration Models

With respect to the econometric methodology used in this chapter, threshold cointegration was first introduced by Balke and Fomby (1997) as a feasible means to combine non-linearity and cointegration. The model has generated significant applied interest, including recent applications to Purchasing Power Parity, see for instance Michael, Nobay and Peel (1998), Baum, Karkuolas and Caglayan (2001) and Choudhury, Sarno and Taylor (2002) or to interest rates, see Balke and Wohar (1998). However, the literature that studies non-linearities in stock indices and futures returns is currently small. Authors such as Yadav, Pope and Paudyal (1994), Kofman, Martens and Vorst (1998) and Tsay (1998) analyse the effects of transaction costs on arbitrage activity. Most of these studies estimate regime-switching models for the basis and/or the returns on the U.S. markets.

Initial studies using a threshold cointegration model to characterise the relationship between cash and futures prices had difficulties with the estimation of the system. The complication of the non-linearities comes from the fact that the threshold variable itself is determined by the cointegration vector which in turn must be estimated. To overcome this problem, the early studies such as Yadav et al. (1994) and Martens et al. (1998) employed a two-step estimation procedure: first, they estimated a Self Exciting Threshold Autoregressive specification to model the dynamics of the basis. Second, they used the threshold values of the basis as exogenous variables to define the different regimes for the returns system. Recent developments allow to test for non-linearities in a multivariate context and to estimate the threshold values within the Error Correction model. Such studies include recent work by Tsay (1998) and Hansen and Seo (2001). However, most of the attention has focused on U.S. markets. We apply these methodologies to analyse the intertemporal relations between the cash and derivatives prices in the U.K. markets.

This chapter generalises the work of these previous studies. Applying a more recent approach suggested by Tsay (1998), we optimally calculate the threshold values within the Vector Error Correction specification such that the thresholds and the model are jointly estimated. Furthermore, these former studies used a scatterplot procedure to locate the threshold values, that often required subjective interpretations. Our threshold values are optimally selected based on the Akaike Information Critetion.

5.3 Theoretical Model and Econometric Specification

5.3.1 Theoretical Model: Cost of Carry Model with Transaction Costs

Given the cost of carry model, the basis or the mispricing error is defined as

$$z_t = \ln F_{t,T} - \ln S_t - (r_{t,T} - q_{t,T})(T - t) \tag{5.1}$$

where $F_{t,T}$ is the futures price at time t of a future contract with maturity T. S_t is the index value in period t, $r_{t,T}$ stands for the risk free interest rate for the period $T - t$ and $q_{t,T}$ is the dividend yield on the index.

The introduction of transaction cost in the cost of carry model provides the motivation for non-linearities in the basis. Transaction costs include the bid-offer spread, stamp duty, market commissions and any impact costs which reflect the size of the trade and the liquidity of the markets. For arbitrage to be profitable in equation (5.1), the basis, z_t, must be sufficiently large to offset the transaction costs.

We therefore propose to use a Self Exciting Threshold Autoregressive framework (SETAR) to model the behaviour of the basis with three different regimes. This specification reflects that arbitragers react to a large enough negative mispricing error that was observed d periods in advance, $z_{t-d} \leq c_1$, and they react to a large positive mispricing error, $z_{t-d} > c_2$. In these regimes the deviations of the basis from zero are big enough to offset the transaction costs, c_1 and c_2. When the deviations of the basis are smaller than the transaction costs, $c_1 < z_{t-d} \leq c_2$, there are no arbitrage opportunities. With the above considerations, the SETAR specification for the basis can be written in three different regimes as

$$\begin{aligned} z_t &= \delta^{(1)} + \sum_{i=1}^{I} \alpha_i^{(1)} z_{t-i} + \xi_t^{(1)} \qquad z_{t-d} \leq c_1 \\ z_t &= \delta^{(2)} + \sum_{i=1}^{I} \alpha_i^{(2)} z_{t-i} + \xi_t^{(2)} \qquad c_1 < z_{t-d} \leq c_2 \\ z_t &= \delta^{(3)} + \sum_{i=1}^{I} \alpha_i^{(3)} z_{t-i} + \xi_t^{(3)} \qquad z_{t-d} > c_2 \end{aligned} \tag{5.2}$$

$c_1$and c_2 are the threshold values for the variable z_{t-d} that define the regime switching. We examine the hypothesis that, because of arbitrage, any mean reversion in the basis is stronger in regimes one and three than in the middle regime, i.e., $\alpha_i^{(1)} << \alpha_i^{(2)}$ and $\alpha_i^{(3)} << \alpha_i^{(2)}$.

The arbitrage trade in regime 1 consists of simultaneously buying index futures and short-selling the security index and an arbitrage trade in regime 3 consists of simultaneously buying the security index and selling the index futures.

Finally, note that the threshold variable is z_{t-d} instead of z_t because it takes time for arbitragers to take appropriate positions in the stock and stock index futures contracts. Consequently, we do not expect arbitrage to occur and affect the futures and the stock index in the same minute as when the arbitrage opportunity appears. This threshold lag, d, gives an indication of the speed at which the market responds to deviations from the no-arbitrage relation.

5.3.2 The Econometric Model

The cointegration relationship between the futures and the cash indices documented in the empirical literature implies that an Error Correction Mechanism characterises the relationship between them (Engle and Granger (1987)). In our case, equation (5.2) suggests three regimes to characterise the dynamic relationship between the FTSE 100 index and its futures contracts. If arbitrage activity affects the size of the responses of the futures and index levels to lagged variables and their adjustment process to the long-term equilibrium, the values of the parameters in the Error Correction model will depend on the regimes. Together, the cointegration, the arbitrage opportunities and the transaction costs suggest a Threshold Error Correction Mechanism (TVECM) to model the dynamics of the cash and futures. This means that current futures and index returns are explained by past futures, past index returns and by the deviation from the no-arbitrage relation d periods in advance. The effects of lagged variables, as well as the effect of the mispricing error are in our specification different for each regime. The VECM for each of the three regimes, j, is specified as

$$\begin{aligned}\Delta \ln F_{t,T} &= \phi_{10}^{(j)} + \sum_{i=1}^{p} \phi_{11,i}^{(j)} \Delta \ln F_{t-i,T} + \sum_{i=1}^{p} \phi_{12,i}^{(j)} \Delta \ln S_{t-i} + \beta_1^{(j)} z_{t-d} + \varepsilon_{1,t}^{(j)} \quad (5.3)\\ \Delta \ln S_t &= \phi_{20}^{(j)} + \sum_{i=1}^{p} \phi_{21,i}^{(j)} \Delta \ln F_{t-i,T} + \sum_{i=1}^{p} \phi_{22,i}^{(j)} \Delta \ln S_{t-i} + \beta_2^{(j)} z_{t-d} + \varepsilon_{2,t}^{(j)}\end{aligned}$$

where Δ is the difference operator, $\Delta X_t = X_t - X_{t-1}$, $\beta_1^{(j)}$ and $\beta_2^{(j)}$ are the error correction coefficients and $\varepsilon_t = (\varepsilon_{1,t}, \varepsilon_{2,t})$ are zero mean, serially uncorrelated error terms that can be contemporaneously correlated. As in equation (5.2), the regimes are determined by

$$\begin{aligned} j &= 1 \quad \text{if} \quad z_{t-d} \leqslant c_1 \qquad (5.4)\\ j &= 2 \quad \text{if} \quad c_1 < z_{t-d} \leqslant c_2\\ j &= 3 \quad \text{if} \quad z_{t-d} > c_2 \end{aligned}$$

In this specification, the parameters of the Error Correction Mechanism depend on the level of mispricing. The thresholds are signals for index arbitrage. To test if regime 2 reflects the non-arbitrage band, we can test if the effects of the correction term in this regime are smaller than in the outer regimes. Thus, in equations (5.3) and (5.4) we test $\left|\beta_1^{(1)}\right| > \left|\beta_1^{(2)}\right|$ and $\left|\beta_1^{(3)}\right| > \left|\beta_1^{(2)}\right|$ for the futures equation, and $\left|\beta_2^{(1)}\right| > \left|\beta_2^{(2)}\right|$ and $\left|\beta_2^{(3)}\right| > \left|\beta_2^{(2)}\right|$ for the cash equation. In addition, note that there can be differences in the impact of arbitragers in the lower and upper regimes as the arbitrage strategies are different in both regimes.

Appendix F explains Tsay (1998) procedure to test for non-linearities and presents the estimation strategy.

5.4 Data and Descriptive Statistics

The empirical analysis in this chapter in based on the FTSE 100 stock index. The FTSE 100 index comprises the 100 largest U.K. companies listed on the London Stock Exchange (LSE). The LSE trades between 08:00 am and 16:30h (London time) from Monday to Friday (excluding the public holidays). Stock trading has been fully automated since 1997, when the LSE introduced an electronic trading system (SETS). SETS enables traders to place buy and sell orders for any of the FTSE 100 shares in an electronic order book. These orders are then automatically matched with other orders placed. The futures contracts on the FTSE indices are traded in the London International Financial Futures and Options Exchange (LIFFE). The LIFFE Connect is the automated trading system in the derivatives exchange and was introduced in May 1999. This electronic trading platform also matches orders, disseminates prices and reports trades. Trading in the stock index futures occurs between 08:00 and 17:30h.

The sample period used in this study covers the month of July 2001. The index data are intra-day minute-by-minute snapshots of the FTSE 100 index values obtained from the LIFFE Exchange. The FTSE 100 index value is updated approximately four times a minute. The data is converted to one observation per minute by using the last observation for each minute. Our futures data correspond to the transaction prices of the FTSE 100 futures maturing on 21 September 2001.

The overlapping trading hours for both markets are between 08:00 and 16:30h. However, to avoid anomalies related to the equity spread and the trading volume of the basis at the beginning of the trading day, the first thirty minutes of each day are discarded. Using the remaining observations, the one minute returns for each market are calculated as the difference of the natural log of the prices, i.e., the futures returns equal to $\Delta \ln F_{t,T} = \ln F_{t,T} - \ln F_{t-1,T}$ and the index level returns are equal to $\Delta \ln S_t = \ln S_t - \ln S_{t-1}$. This results in 478 (or less when the trading starts after 08:00h or finishes earlier) returns per day. When stacking several days, overnight returns are removed. Each of our data series contains 10,470 observations.

To calculate the cost of carry, we follow Dwyer, Locke and Yu (1996). First, we subtract daily means from the logarithms of the futures and cash indexes. Demeaning the futures removes any constant in the logarithms of the futures due to the constant part of dividends and interest rates for that day. The difference between the demeaned logarithms of the futures and cash indexes is the deviation of the basis from its daily mean. If dividends and interest rates are relatively constant during the day, this adjusted basis is an estimate of a mispricing series that does not require other explicit assumptions about expected dividend or interest rates. This last point is important as the validity of the mispricing series relies heavily on the use of appropriate ex-ante dividends and interest rates. An alternative would be to use the actual dividends yield on the FTSE 100 index reported by FT Interactive Data. However, they are realised dividends, no expected dividends. Therefore, we prefer to substract the daily means from the series. Henceforth, the mispricing error will be denoted by z_t and we will present the values of the basis as $100 * z_t$ for notational reasons.

It is useful to examine the properties of the basis and the returns prior to modelling their dynamics. Some summary statistics are provided in Table 5.1. In the table, we observe that the futures returns are more volatile and have a higher mean than the cash returns. There is evidence of positive first-order autocorrelation in index returns. As demonstrated by Fisher (1966) and Lo and McKinley (1990), this pattern occurs if stocks in the index trade infrequently. The futures returns exhibit negative first order autocorrelation. A likely explanation is that transaction prices bounce between the bid and ask levels (Glosten and Milgrom (1985)). The mispricing changes also exhibit negative first-order autocorrelation. Taking into account the 'infrequent trading' effect and the 'bid-ask bounce' effect, Miller, Mutshuswamy and Whaley (1994) demonstrated analytically that negative first-order autocorrelation in mispricing changes is likely to occur under quite general conditions. Table 5.1 statistics also show that the basis is more volatile than the futures and cash returns.

Table 5.1: Summary statistics

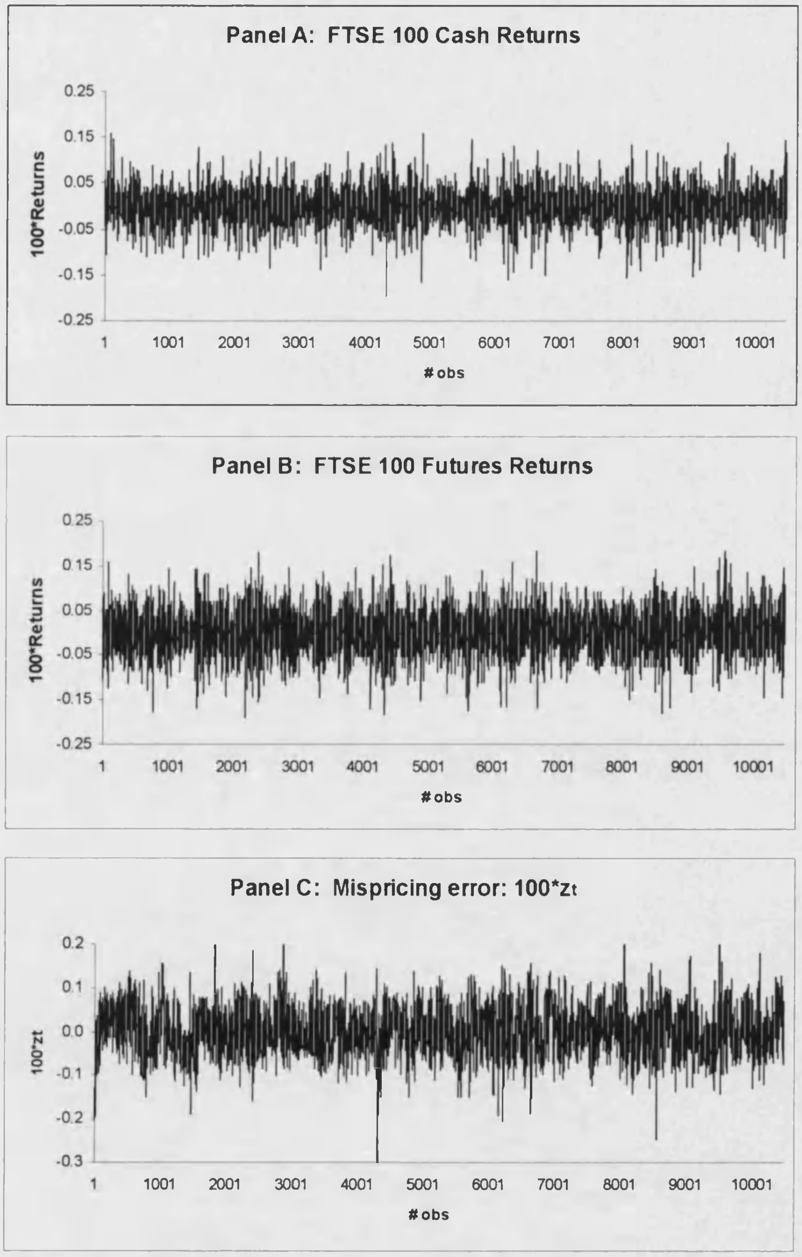
	$\ln F_{t,T}$	$\ln S_t$	$100 * z_t$
Maximum	0.0025	0.0023	0.220
Minimum	-0.0027	-0.0016	-0.300
Mean	$1.1{\cdot}10^{-6}$	$3.7{\cdot}10^{-7}$	$2.7{\cdot}10^{-3}$
Median	0.000	0.000	$3.0{\cdot}10^{-3}$
Std. Dev.	$3.9{\cdot}10^{-4}$	$4.0{\cdot}10^{-4}$	$4.9{\cdot}10^{-4}$
ρ_1	-0.013	0.189	-0.499[a]

Notes: the number of observations for each time series is 10,470. The basis is calculated according to equation (5.1) $z_t = \ln F_{t,T} - \ln S_t - (r_{t,T} - q_{t,T})(T - t)$. ρ_1 is the first order autocorrelation coefficient.

[a] the first order autocorrelation coefficient is calculated for the first differences in the basis.

Additionally, time series plots of one-minute returns of the FTSE 100 futures, the index values and the associated basis are presented in Figure 5.1. We observe that all the series fluctuate around a fixed mean and within a fixed range.

Figure 5.1: Time plots of one minute FTSE 100 index, futures returns and the basis



Remark 1. *Arbitrage activity is of some significance in the FTSE 100 markets.*

To test for non-stationarity, Augmented Dickey Fuller (ADF) tests are performed on the one minute frequency log price series and on the basis.[3] The results of the tests are given on Table 5.2. Panel A shows that both the futures and cash prices have a unit root, namely they are non-stationary, while the returns on these assets are stationary. However, the null hypothesis of a unit root can be rejected at the 1 percent level of significance for the basis equation. This means that the basis is a stationary process rather than a random walk.

Miller et al. (1994) argue that in the absence of arbitrage activity, if index levels and futures prices follow a random walk, then the basis should also follow a random walk. By contrast, if arbitragers exist in the market, then mispricing will be removed within a very short period of time. Consequently, the basis will follow a mean reverting process. Results in Table 5.2, Panel A showing that the basis follows a stationary process suggest that arbitrage activity is of some significance in the FTSE 100 markets.

Possible cointegration between these prices is investigated by applying the Johansen Cointegration test to the futures and index price series. The results of the test are presented in Table 5.2, Panel B. The first part of the table presents the results of the cointegration test between the futures price and the index value. The second part of the table gives the cointegration test between the futures price and the theoretical futures price, i.e., the futures price implied by the cost of carry model. The results in both parts indicate the existence of one cointegration equation at the five percent significant level. In other words, the futures and the index price, adjusted for the cost of carry and without adjusting for it, are cointegrated.

Given that the Johansen Cointegration test does not reject the existence of one cointegration equation, the last row of each part of the table presents the stationary linear combination that exists between the futures and the index prices, namely, the cointegration relation or the Error Correction term. There is some evidence that

[3]In the rest of the paper, we refer to "log prices" as simple "prices" unless stated otherwise.

Table 5.2. Panel A: Augmented Dickey Fuller unit root test

	$\ln F_{t,T}$	$\ln S_t$	z_t	Critical Value 1 percent
ADF Levels	-1.17	-1.13	-18.4	-3.41
ADF Differences	-45.5	-30.1	-21.1	-3.41

Note: the unit root regressions for the futures and index prices contain a constant and 10 lags, while the unit root regression for the basis contains a constant and 4 lags.

Table 5.2. Panel B: Johansen cointegration test

Cointegration between $\ln F_{t,T}$ and $\ln S_t$			
λ_i	Likelihood Ratio	Critical Value 5 percent	H_0
0.0159	172.7	15.41	$r = 0$
0.0002	3.147	3.76	$r \leqslant 1$
EC term:	$\ln F_{t,T} - \underset{(0.003)}{1.053} \ln S_t$	$\ln S_t - \underset{(0.004)}{0.949} \ln F_{t,T}$	
Cointegration between $\ln F_{t,T}$ and $\ln S_t^{(c)}$ adjusted for cost of carry			
λ_i	Likelihood Ratio	Critical Value 5 percent	H_0
0.0388	421.3	15.41	$r = 0$
0.0002	3.144	3.76	$r \leqslant 1$
EC term:	$\ln F_{t,T} - \underset{(0.001)}{1.017} \ln S_t^{(c)}$	$\ln S_t^{(c)} - \underset{(0.001)}{0.983} \ln F_{t,T}$	

Notes: the test is carried assuming that the series have linear trends. λ_i refers to the eigenvalues, the second column displays the Likelihood Ratio test statistic. For each part of the table, the first row tests the hypothesis of no cointegration, the second row tests the hypothesis of one cointegration relation, the third row presents the cointegration vector. Standard errors are reported in parentheses.

the cointegrating vector is not strictly (1,-1). However, if we restrict the vector according to (1,-1) we still find strong evidence of cointegration. To calculate the basis according to the mispricing error equation as defined in (5.1), to facilitate the intepretation of the results and to be consistent with the finance literature analysing the behaviour of the basis, we will use the (1,-1) vector as the cointegration vector in our analysis. In practice, we calculate the basis (or cost of carry) substracting the daily means from the logarithms of the futures and cash indices as explained earlier in this section.

The economic model of the cost of carry describes the relationship between cash and futures prices providing that the term structure of interest rates is flat and constant. The model as described by equation (5.1) also assumes no-arbitrage conditions with no transaction costs. The arbitrage activity behind the cost of carry economic model focusses in a longer term horizon than that used in this study. Equation (5.1) only takes into account dividend yields and risk free interest rates to determine the theoretical price of the futures contracts. There are other microstructure effects that play an important role in shaping the mispricing when working with high frequency data. As Garret and Taylor (2001) demonstrate, the "non-trading effect" (not all stocks in the index will trade during each minute) and the "bid-ask bounce" (observed prices randomly bounce between the bid and the ask prices) play an important role is shaping the dynamics of the high-frequency mispricing. A possible explanation of why we find a cointegration coefficient different from (1,-1) as shown in Table 5.2.B is the exclusion of these specific high-frequency data effects in the specification of the cost of carry in equation (5.1).

5.5 Estimation Results: Tests for Non-linearities

In this section we examine the non-linear behaviour of the FTSE 100 futures and index prices. First, we apply the test described in Appendix F to examine the non-linearities in the behaviour of the basis. Next, we turn to test the non-linearities in the behaviour of the returns.

5.5.1 Non-linearity Test for the Basis

We start by testing the SETAR behaviour for the basis, z_t. We examine the hypothesis that the basis follows a linear AR(I) process against the alternative hypothesis that the basis follows a non-linear model.

We start selecting the AR order I for the basis. Following Martens et al. (1998) we use the partial autocorrelation function of z_t and we choose the lag order for the basis $I = 4$.

Next, we choose the set D of possible threshold lags. We assume that $d \in D$ can be chosen by practical experience. The electronic trading system in the LSE allows the possibility of simultaneous trading in both index and futures markets. Therefore, we expect the arbitrage opportunities to be observed almost immediately and we use $d \in \{1, 2, 3, 4, 5\}$.[4]

Remark 2. *The results of the linearity test for the basis point out that a discrete regime-switching model is a sensible representation of the dynamic behaviour of the basis.*

Table 5.3, Panel A presents the results of the test statistic $C(d)$ in equation (F.3). We test the null hypothesis that the basis follows a linear AR(4) process, so that the model in equation (5.2) reduces to a univariate model. The test statistic follows an asymptotic chi-square distribution with 5 degrees of freedom, the p-values of the test-statistic are also presented in the table. The recursive estimation starts with $m_0 = 250$, which is about $2.5\sqrt{10,470}$.[5]

[4]Notice that minute-by-minute transaction prices are used. $d \in \{1, 2, 3, 4, 5\}$ indicates that any arbitrage trading order is executed within five minutes.

[5]The choice of m_0 is explained in Tsay (1998). Small m_0 may introduce bias in the empirical distribution of $C(d)$. He suggests a starting value for the recursive autoregression around $2.5\sqrt{N}$, where N is the total number of observations.

The results of the tests in Table 5.3 show that p-values are close to zero for the threshold lags $d = 1, 2$ and 3 and thus, the tests reject linearity for these lags. Moreover, the maximum value of the test statistic corresponds to $d = 1$, indicating that 1 is the optimal delay for the threshold variable. These results point out that a SETAR model like the one suggested in equation (5.2) is a sensible representation of the behaviour of the basis.

We want to point that the results of an ARCH test performed on the residuals from the estimated models indicated that there is significant heteroskedasticity present. Therefore, White heteroskedasticity consistent standard errors are presented in the estimations and the tests of this chapter.

5.5.2 Non-linearity Test for the Returns

Non-linearities in the basis require a TVECM to model the behaviour of the futures and index returns. As a consequence, when applying the linearity test to the system $y_t = \{\Delta \ln F_{t,T}, \Delta \ln S_t\}$ in equation (F.1), we expect that the test rejects linearity and that the threshold variable is the same as the one found in the previous subsection for the basis, i.e., $d = 1$.

For the linear Error Correction representation, we choose a lag-length $p = 9$ based on the significant coefficients at the 10 percent level. This long lag structure provides a broader picture of the lead-lag relationship between the futures and the index returns. As in the previous subsection, $d \in \{1, 2, 3, 4, 5\}$ is used as the possible set of values for d.

Remark 3. *The linearity tests are rejected for the returns series, suggesting a non-linear cointegration model for the returns.*

Table 5.3, Panel B presents the test results of the multivariate linearity test applied to the futures and index returns. The null hypothesis is that the return series are linear, so that model in equations (5.3) and (5.4) reduces to a bi-variate linear Vector Error Correction model. The alternative hypothesis is that the return series present non-linear patterns. The test statistic $C(d)$ from equation (F.3) is carried out with $p = 9$ and $d \in \{1,2,3,4,5\}$. The $C(d)$ follows a chi-square distribution with 40 degrees of freedom.

The results of the test reject linearity more clearly for the returns' system than for the basis equation. Consequently, our results point to a non-linear specification for the behaviour of the futures and index returns. Furthermore, the test statistic $C(d)$ reaches its maximum value when $d = 1$, which also confirms that the optimal threshold variable is z_{t-1}.

Table 5.3: Non-linearity tests, $C(d)$

Panel A: $C(d)$ tests H_0: "z_t follows a linear AR(4)" against H_1: "z_t is non-linear"

$d=$	1	2	3	4	5
$C(d)\tilde{}\chi^2(5)$	23.07	15.37	13.77	9.243	8.810
$p-value$	**0.000**	0.008	0.017	0.099	0.117

Panel B: $C(d)$ tests H_0: "$y_t = \{\Delta \ln F_{t,T}, \Delta \ln S_t\}$ follows a linear VECM(9)" against H_1: "y_t is non-linear"

$d=$	1	2	3	4	5
$C(d)\tilde{}\ \chi^2(40)$	94.21	74.40	64.90	44.13	46.96
$p-value$	**0.000**	0.000	0.008	0.301	0.209

Notes: the sample size is 10,470 and the starting point of the recursive least squares is 250. Tests present heterokedasticity consistent results.

5.6 The Dynamics of the Basis

5.6.1 Estimation Results

In this section we estimate the implied SETAR model for the basis described in equation (5.2) with three different regimes. As pointed out in the Appendix F, given the complicated nature of the non-linearity, we use a two stage estimation process. The first stage involves a grid search to locate the threshold values c_1 and c_2. Second, we estimate the implied SETAR model taken c_1 and c_2 as fixed parameters in the estimation.[6]

Based on the empirical range of z_{t-1}, we assume that the candidates for the threshold values are $c_1 \in [-0.078, -0.041]$ and $c_2 \in [0.038, 0.082]$.[7] The minimum value for c_1 and the maximum value for c_2 are chosen such that there are at least 500 observations, approximately 5 percent of the total observations, included in the outer regimes. Using a grid search of 300 points on each of the intervals, the minimum Akaike Information Criterion (AIC) selects $\widehat{c}_1 = -0.060$ and $\widehat{c}_2 = 0.049$, which correspond to the values that trigger the arbitrage. Such values leave 1,003 observations in the lower regime, 7,600 observations in the middle regime and 1,867 observations in the upper regime. The minimum AIC is $-166,087$.

Our optimal threshold values indicate that the non-arbitrage range lies between -6.0 and 4.9 basis points. These estimated values of the transaction costs are very low if we compare them with the results of previous studies.[8] Several points are worth noting. First, the small magnitude of the transaction costs is consistent with

[6]We want to thank Dick van Dijk for sharing his GAUSS codes. The procedures to compute the estimates for the SETAR model and to compute the Generalised Impulse Response functions can be downloaded from: *http://www.few.eur.nl/few/people/dvandijk.*

[7]Note that the selection of I and d beforehand dramatically reduces the state space of the grid search to choose c_1 and c_2.

[8]Garrett and Taylor (2001) analyse FTSE 100 data from the period January to April 1998 and they find that the symmetric transaction costs for the markets during 12:00 to 16:00h is 26.23 basis points.

the fact that the electronic trading system has significantly reduced the magnitude of the transaction costs that investors face. Second, as the FTSE 100 markets are among the most liquid markets in Europe, we do not expect to find large bid-ask spreads in these markets.[9] Finally, Deutsche Bank's mispricing estimates for the month of July 2001 range between -1.3 and 12.7 basis points, which also points to very small deviations of the basis from its equilibrium value.[10]

Remark 4. *The mispricing presents stronger mean-reversion to the cost of carry in the regimes where arbitrage is presumably profitable.*

We turn next to present the estimates the SETAR model for the basis as stated in system (5.2). Table 5.4 displays the results of the AR(4) estimation for each regime. The results show strong support for the notion that the basis follows a different process depending on whether arbitrage opportunities are present. The estimates of the coefficients $\alpha_1^{(j)}$ corresponding to z_{t-1} are $0.490, 0.615$ and 0.436 for regimes $j = 1, 2$ and 3 respectively: the further the mispricing is away from the equilibrium, the stronger is its reversion back to the theoretical cost of carry level. There is statistical difference between $\alpha_1^{(1)} = 0.490$ and $\alpha_1^{(2)} = 0.615$ ($Chi-square = 2.31, probability = 0.126$). [11] This fitted model confirms the expectations that z_t has stronger mean-reverting tendency in the outer regimes, where arbitrage is presumably possible. This result indicates that, as soon as arbitrage opportunities are observable, the arbitrageurs enter the market to take advantage of such opportunities. In other words, the U.K. markets respond to deviations from the non-arbitrage relation in just a few minutes.

However, when comparing the mean reversion coefficients between regimes 1 and 3, the coefficients $\alpha_1^{(1)} = 0.490$ and $\alpha_1^{(3)} = 0.436$ are not statistically different

[9]The fact that institutional investors trade within the spread and they do not pay stamp duty justifies the small magnitude of the threshold values

[10]Source: "Deutsche Bank Portfolio, Index and Futures Research". Deutsche Bank Derivatives Research Group produces a daily Global Fair Value sheet for European Futures.

[11]The changes in the dynamic pattern of z_t are robust to different threshold values in the neighbourhood of $\widehat{c}_1$ and $\widehat{c}_2$.

$(Chi-square = 32.23, probability = 0.000)$, which indicates that the mean reversion is not stronger in one of the outer regimes than in the other.

Table 5.4: Self Exciting Threshold Autoregressive model for the basis

	Regime 1		Regime 2		Regime 3	
	$z_{t-1} \leq -0.060$		$-0.060 < z_{t-1} \leq 0.049$		$z_{t-1} > 0.049$	
	Coef.	Std. Error	Coef.	Std. Error	Coef.	Std. Erro
z_{t-1}	**0.490*****	0.066	**0.615*****	0.017	**0.436*****	0.046
z_{t-2}	0.046	0.044	0.090***	0.015	0.095***	0.032
z_{t-3}	0.104**	0.043	0.023	0.014	−0.013	0.031
z_{t-4}	0.113***	0.039	0.055***	0.012	0.107***	0.026
$\delta^{(j)}$	$-2.8 \cdot 10^{-5}$	$5.1 \cdot 10^{-5}$	$1.1 \cdot 10^{-5,***}$	$3.8 \cdot 10^{-6}$	$1.2 \cdot 10^{-4,***}$	$3.3 \cdot 10^{-5}$
$\widehat{\sigma}^{2,(j)}$	$4.1 \cdot 10^{-4}$		$3.5 \cdot 10^{-4}$		$3.7 \cdot 10^{-4}$	
$R^2(\%)$	18.1		27.8		11.1	

Notes: the model estimated is given in equation (5.2):

$$z_t = \delta^{(j)} + \sum_{i=1}^{I} \alpha_i^{(j)} z_{t-i} + \xi_t^{(j)} \qquad c_{j-1} < z_{t-1} \leqslant c_j$$

where j=1,2,3 and the threshold lag equals to 1. The optimal threshold values are $\widehat{c}_1$=-0.060 and $\widehat{c}_2$=0.049, which define the three regimes.

Number of observations is 1,003, 7,600 and 1,867 in regimes 1, 2 and 3 respectively.

White heteroskedasticity consistent standard errors are given. $\widehat{\sigma}^{2,(j)}$ is the sum of squared residuals in the regression.

*,** and *** stand for significance at 10, 5 and 1 percent levels respectively.

To further analyse the behaviour of the basis, there are two interpretations in the literature of why the basis may be mean reverting. The first is that it reflects the effects of arbitrage. Authors like Garrett et el. (2001) and Martens et al. (1998) defend that if prices follow a random walk, then in the absence of arbitrage activity, mispricing should also follow a random walk. Thus, mispricing will persist indefinitely. By contrast, if arbitrageurs exist in the market, then the mispricing will be removed within a very short period of time. A second interpretation concerns the infrequent trading effect on the index. For example, Miller et al. (1994) investigate the mean-reversion of the S&P 500 index basis changes and conclude that infrequent trading causes this mean reversion in most cases. It is obvious that due to transaction costs, arbitrageurs will only cause the mean-reversion when the deviation is large. For smaller deviations, the infrequent trading in the index will, however, be effective. To further investigate the mean reversion of the basis in each of the regimes, we run a Dickey Fulley type regression test applied to each of the subsamples. In particular, we run the following regression for the subsample of regimes 1, 2 and 3 and we test if $\beta_1 = 0$.

$$\Delta z_t = \beta_0 + \beta_1 z_{t-1} + u_t$$

The results of this regression are presented in Table 5.5. The test statistic of β_1 is different from zero, indicating that the null hypothesis of a unit root can be rejected in the three regimes. This implies that the basis is also mean reverting in regime 2 and thus, the mispricing does not persist indefinitely in this regime. Our results are in line with Miller et al. (1994) and indicate that infrequent trading in the index may cause the mean reversion in the middle regime. Our results in Table 5.5 capture both effects, arbitrage activity and infrequent trading.

Another possible explanation for the finding that the basis does not follow a random walk in the middle regime may be that our threshold cut offs are wrong. As authors like Taylor et al. (2000) state, our model allows a very limited number of different regimes and transaction costs and thus, our results heavily rely on the fact that these threshold values are correctly chosen. To account for a more realistic representation of the heterogeneity of the investors that each face different transaction costs, Taylor et al. (2000) suggest a Smooth Transition Error Correction Model. It would be interesting to investigate the mean reversion of the basis with this kind of model and to further analyse if the mean reversion we find is due to infrequent trading effects or to the fact that our thresholds are not correctly chosen.

Table 5.5: Dickey Fulley regression for each subsample

Independent variable: Δz_t

	Coefficient	Std. Error	Regime
β_0	$-2.8 \cdot 10^{-6}$	$2.3 \cdot 10^{-6}$	Regime 1:
β_1	-0.488^{***}	0.213	$z_{t-1} \leq -0.060$
β_0	$1.2 \cdot 10^{-5,***}$	$4.0 \cdot 10^{-6}$	Regime 2:
β_1	-0.281^{***}	0.014	$-0.060 < z_{t-1} \leq 0.049$
β_0	$7.6 \cdot 10^{-6}$	$7.2 \cdot 10^{-6}$	Regime 3:
β_1	-0.583^{***}	0.325	$z_{t-1} > 0.049$

Notes: Dickey Fuller type regression applied to regimes 1, 2 and 3 respectively. *** indicates significance at 1 percent level.

5.6.2 Non-linear Impulse Response Functions

To further evaluate the dynamic properties of the estimated regime switching model for the basis, we analyse its Impulse Response Functions. These functions examine the effects of shocks ξ_t on the evolution of the time series z_t.[12]

[12] As noted by Koop, Pesaran and Potter (1996), non-linear models produce impulse response functions that depend on the sign and size of the shock, as well as on the history of the time series. They introduce the Generalised Impulse Response Function (GIRF) which provides a solution to the problems involved in defining impulse responses in nonlinear models. The GIRF for an arbitrary impulse $\xi_t = \delta$ and a history w_{t-1} is defined as

$$GIRF_z(h, \delta, w_{t-1}) = E[z_{t+h}|\xi_t = \delta, w_{t-1}] - E[z_{t+h}|w_{t-1}] \tag{5.5}$$

The Generalised Impulse Response Functions are illustrated in Figure 5.2. A shock of size ±1 percent and ±2 percent is introduced in date $t = 0$. The graphs are just a representative example of many possible impulse response functions depending on the history. Panel A plots the impulse response function after a shock in regime 1. Panel B depicts the response after a shock in regime 2 and Panel C draws the adjustment path after a shock in regime 3. Even though the effects of all shocks almost disappear within ten minutes of the introduction of the shock, we observe that the degree of persistence of the shocks is higher in regime 2, within the non-arbitrage band, than in regimes 1 and 3. This result confirms the finding that the further the mispricing error is away from its equilibrium, the stronger is the reversion back to its equilibrium due to the activity of the arbitrageurs.

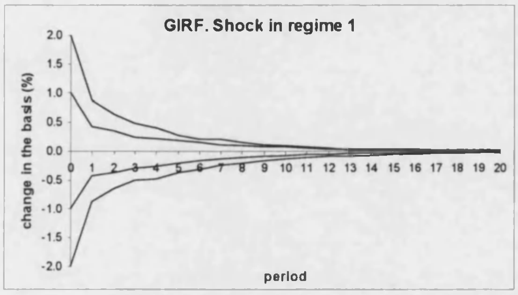
Panels A, B and C plot that the system remains in the same regime after a shock. This is not the case in Panel D, where an example of non-linear behaviour is illustrated. The negative shock implies a switch in regime, in particular, it moves the system form regime 3 into regime 2. Thus, the GIRF is also affected by the difference between the parameter estimates in regimes 3 and 2 explaining the rapid increase to zero and negative values after the shock.

Overall, we can conclude that, even with a narrow arbitrage band, our SETAR estimates and the Impulse Response Functions support evidence of non-linearities in the dynamic behaviour of the mispricing error.

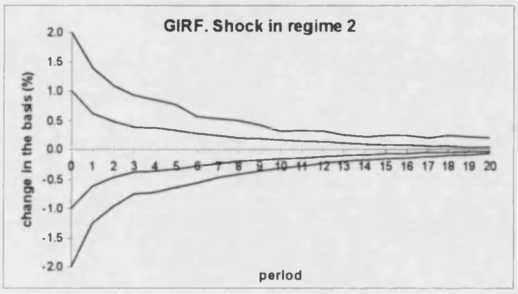
Unlike linear models, this expected response to shocks can not be derived analytically and is therefore derived by averaging over many simulated response paths.

Figure 5.2: Generalised Impulse Response Functions for the basis

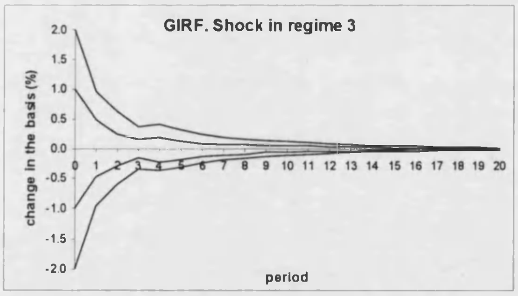
Panel A: observation t=5,545. History (t-4,...,t) = -0.007, 0.022, -0.003, -0.012, -0.082



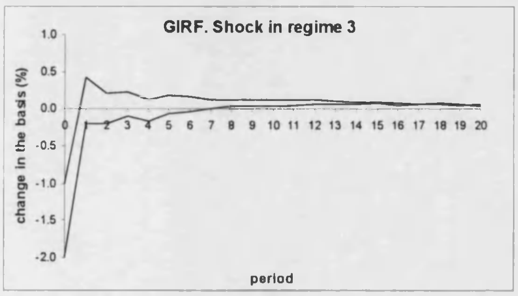
Panel B: observation t=6,029. History (t-4,...,t) = -0.094, -0.016, -0.029, 0.014, 0.016



Panel C: observation t=1,020. History (t-4,...,t) = 0.074, 0.101, 0.101, 0.051, 0.158



Panel D: observation t=7,687. History (t-4,...,t) = -0.007, 0.016, 0.038, 0.033, 0.055



5.7 The Dynamics of the Futures and Cash Indices

In this section we estimate a Threshold Error Correction Mechanism (TVECM) to characterise the non-linear dynamic dependence between the FTSE 100 cash and futures returns described in equations (5.3) and (5.4).

As in the previous section, we start with searching the threshold values. The threshold candidates are assumed to be in the intervals $c_1 \in [-0.078, -0.041]$ and $c_2 \in [0.038, 0.082]$. Using a grid search of 300 points in these intervals, the minimum AIC provides $\widehat{c}_1 = -0.057$ and $\widehat{c}_2 = 0.059$, with the minimum AIC equal to $-346,436$. These values leave 1,134 observations in the lower regime, 7,844 observations in the middle regime and 1,491 observations in the upper regime. These selected optimal threshold values are consistent with those obtained for the basis.

Given z_{t-1} and the three regimes defined by $\widehat{c}_1$ and $\widehat{c}_2$, we estimate the conditional Error Correction Model for each regime. The lag-length in each regime and for each equation is based on significant coefficients, at the 10 percent level, with a minimum of one lag. The results of the estimation are presented in Table 5.6.

Remark 5. *The lead-lag relationship between the FTSE 100 cash index and its futures depends on arbitrage activity.*

The main feature in Table 5.6 is the difference in the estimated coefficients for the three regimes.

Panel B in Table 5.6 displays the coefficient estimates of the cash equation, $\Delta \ln S_t$. The results show that the Error Correction term is statistically significant in all the regimes, $\beta_2^{(j)} = 0.181, 0.099$ and 0.222 in regimes $j = 1, 2$ and 3 respectively. The magnitude of this coefficient is approximately twice as large in regimes 1 and 3 as in regime 2. This increase in the dependence on the Error Correction term on regimes 1 and 3 reflects that the index prices immediately react to departures of the mispricing error from its non-arbitrage band. In addition, we observe that the lag dependence of the cash returns to its own returns and to the futures returns tends to be lower in regime 2, $\phi_{21,i}^{(2)} < \phi_{21,i}^{(1)}, \phi_{21,i}^{(2)} < \phi_{21,i}^{(3)}$ and $\phi_{22,i}^{(2)} < \phi_{22,i}^{(1)}, \phi_{22,i}^{(2)} < \phi_{22,i}^{(3)}$. In particular, the coefficient $\phi_{21,1}^{(j)}$ corresponding to $\Delta \ln F_{t-1,T}$ increases from 0.191 in regime 2 to 0.273 and 0.269 in regimes 1 and 3 respectively. This evidence suggests that the cash index adjusts more quickly to the future market movements when arbitrage opportunities are available in the market.

Panel A in Table 5.6 displays the coefficient estimates of the futures equation $\Delta \ln F_{t,T}$. A completely different story comes out from the results. First, the error correction coefficient is not significant in regimes 1 and 3, $\beta_2^{(j)} = -0.042, -0.054$ and -0.069 in regimes $j = 1, 2$ and 3 respectively. Besides, the futures returns do not depend on past futures returns in regimes 1 and 3 as the estimates of $\phi_{11}^{(1)}$ and $\phi_{11}^{(3)}$ are not statistically significant.

Table 5.6: Threshold Error Correction Model for the returns

	Regime 1		Regime 2		Regime 3	
	$z_{t-1} \leq -0.057$		$-0.057 < z_{t-1} \leq 0.059$		$0.059 < z_{t-1}$	
	Coef.	Std. Error	Coef.	Std. Error	Coef.	Std. Erro
Futures equation, $\Delta \ln F_{t,T}$:						
z_{t-1}	-0.042	0.070	-0.054^{***}	0.015	-0.069	0.065
$\Delta \ln F_{t-1,T}$	0.013	0.050	-0.045^{***}	0.015	-0.019	0.038
$\Delta \ln S_{t-1}$	0.153^{***}	0.059	0.163^{***}	0.018	0.115^{***}	0.043
Constant	$3.6 \cdot 10^{-5}$	$5.3 \cdot 10^{-5}$	$6.1 \cdot 10^{-6}$	$4.2 \cdot 10^{-6}$	$-8.5 \cdot 10^{-5}$	$4.9 \cdot 10^{-5}$
Adj. $R^2(\%)$	1.51		1.50		0.65	

Notes: the estimated TVECM is given in equations (5.3) and (5.4). The lag-length in each regime and for each equation is based on significant coefficients.

Number of observations is 1,134, 7,845 and 1,491 in regimes 1, 2 and 3 respectively.

The White heteroskedasticity consistent standard errors are reported in the parenthesis.*, ** and *** stand for significance at 10, 5 and 1 percent levels respectively.

Table 5.6: Continues. Threshold Error Correction Model for the returns

	Regime 1		Regime 2		Regime 3	
	$z_{t-1} \leq -0.057$		$-0.057 < z_{t-1} \leq 0.059$		$0.059 < z_{t-1}$	
	Coef.	Std. Error	Coef.	Std. Error	Coef.	Std.
Cash equation, $\Delta \ln S_t$:						
z_{t-1}	0.181***	0.051	0.099***	0.012	0.222***	0.0
$\Delta \ln F_{t-1,T}$	0.273***	0.034	0.191***	0.012	0.269***	0.0
$\Delta \ln F_{t-2,T}$	0.187***	0.034	0.167***	0.012	0.188***	0.0
$\Delta \ln F_{t-3,T}$	0.081**	0.032	0.129***	0.011	0.116***	0.0
$\Delta \ln F_{t-4,T}$	0.050*	0.027	0.104***	0.011	0.118***	0.0
$\Delta \ln F_{t-5,T}$	0.094***	0.024	0.084***	0.011	0.092***	0.0
$\Delta \ln F_{t-6,T}$			0.068***	0.011	0.087***	0.0
$\Delta \ln F_{t-7,T}$			0.051***	0.010	0.053**	0.0
$\Delta \ln F_{t-8,T}$			0.032***	0.010		
$\Delta \ln F_{t-9,T}$			0.025***	0.009		
$\Delta \ln S_{t-1}$	−0.099**	0.043	−0.094***	0.015	−0.137***	0.0
$\Delta \ln S_{t-2}$	−0.055	0.043	−0.105***	0.015	−0.048	0.0
$\Delta \ln S_{t-3}$	−0.092**	0.045	−0.104***	0.014	−0.089**	0.0
$\Delta \ln S_{t-4}$			−0.086***	0.014	−0.113***	0.0
$\Delta \ln S_{t-5}$			−0.052***	0.014	−0.083**	0.0
$\Delta \ln S_{t-6}$			−0.075***	0.013	−0.052*	0.0
$\Delta \ln S_{t-7}$			−0.029**	0.012		
$\Delta \ln S_{t-8}$			−0.039***	0.012		
Constant	$5.0 \cdot 10^{-5}$	$3.9 \cdot 10^{-5}$	$-2.5 \cdot 10^{-6}$	$2.8 \cdot 10^{-6}$	$-1.0 \cdot 10^{-4,***}$	$3.2 \cdot$
Adj. R^2(%)	15.7		10.8		14.4	

To conclude, our results point out that new information coming into the markets is first impounded in the futures prices. The futures market fixes the value of the mispricing error and the cash market adapts to the futures movements. In this sense, the lead-lag dependence between the FTSE 100 futures and cash markets is best described by the cash equation as described in Panel B.

Finally, we want to describe the main common stylised facts across the regimes in Table 5.6 to compare them with previous linear studies of the lead-lag relationship between derivatives and cash markets in the U.K. First, not surprisingly the error correction term is negative in the futures equation and positive in the stocks equation, i.e., $\beta_1^{(j)} < 0$ and $\beta_2^{(j)} > 0$ for $j = 1, 2, 3$. Only the estimates of the cash equation are statistically significant different from zero. This result indicates that the adjustment of the cash market to a mispricing disequilibrium is very rapid. Second, the index returns depend negatively on their own past returns and positively on the future returns, i.e., $\phi_{21,i}^{(j)} > 0$ and $\phi_{22,i}^{(j)} > 0$ for $j = 1, 2$ and 3. Third, it is apparent that the FTSE 100 futures market generally leads the cash market in all the regimes by 5 to 9 minutes, i.e., $\phi_{21,1}^{(j)}, ..., \phi_{21,5}^{(j)}, ..., \phi_{21,9}^{(2)}$ are statistically significant. Finally, the fitted equations perform better in the cash equation than in the futures equation as the larger adjusted R^2 indicates.

All these results are in line with previous linear studies on the relationship between the FTSE derivatives markets and the cash market; see for instance Gwilym and Buckle (2001) and Abhyankar (1995). All the studies on linear lead-lag relationship in the stock index futures markets state that the index futures returns generally lead the stock index returns with little or no feedback from the cash to the futures markets. As Abhyankar (1998) points out, *"this conclusion is common across many national stock index futures markets"*. A possible explanation for this finding is that informed traders are more likely to trade in stock index futures as a consequence of the leverage and transaction costs benefits offered by these markets and thus, price movements of stock index futures are likely to lead price index movements.[13]

[13]Fleming, Ostdiek and Whaley (1996) demonstrate that the cost of taking a position in a stock

However, as the empirical linear studies do not take into account the transaction costs that define the different regimes, they fail to capture the different behaviour of the dynamic relationship between the FTSE 100 futures and the cash market due to the arbitrage activity in the markets.

In summary, arbitrage activity is of some significance in the FTSE 100 markets. Our evidence indicates that new information is first incorporated in the futures market and then, cash prices react very rapidly to futures price movements. The Threshold Vector Error Correction Mechanism presented in this section contextualises the non-linear adjustment process of the cash prices to the mispricing disequilibrium.

5.8 Robustness Analysis

The analysis presented in this chapter so far has used one minute frequency data. In this section we repeat the analysis using lower frequency data over the same sample period to assess if our results are robust to changes in the frequency of the data. In particular, we repeat the analysis with two and five minute frequency data over the same sample period.

Remark 6. *Results concerning non-linearities are not robust to changes in the sample frequency. Index arbitrage activity in the FTSE 100 is of some significance for frequencies with time spans lower than five minutes.*

To begin with, the Augmented Dickey Fuller (ADF) tests and the Johansen cointegration tests are performed on the new frequency series. The results of the tests and the cointegration equations are reported in Table 5.7. For both cases, the results of the tests are robust with those obtained using one minute frequency data, namely, the futures and cash prices contain a unit root and both price series are cointegrated.

The second step is to calculate the non-linearity test $C(d)$. To make the analysis comparable with the one minute frequency results, we set $d = \{1, 2\}$ when two

index futures is considerably lower than the cost of taking an equivalent position in stocks.

minute frequency data is used, which corresponds with actual delays of two and four minutes. In the same way, when we use five minute frequency data, we set a delay parameter $d = \{1\}$, which is equivalent to a delay of five minutes. Table 5.8 reports the test statistic and the p-values. Several interesting features stand out from this table. First, with two minute frequency data the test suggests threshold non-linearity in the basis series and the return series when $d = 1$ ($p - value = 0.000$). However, the test does not reject linearity in the basis series when $d = 2$ ($p - value = 0.120$). These results imply that the optimal delay for the threshold variable is $d = 1$. Second, with five minute frequency data, the test statistics do not reject linearity ($p - value = 0.107$ and 0.378 for the basis and returns respectively). Third, these outcomes are robust with the test-statistics obtained in Table 5.3 using one minute frequency data. In that case, the test did not reject linearity for the delays d equal to 4 and 5 minutes.

On the back of these results we can conclude that the regime-switching models are not the appropriate specification to describe the dynamics of the FTSE 100 futures and cash returns when we work with five minute frequency data, but they are appropriate when we analyse higher frequency returns dynamics. We suggest to estimate a regime-switching model for the two minute frequency data sample, namely a SETAR for the basis and a TVECM for the returns dynamics, and a linear model when using the five minute frequency subsample.

Table 5.7: Unit root tests and cointegration tests. Two and five minute frequency datasets

Panel A: ADF unit root test on the prices

	$\ln F_{T,t}$	$\ln S_t$	$100 * z_t$
2 minute sample:			
Levels	−1.80	−1.81	−20.9
Differences	−31.4	−30.6	−47.7
5 minute sample:			
Levels	−1.74	−1.72	−15.1
Differences	−21.4	−21.9	−32.5

Panel B: Johansen cointegration test

	λ_i	Likelihood Ratio	H_0
2 minute:	0.0147	79.3	$r = 0$
	0.0006	3.27	$r \leq 1$
	EC term:	$\ln F_{t,T} - \underset{(0.004)}{1.053} \ln S_t$	$\ln S_t - \underset{(0.004)}{0.949} \ln F_{t,T}$
5 minute:	0.0146	32.8	$r = 0$
	0.0014	3.76	$r \leq 1$
	EC term:	$\ln F_{t,T} - \underset{(0.007)}{1.052} \ln S_t$	$\ln S_t - \underset{(0.006)}{0.949} \ln F_{t,T}$

Notes: tests are applied to two and five minute frequency datasets.

The 1 percent critical value of the ADF test is -3.43. The 5 percent critical values of the Likelihood Ratio test are 15.41 and 3.76 respectively.

See notes for Table 5.2.

Table 5.8: Non-linearity tests. Two and five minute frequency datasets

Panel A. H_0: "z_t follows a linear AR(I)"			
	$d=$	1	2
2 minute:	$C(d)\tilde{}\chi^2(3)$	17.43	5.803
	$p-value$	**0.000**	0.120
5 minute:	$C(d)\tilde{}\chi^2(2)$	4.46	
	$p-value$	0.107	

Panel B. H_0: "y_t follows a linear VECM(p)"			
	$d=$	1	2
2 minute:	$C(d)\tilde{}\chi^2(24)$	66.20	34.01
	$p-value$	**0.000**	0.084
5 minute:	$C(d)\tilde{}\chi^2(12)$	12.87	
	$p-value$	0.378	

Notes: two minute frequency series: sample size is 5,124 observations. The starting point of the recursive OLS is 175.

Five minute frequency series: sample size is 2,028 observations. The starting point of the recursive OLS is 110.

Tests present heterokedasticity consistent results. All the delays are chosen to include up to 10 minutes in the estimations.

Next, we estimate the non-linear regime-switching models using the two minute frequency data. The new dataset contains 5,124 observations. To make it consistent with the previous estimation, we choose the lag order of the SETAR model for the basis $I = 2$, which corresponds to four minutes and the lag order of the TVECM equal to ten minutes, $p = 5$. The candidates for the threshold values are also the same as the ones selected for the one minute frequency analysis, i.e., $c_1 \epsilon [-0.078, -0.041]$ and $c_2 \epsilon [0.038, 0.082]$. The minimum AIC criterion for the SETAR selects $\widehat{c}_1 = -0.051$ and $\widehat{c}_2 = 0.045$, with the AIC value equal to $-38,317$. The AIC criterion for the TVECM selects $\widehat{c}_1 = -0.058$ and $\widehat{c}_2 = 0.049$, with the AIC value equal to $-91,126$. Table 5.9 reports the estimated parameters of the SETAR model for the basis. Table 5.10 displays the estimates of the TVECM for the returns system. The results are very similar to those obtained using one minute frequency data: Table 5.9 shows that the mean reversion of the basis is stronger in regimes 1 and 3 where arbitrage is presumably profitable, $\alpha_1^{(j)} = 0.377, 0.472$ and 0.439 in regimes $j = 1, 2$ and 3 respectively. In Table 5.10 we observe that the estimated coefficients of the Error Correction term in the futures equation can be treated as zeros, $\beta_1^{(1)} = 0.032$, $\beta_1^{(3)} = -0.062$ and not-significant. The estimated coefficients $\beta_2^{(j)}$ in the cash equation point out that cash prices are the ones that react to any disequilibrium movements. This fact is especially remarkable in regime 1, where the Error Correction coefficient is more than four times larger than the one in regime 2, $\beta_2^{(j)} = 0.467$, 0.111 and 0.199 for $j = 1, 2$ and 3 respectively.

Table 5.9: Self Exciting Threshold Autoregressive model for the basis z_t. Two minute frequency dataset

	Regime 1		Regime 2		Regime 3	
	$z_{t-1} \leq -0.051$		$-0.051 < z_{t-1} \leq 0.045$		$z_{t-1} > 0.045$	
	Coef.	Std. Error	Coef.	Std. Error	Coef.	Std. Err
z_{t-1}	**0.377*** **	0.089	**0.472*** **	0.028	**0.439*** **	0.071
z_{t-2}	0.153	0..041	0.152***	0.019	0.157***	0.034
$\delta^{(j)}$	$-2.8 \cdot 10^{-5}$	$6.4 \cdot 10^{-5}$	$1.4 \cdot 10^{-5,**}$	$8.8 \cdot 10^{-6}$	$7.6 \cdot 10^{-6}$	$5.0 \cdot 10$
$\widehat{\sigma}^{2,(j)}$	$4.4 \cdot 10^{-4}$		$4.0 \cdot 10^{-4}$		$4.1 \cdot 10^{-4}$	
Adj. $R^2(\%)$	7.13		13.9		9.31	

Notes: see notes for Table 5.3.

The threshold lag equals to 1. The optimal threshold values are $\widehat{c}_1$=-0.055 and $\widehat{c}_2$=0.045, which define the three regimes.

Number of observations is 675, 3,456 and 993 in regimes 1, 2 and 3 respectively.

Table 5.10: Threshold Error Correction Model for the returns. Two minute frequency dataset

	Regime 1		Regime 2		Regime 3	
	$z_{t-1} \leq -0.058$		$-0.058 < z_{t-1} \leq 0.049$		$0.049 < z_{t-1}$	
	Coef.	Std. Error	Coef.	Std. Error	Coef.	Std. E
Futures equation, $\Delta \ln F_{t,T}$:						
z_{t-1}	−0.032	0.141	−0.134***	0.032	−0.062	0.10
$\Delta \ln F_{t-1,T}$	0.133**	0.067	−0.022	0.026	0.014	0.04
$\Delta \ln S_{t-1}$	0.040	0.078	0.164***	0.028	0.088*	0.05
Constant	$1.3 \cdot 10^{-4}$	$1.0 \cdot 10^{-4}$	$8.6 \cdot 10^{-6}$	$8.7 \cdot 10^{-6}$	$-3.0 \cdot 10^{-5}$	$7.3 \cdot 1$
Adj. $R^2(\%)$	2.31		1.92		0.72	
Cash equation, $\Delta \ln S_t$:						
z_{t-1}	0.467***	0.111	0.111***	0.027	0.199***	0.08
$\Delta \ln F_{t-1,T}$	0.450***	0.057	0.288***	0.023	0.318***	0.04
$\Delta \ln F_{t-2,T}$	0.095	0.056	0.209***	0.022	0.205***	0.04
$\Delta \ln F_{t-3,T}$	0.158**	0.052	0.143***	0.022	0.138**	0.03
$\Delta \ln F_{t-4,T}$			0.066***	0.021	0.039	0.04
$\Delta \ln F_{t-5,T}$			0.045***	0.018	0.058*	0.03
$\Delta \ln S_{t-1}$	−0.177**	0.073	−0.139***	0.028	−0.183**	0.05
$\Delta \ln S_{t-2}$	−0.054	0.074	−0.135***	0.026	−0.214***	0.04
$\Delta \ln S_{t-3}$	−0.170**	0.052	−0.106***	0.025	−0.106**	0.04
$\Delta \ln S_{t-4}$	−0.165***	0.038	−0.080***	0.024	−0.075***	0.03
$\Delta \ln S_{t-5}$			−0.042**	0.018		
Constant	$2.1 \cdot 10^{-4,**}$	$7.4 \cdot 10^{-5}$	$-3.0 \cdot 10^{-6}$	$6.1 \cdot 10^{-6}$	$-1.3 \cdot 10^{-5}$	$5.7 \cdot 1$
Adj. $R^2(\%)$	18.0		10.7		9.98	

Notes: number of observations is 681, 3,584 and 922 in regimes 1, 2 and 3 respectively.

Regarding the five minute frequency data, we present the linear AR(1) and the VECM(2) estimates. The new dataset contains 2,028 observations. As in the previous samples, we select the lag order to account for delays of up to ten minutes, in particular $I = 1$ and $p = 2$. Equation (5.6) below presents the estimated AR(1) model for the basis.[14] White heteroskedasticity standard errors are given in parentheses. The estimated results indicate that the mispricing error follows a stationary process as $\alpha_1 = 0.343$ indicates in equation (5.6).

$$z_t = \underset{(9.9 \cdot 10^{-6})}{2.6 \cdot 10^{-5,***}} + \underset{(0.022)}{0.343^{***}} z_{t-1} + \xi_t \tag{5.6}$$

Finally, Table 5.11 presents the estimates of the linear VECM(2) for the FTSE 100 cash and futures returns. The results in this table are in line with those of previous linear studies on the lead-lag relationship between futures and cash prices. The signs of the adjustment coefficients in the VECM are those expected and significantly different from zero, $\beta_1 = -0.189$ in the futures equation and $\beta_1 = 0.308$ in the cash equation. The index futures returns lead the stock index returns, $\phi_{21}^1 = 0.300$ and $\phi_{21}^2 = 0.115$.

To summarise the findings in this section, the non-linear properties of the FTSE 100 cash and futures returns are not robust to changes in sample frequencies. Nonlinearities are still present in the FTSE 100 markets when we work with frequencies higher than five minutes. This finding indicates that the introduction of screen trading has accelerated the price discovery process in the FTSE 100 markets, namely, the information is incorporated more rapidly into prices.

[14]We also estimated the linear models with longer lag orders. The new coefficients turned out not to be significant.

Table 5.11: Linear VECM(2) for the returns. Five minute frequency dataset

	Coef.	Std. Error
Futures equation, $\Delta \ln F_{t,T}$:		
z_{t-1}	-0.189^{***}	0.059
$\Delta \ln F_{t-1,T}$	0.1085	0.057
$\Delta \ln S_{t-1}$	0.017	0.061
Constant	$6.7 \cdot 10^{-6}$	$1.9 \cdot 10^{-5}$
Adj. $R^2(\%)$	1.07	
Cash equation, $\Delta \ln S_t$:		
z_{t-1}	0.308^{***}	0.051
$\Delta \ln F_{t-1,T}$	0.300^{***}	0.048
$\Delta \ln F_{t-2,T}$	0.115^{**}	0.041
$\Delta \ln S_{t-1}$	-0.176^{***}	0.052
$\Delta \ln S_{t-2}$	-0.138^{***}	0.041
Constant	$-1.4 \cdot 10^{-5}$	$1.6 \cdot 10^{-5}$
Adj. $R^2(\%)$	14.0	

Notes: the system estimated is

$$\begin{aligned}
\Delta \ln F_{t,T} &= \phi_{10}+\sum_{i=1}^{2}\phi_{11,i}\Delta \ln F_{t-i,T}+\sum_{i=1}^{2}\phi_{12,i}\Delta \ln S_{t-i}+\beta_1 z_{t-1}+\varepsilon_{1,t} \\
\Delta \ln S_t &= \phi_{20}+\sum_{i=1}^{2}\phi_{21,i}\Delta \ln F_{t-i,T}+\sum_{i=1}^{2}\phi_{22,i}\Delta \ln S_{t-i}+\beta_2 z_{t-1}+\varepsilon_{2,t}
\end{aligned}$$

White heteroskedasticity consistent standard errors are given. *,** and *** stand for significance at 10, 5 and 1 percent levels respectively.

5.9 Summary and Conclusions

This chapter has analysed the dynamic interactions between prices that are theoretically related; in particular, between futures and cash indices for the FTSE 100 using one minute frequency data. We have analysed the role of transaction costs and arbitrage activity to explain the non-linear dynamics observed between these contracts. We suggested a discrete regime-switching framework to define the bands within which arbitrage may be profitable. First, we estimated a Self Exciting Vector Autoregressive for the basis. Second, a Threshold Error Correction Model explicitly modelled the behaviour of arbitrageurs and allowed for non-linear adjustments of the returns towards the long-term equilibrium. Intuitively, index-futures arbitrage only occurs when the deviations from the non-arbitrage relationship are sufficiently large to compensate for the transaction costs. In this context, the TVECM provides the bands within which arbitrage is not profitable and the effects of arbitrage on the convergence of futures and cash values.

The main conclusion from this chapter is that arbitrage activity is of some significance in shaping the short-term dynamic relationship between the FTSE 100 cash and futures prices. Our evidence confirms the presence of non-linearities in the behaviour of the basis and the returns when using one minute frequency data. The main findings of this chapter can be summarised as follows:

- The basis or mispricing follows different processes depending on whether arbitrage opportunities are present. In particular, the mean reversion of the basis to the cost of carry in the regimes in which arbitrage is profitable is stronger than in the regime in which there are no arbitrage opportunities.

- As for the dynamic relationship between the futures and cash prices, our results show that the parameters of the Error Correction Mechanism depend on the level of the mispricing. In particular, the adjustment process of the FTSE 100 cash index to deviations from the mispricing equilibrium exhibits clear non-linearities. New information coming into the market is first included in futures prices. The index market then responds to arbitrage opportunities pushing the mispricing error back to the non-arbitrage band. This behaviour is particularly strong in the arbitrage regime where the deviations of the basis are large and positive. In such situations, the arbitrage strategy consists of selling futures contracts on the FTSE 100 and simultaneously buying the stocks underlying the index.

- We extended the analysis to assess whether our results are robust to changes in the frequency of the data. In particular, we repeated the analysis with two and five minute frequency data series over the same sample period. We find that the non-linear dynamic behaviour is not robust to changes in data frequencies. When using five minute frequency data, the non-linearities are not present and thus, the regime-switching models are not an appropriate specification to model the lead-lag relationship between the FTSE 100 cash and futures indices, indicating that index arbitrage opportunities in the FTSE markets vanish within five minutes.

Overall, the introduction of the electronic trading systems in the FTSE 100 markets has increased the efficiency of the markets by enhancing the price discovery process, namely by facilitating the increase of the speed of adjustment of the futures and cash prices to departures of the mispricing error from its non-arbitrage band. Nevertheless, the automation of the markets has not completely eliminated the non-linear properties of the return series.

Chapter 6

Summary and Conclusions

The aim of this thesis is to help better understand the return spillovers between equity markets. A good understanding of the origins and transmission intensity of shocks is necessary for many financial decisions, including optimal asset allocation, the construction of global investment and hedging strategies, as well as the development of various regulatory policies like capital requirements or capital controls.

There are many possible sources of stock market co-movements. This thesis provides evidence of four of these. First, technology shocks generate international stock returns spillovers. At the same time, equity markets transmit economic shocks through the wealth effect of profits and dividends, where dividends in one country allow investors to purchase more shares and goods in another country (see Chapter 2).

A second source of international stock market interactions is the "global factor hypothesis", where investors in one country act based on stock price innovations in another country because these prices reveal global information (see Chapter 3).

Third, the analysis in this thesis also shows that international co-movements between equity markets are partly due to common reactions to public economic releases (see Chapter 4).

Finally, this thesis provides evidence that arbitrage activity is a key driver in transferring price movements from one market to another, limiting price correction to those situations where arbitrage is profitable (see Chapter 5).

The first part of the thesis is a theoretical analysis of stock market integration and economic activity. **Chapter 2** presents a stochastic general equilibrium model in which shares are explicitly introduced. This chapter is the first theoretical work that models international stock market integration with a New Open Economy framework. Special attention is devoted to study to what extent international stock market co-movements are attributable to supply shocks and the role of profits and dividends as a channel of international transmission of shocks. The main theoretical predictions of the model are:

- There is a positive correlation between domestic and foreign stock returns when stock exchanges respond to supply shocks. Intuitively, a domestic productivity shock increases the dividends domestic shares pay and thus, it pushes domestic stock returns up. Consequently, domestic agents experience a rise in wealth and they decide to increase the demand of foreign shares, pushing the price of foreign shares and foreign returns up and signifying positive international spillovers between stock exchanges. This result has two main implications. First, it draws attention to the role of supply shocks in helping to explain the dynamic behaviour of international stock market returns. Second, it indicates that dividends act as channels of the international transmission of economic shocks.

- The dynamic response of holdings of domestic shares is significantly reliant upon the level of transaction costs, namely upon the degree of stock market integration. Our model predicts that when stock markets are not perfectly integrated, imperfect capital mobility and barriers to portfolio diversification limit the ability of agents to take optimal decisions; thus, affecting the dynamic response of variables to technology shocks and the international spillovers. Not surprisingly, the contemporaneous correlations of stock returns, share prices and consumption decrease when transaction costs of investing in foreign shares increase.

- In contrast, the initial level of holdings of foreign shares has a very limited impact on the transmission of supply shocks. The model thus predicts that transaction costs of foreign shares are much more important in determining the dynamic behaviour of international stock markets than the level of foreign share holdings.

The second part of the thesis presents empirical studies that explore different sources of stock prices spillovers using high frequency datasets. This part comprises Chapters 3, 4 and 5.

Chapter 3 empirically investigates the extent to which international stock market spillovers are due to the fact that stock price movements in one country contain global information and thus, affect stock returns in other countries. In particular, the chapter uses intra-day data to quantify the intraday dynamic interactions between the FTSE 100 and the Dow Jones Industrial Average returns. The findings in this chapter are:

- There are significant bi-directional returns and volatility spillovers between the FTSE 100 and the Dow Jones Industrial Average. As New York and London Stock Exchanges have different opening times, both American and English traders extract information from unexpected stock price movements in historical foreign prices. The globalisation of industries and international portfolio diversification are increasing the interdependencies between national stock exchanges, reducing the role of the U.S. as the only producer of information that may affect international stock prices.

- Our empirical evidence supports the "global factor hypothesis" as a possible source of international stock market co-movements. This hypothesis states that part of the movements of the foreign stock returns are attributed to contain global information and thus, domestic investors learn from stock price innovations in foreign markets and incorporate this information into their subsequent trading decisions.

Chapter 4 explores the short-term dynamics between the returns on the DAX, the Eurostoxx 50 and the FTSE 100 futures and the role of public macroeconomic announcements as a source of international equity market linkages. In the first part of the chapter, the spillovers between the European stock exchanges are analysed. The second part of the chapter studies the effects of macroeconomic news on international stock market spillovers. A better understanding of the transmission mechanism and the market integration when new public information arrives onto the market may provide investors with more efficient strategies to speculate or hedge with stock indices. The main observations are:

- Even though there are clear dynamic interactions between the DAX, the Eurostoxx 50 and the FTSE 100 futures returns, there are no profit opportunities when trading the futures on these indices. Our empirical results do not identify a clear dynamic pattern in which, for instance, the FTSE index leads the continental European indices.

- Domestic macroeconomic surprises significantly affect the domestic and the foreign stock returns in the very short-term, which is consistent with the view that equity market linkages are partially attributable to common reactions to public economic information.

- Dynamic cross-market linkages between the FTSE 100, the Eurostoxx 50 and the DAX futures do not strengthen around economic announcement periods. Specifically, the lead of the domestic market does not strengthen at the time of domestic macroeconomic news releases. However, the contemporaneous correlation between the three futures returns increase in the minutes after macroeconomic data is released.

- Finally, the fact that official announcements have pre-scheduled times, as with British and Euro-Zone news announcements, or non pre-scheduled times, the case of German news releases, affects the short-term stock market interactions around announcement periods.

Overall, the results in this chapter suggest that investors directly react to the content of foreign news itself and do not wait to follow the foreign market's response to the news. This evidence supports the "public information hypothesis", which states that co-movements between national stock exchanges are partly attributable to the markets' common response to public economic information. However, the small magnitude of the coefficient estimates implies that economic releases are not the main driver of international stock return co-movements.

Chapter 5 is about the dynamic relationship between theoretically related, instead of geographically related, markets. The focus is on the dynamic relationship between the FTSE 100 futures and cash indices and the effects of arbitrage on their convergence values. The cost of carry model with non-zero transaction costs motivates the estimation of a non-linear dynamic relationship between the futures and cash indices. Discontinuous arbitrage suggests that a Threshold Error Correction Mechanism may characterise many aspects of the relationship between these indices. We use one-minute frequency data to carry out the analysis. The results indicate that non-linear dynamics are important and related to arbitrage. The main empirical results of Chapter 5 are:

- The mispricing follows a different process depending upon whether arbitrage opportunities are present in the markets. In particular, the mean reversion of the basis to the cost of carry in the regimes in which arbitrage is profitable is stronger than in the regime where there are no arbitrage opportunities.

- The adjustment process of the FTSE 100 cash index to deviations from the equilibrium exhibits clear non-linearities. First, the parameters of the Error

Correction Mechanism depend on the level of mispricing. Second, new information coming into the market is included earlier in futures prices than in cash prices.

- The non-linear dynamic behaviour is not robust to the use of lower data frequencies. When using five-minute frequency data, the non-linearities are not present in the market dynamics and thus, the regime-switching models are not the appropriate specification to model the lead-lag relationship between the FTSE 100 cash and futures indices.

Overall, evidence from Chapter 5 suggests that the introduction of the electronic trading systems in the FTSE 100 markets has increased the efficiency of the markets by facilitating the increase of the speed of the futures and cash prices adjustment to departures of the mispricing error from its non-arbitrage band. Nevertheless, the automation of the markets has not completely eliminated the non-linear properties of the return series.

Appendix A

Appendices for Chapter 2

Appendix A

This appendix solves for the steady state allocation and presents the log-linear system for the benchmark model in Chapter 2.

We characterise a perfect foresight steady state with $z = z^* = 0$ and we consider a steady state where the CPI inflation rates are zero

$$P_t/P_{t-1} = P_t^*/P_{t-1}^* = 1$$

We use variables with upper bars to refer to steady state values. Equations (2.6) and (2.10) imply that the nominal interest rates in both economies are

$$1 + \bar{i} = \frac{1}{\beta} = 1 + \bar{i}^*$$

Since the net supply of bonds equals zero in both economies, it turns out that $\overline{B} = \overline{B}^* = 0$ in steady state.

Equations (2.7) and (2.11) then imply that the nominal stock exchange returns $1 + \overline{R}_s$ and $1 + \overline{R}_s^*$ equal to

$$1 + \overline{R}_s = \frac{1}{\beta} = 1 + \overline{R}_s^*$$

which along with equation (2.8) implies that in steady state the cost equals to one, $\overline{\Psi} = 1$. Given the functional form of the cost, it follows that $\overline{x}_F = 0$ in steady state. The fact that holdings of foreign assets are zero in steady state implies that the initial equilibrium is symmetric across countries and simplifies the interpretation of the log-linearised system. Later in the chapter, we characterise a more general case where the level of net foreign assets is different from zero, $\overline{x}_F = \overline{x} \neq 0$.

From the domestic and foreign budget constraints we obtain

$$\overline{Y}\overline{\frac{P_H}{P}} = \overline{C} \quad ; \quad \overline{\overline{Y}}^*\overline{\frac{P_F^*}{P^*}} = \overline{C}^* \tag{A.1}$$

If we plug (A.1) in equations (2.2) and (2.3) we get

$$\overline{C} = \left(\overline{\frac{P_H}{P}}\right)^{1-\theta} \left[(1-b)\overline{C} + b\overline{C}^*\right] \tag{A.2}$$

$$\overline{C}^* = \left(\overline{\frac{P_F^*}{P}}\right)^{1-\theta} \left[(1-b)\overline{C}^* + b\overline{C}\right] \tag{A.3}$$

The definition of the CPI price index (2.1) becomes

$$1 = (1-b)\left(\frac{P_H}{P}\right)^{1-\theta} + b\left(\frac{P_F^*}{P}\right)^{1-\theta} \tag{A.4}$$

Combining conditions (A.2), (A.3) and (A.4) and after some algebra manipulation, we obtain that $\overline{C} = \overline{C}^*$.

Markups are constant in the steady state, implying a product wage $\frac{w}{P_H} = \frac{\theta-1}{\theta}$. This fact can be combined with equilibrium in labour markets given by equations (2.9) and (2.12) and with (A.1) to obtain

$$\overline{C}^{\phi+\sigma}\left(\frac{\overline{P_H}}{P}\right)^{\phi+2} = \frac{\theta-1}{\theta} \tag{A.5}$$

$$\overline{C^*}^{\phi+\sigma}\left(\frac{\overline{P_F^*}}{P^*}\right)^{\phi+2} = \frac{\theta-1}{\theta} \tag{A.6}$$

If $\overline{C} = \overline{C}^*$, (A.5) and (A.6) together with (A.4) imply that $\overline{\frac{P_H}{P}} = \overline{\frac{P_F^*}{P^*}} = 1$. Additionally, taking into account that PPP holds, $\overline{S} \equiv \overline{\frac{P_F}{P_H}} = 1$. Plugging these into (A.1) we get $\overline{Y} = \overline{C} = \overline{C}^* = \overline{Y}^*$. And finally, from equations (A.5) and (A.6) we get the values of consumption and output in steady state

$$\overline{Y} = \overline{C} = \overline{C}^* = \overline{Y}^* = \left(\frac{\theta-1}{\theta}\right)^{\frac{1}{\sigma+\phi}}$$

Plugging the values in the profit function (2.15) we get $\frac{\overline{\Omega}}{P} = \frac{\overline{Y}}{\theta}$. Finally, using the definition of stock exchange returns, we obtain the steady state value of the real share price on terms of the CPI index $\overline{\frac{q}{P}} = \overline{\frac{q^*}{P^*}} = \frac{\beta}{1-\beta}\frac{\overline{Y}}{\theta}$.

We next present the log-linear system. Though the rest of the appendix and the chapter, hats represent the percentage deviation of a variable from its steady state value; for instance $\widehat{X}_t = \log(\frac{X_t}{\overline{X}})$.

1. Identities, Aggregate Demand and Output Determination

We distinguish between domestic inflation, defined as the rate of change in the index of domestic good prices, $\pi_{H,t} \equiv \log\left(\frac{P_{H,t+1}}{P_{H,t}}\right)$, and CPI inflation, defined as the rate of change in the general price index, $\pi_t \equiv \log\left(\frac{P_{t+1}}{P_t}\right)$. Taking into account the identity of the terms of trade; $\widehat{S}_t \equiv \widehat{P}_{F,t} - \widehat{P}_{H,t} = \widehat{e}_t + \widehat{P}^*_{F,t} - \widehat{P}_{H,t}$ the relationship between domestic and CPI inflation is

$$\widehat{\pi}_t = (1-b)\widehat{\pi}_{H,t} + b\widehat{\pi}_{F,t} = \widehat{\pi}_{H,t} + b\Delta\widehat{S}_t \tag{A.7}$$

Equally, in the Foreign country

$$\widehat{\pi}^*_t = (1-b)\widehat{\pi}^*_{F,t} + b\widehat{\pi}^*_{H,t} = \widehat{\pi}^*_{F,t} - b\Delta\widehat{S}_t \tag{A.8}$$

It is also useful to write down the evolution of the terms of trade

$$\widehat{S}_t = \widehat{S}_{t-1} + \Delta\widehat{e}_t + \widehat{\pi}^*_{F,t} - \widehat{\pi}_{H,t} \tag{A.9}$$

The log-linear version of the first order conditions of the domestic household, substituting the CPI inflation in equations (2.6)-(2.8) yield

$$\widehat{i}_t = E_t\left\{\sigma\widehat{C}_{t+1} - \widehat{\pi}_{H,t+1} - b\Delta\widehat{S}_{t+1}\right\} - \sigma\widehat{C}_t \tag{A.10}$$

$$\sigma\widehat{C}_t = E_t\left\{\sigma\widehat{C}_{t+1}\right\} - E_t\left\{\widehat{R}_{s,t+1} - \widehat{\pi}_{H,t+1} - b\Delta\widehat{S}_{t+1}\right\} \tag{A.11}$$

$$\sigma\widehat{C}_t = E_t\left\{\sigma\widehat{C}_{t+1}\right\} - E_t\left\{\widehat{R}^*_{s,t+1} - \widehat{\pi}^*_{F,t+1} + b\Delta\widehat{S}_{t+1}\right\} - \widehat{\Psi}_t \tag{A.12}$$

Equation (A.12) indicates that the transaction costs on foreign equities directly affect the optimal consumption path of the domestic households.

In this appendix, the steady state level of foreign assets is zero, $\overline{x}_F = 0$. The log-linear form of the cost function (2.4) is $\widehat{\Psi}_t = -\psi\widehat{x}_{F,t}\overline{C}$, where $\widehat{x}_{F,t} = \log\left(\frac{x_{F,t}}{\overline{C}}\right)$. As we pointed out before, the fact that the level of foreign assets equals zero implies that the steady state equilibrium is symmetric across economies. It follows that most of the following equations are symmetric between the domestic and the foreign economy.[1]

[1]In Section 2.6 we present an extension of the model where the level of foreign assets in steady state is different from zero. This implies that the initial steady state is not symmetric across countries and some of the log-linearised equations will change.

Analogously, the foreign households' FOC (2.10) and (2.11) yield

$$\sigma\widehat{i}_t^* = E_t\left\{\sigma\widehat{C}_{t+1}^* - \widehat{\pi}_{F,t+1}^* + b\Delta\widehat{S}_{t+1}\right\} - \sigma\widehat{C}_t^* \tag{A.13}$$

$$\widehat{C}_t^* = E_t\left\{\sigma\widehat{C}_{t+1}^*\right\} - E_t\left\{\widehat{R}_{s,t+1}^* - \widehat{\pi}_{F,t+1}^* + b\Delta\widehat{S}_{t+1}\right\} \tag{A.14}$$

Log-linearising the aggregate output for the home (2.2) and foreign (2.3) economy we obtain

$$\widehat{Y}_t = (1-b)\widehat{C}_t + b\widehat{C}_t^* + \theta b\widehat{S}_t \tag{A.15}$$

$$\widehat{Y}_t^* = (1-b)\widehat{C}_t^* + b\widehat{C}_t - \theta b\widehat{S}_t \tag{A.16}$$

Equations (A.15) and (A.16) determine output as a weighted average of home and foreign expenditures in consumption plus an 'expenditure switching factor', which is proportional to the terms of trade.

2. The Aggregate Supply Block

The dynamics of the domestic price index are described by the equation (2.1), which can be log-linearised and combined with equation (2.13) to yield, after some algebra, the inflation equations[2]

$$\widehat{\pi}_{H,t} = \beta E_t\left\{\widehat{\pi}_{H,t+1}\right\} + \lambda\widehat{mc}_t \tag{A.17}$$

$$\widehat{\pi}_{F,t}^* = \beta E_t\left\{\widehat{\pi}_{F,t+1}^*\right\} + \lambda\widehat{mc}_t^* \tag{A.18}$$

where $\lambda \equiv \frac{(1-\alpha)(1-\alpha\beta)}{\alpha}$ and $\widehat{mc}_t$ is the percent deviation of the real marginal cost from its steady state value. Equations (A.17) and (A.18) represent what in the literature is typically defined as New Keynesian Phillips curves. To obtain the log-linear equation for the real marginal cost in the home economy, we can combine equations (2.9) and (2.12) to obtain

$$\frac{U'_{N_t}}{U'_{C_t}}\frac{P_t}{P_{H,t}}\frac{1}{z_t} = mc_t$$

[2]See Gali and Monacelli (2002) for a detailed derivation of these equations.

If we log-linearise the previous equation and its equivalent corresponding to the foreign economy, we obtain

$$\widehat{mc}_t = \phi\widehat{Y}_t + \sigma\widehat{C}_t - (1+\phi)\widehat{z}_t + b\widehat{S}_t \tag{A.19}$$

$$\widehat{mc}_t^* = \phi\widehat{Y}_t^* + \sigma\widehat{C}_t^* - (1+\phi)\widehat{z}_t^* - b\widehat{S}_t \tag{A.20}$$

The log-linear version of this equation shows that the real marginal cost depends on the dynamics of the terms of trade if and only if $b \neq 0$.

3. Stock Markets

Before log-linearising the definition of stock returns, it is necessary to log-linearise the profits equation (2.15)

$$\widehat{\Omega}_t = \widehat{Y}_t + (\theta-1)\widehat{z}_t - (\theta-1)\widehat{mc}_t - b\widehat{S}_t$$

where $\widehat{\Omega}_t$ stands for real profits, i.e.,$\frac{\Omega_t}{P_t}$. If $\theta > 1$, a positive supply shock in the home economy directly affects home firms' profits, which in turn affect the home stock return. A similar equation holds for foreign firms' profits.

To analyse the evolution of share prices, we first write down the equation of real stock returns in the home economy: $(1+R_{s,t})\frac{P_{t-1}}{P_t} = \frac{q_t/P_t+\Omega_t/P_t}{q_{t-1}/P_{t-1}}$.

Log-linearising this equation and plugging in the equations of $\widehat{mc}_t$ and $\widehat{\Omega}_t$, the evolution of real share prices is described by

$$\beta\widehat{q}_t - \widehat{q}_{t-1} = \widehat{R}_{s,t} - \widehat{\pi}_{H,t} - \pi_1\widehat{z}_t - \pi_2\widehat{C}_t - \pi_3\widehat{C}_t^* + (\pi_4 - b)\widehat{S}_t + b\widehat{S}_{t-1} \tag{A.21}$$

where $\pi_1 = (1-\beta)(\theta-1)^2(1+\phi)$, $\pi_2 = (1-\beta)[(1-\phi(\theta-1))(1-b) - (\theta-1)\sigma]$, $\pi_3 = (1-\beta)(1-\phi(\theta-1))b$ and $\pi_4 = (1-\beta)b\theta\phi(\theta-1)$. The above equation shows that the stock returns deviations is the main driver of real share prices. Unless $\phi < \theta b + \frac{1}{\theta-1} - \frac{\sigma}{1-b}$, the sign of π_2 is negative. It is also the case that always $\pi_1 < |\pi_2|$, which implies that our model predicts an increase in share prices when a positive supply shock occurs in the Home country. Notice as well that the sign of π_3 depends on the magnitude of θ, i.e., on the elasticity of substitution between domestic and foreign goods.

Analogously, the evolution of foreign share prices is given by

$$\beta \widehat{q}_t^* - \widehat{q}_{t-1}^* = \widehat{R}_{s,t}^* - \widehat{\pi}_{F,t}^* - \pi_1 \widehat{z}_t^* - \pi_3 \widehat{C}_t - \pi_2 \widehat{C}_t^* - \pi_4 \widehat{S}_t - b\widehat{S}_{t-1} \tag{A.22}$$

4. Evolution of Net Foreign Shares

If we log-linearise the aggregate resource constraint for the home economy (2.16) and we substitute $\widehat{Y}_t$ and $\widehat{\Omega}_t^*$, we obtain the evolution of foreign shares as a function of home and foreign consumption, terms of trade and the foreign shock

$$\begin{aligned} \beta \widehat{x}_{F,t} - \widehat{x}_{F,t-1} &= -\widehat{\Psi}_{t-1} + \pi_1 \widehat{z}_t^* + (\pi_2 + (1-\beta)\theta b)\widehat{C}_t^* + (\pi_3 - (1-\beta)\theta b)\widehat{C}_t \\ &\quad + (\pi_4 + (\theta - 1)\theta b)\widehat{S}_t \end{aligned} \tag{A.23}$$

As expected, Equation (A.23) demonstrated that the cost of investing in foreign shares negatively affects the holdings of foreign assets, with a factor of proportionality that depends on ψ, the degree of stock market integration.

Equation (A.23) also shows that a positive supply shock in the foreign economy has ambiguous effects on the domestic holdings of foreign shares. To further explore this point we compare the magnitude of π_1 with that of $\pi_3 - (1-\beta)\theta b$ in the above equation.[3] For values of θ such that $\theta^2 + \theta\,(b(1+\phi) - 2) - (b(1+\phi) - 1) < 0$, it turns out that $\pi_1 < |\pi_3 - (1-\beta)\theta b|$, which implies that the income effect is more important than the substitution effect to determine the changes in foreign shares' holdings. In this case, an increase in the domestic consumption level is associated with a decrease in the holdings of foreign shares. In other words, domestic consumers sell foreign shares when a positive supply shock in the foreign economy occurs.[4] On the opposite, for those values of θ which imply $\pi_1 > |\pi_3 - (1-\beta)\theta b|$, the substitution effect determines the direction of $\widehat{x}_{F,t}$ after a foreign positive technology

[3]Notice that $\pi_3 - (1-\beta)\theta b$ is always negative.

[4]The fact that individuals are risk averse in our model induces a negative relationship between consumption and holdings of Foreign shares.

shock. For larger values of θ, foreign shares become more attractive when a positive supply shock occurs abroad as they pay more dividends. In turn, domestic investors optimally increase their holdings of foreign shares as a response to positive supply shocks abroad.

5. Monetary Policy Arrangements

Given the price stability regime that aims at a full stabilisation of prices of domestic produced goods, equations (A.17) and (A.18) show that, when producer inflation rates are stabilised to zero in both countries, the real marginal costs are constant in all periods and thus, the following conditions must be satisfied at all dates t

$$\widehat{mc}_t = 0 = \widehat{mc}_t^*$$

To understand the relationship between optimal monetary policy and technology shocks, it is convenient to have an expression that relates real marginal costs to real interest rate, both at home and abroad. Such expression can be derived by combining (A.15), (A.19) with (A.1) and (A.13), which yields

$$\begin{aligned} \widehat{mc}_t &= E_t(\widehat{mc}_{t+1}) - (\frac{\phi(1-b)}{\sigma} + 1)(\widehat{i}_t - E_t(\widehat{\pi}_{H,t+1})) - \frac{\phi b}{\sigma}(\widehat{i}_t^* - E_t(\widehat{\pi}_{F,t+1}^*)) \\ & -(1+\phi)(1-\rho)\widehat{z}_t + \alpha_1 E_t(\Delta\widehat{S}_{t+1}) \qquad \text{(A.24)} \end{aligned}$$

where $\alpha_1 = \frac{\phi b}{\sigma}(1 - 2b - \sigma\theta)$. If the monetary authority seeks to stabilise the real marginal cost at its steady state level, i.e., $\widehat{mc}_t = 0 \ \forall t$, we can derive from (A.24) an expression for the interest rate that is consistent with such policy

$$\widehat{i}_t = -\alpha_2\widehat{i}_t^* - \alpha_3 E_t(\Delta\widehat{S}_{t+1}) - \alpha_4\widehat{z}_t \qquad \text{(A.25)}$$

where $\alpha_2 = \frac{\phi b}{\phi(1-b)+\sigma}$, $\alpha_3 = \frac{\phi b\sigma}{\phi(1-b)+\sigma}(\theta\sigma + 2b - 1)$ and $\alpha_4 = \frac{(1+\phi)(1-\rho)\sigma}{\phi(1-b)+\sigma}$. Equation (A.25) shows that given the price stabilisation rule, the optimal interest rate in the domestic economy is a function of the foreign interest rate, the evolution of the terms of trade and the domestic productivity.

6. Exogenous variables: Shocks

The driving forces are assumed to follow Autoregressive processes of the form

$$\begin{pmatrix} \widehat{z}_t \\ \widehat{z}_t^* \end{pmatrix} = \begin{pmatrix} \rho & 0 \\ 0 & \rho^* \end{pmatrix} \begin{pmatrix} \widehat{z}_{t-1} \\ \widehat{z}_{t-1}^* \end{pmatrix} + \begin{pmatrix} \varepsilon_t \\ \varepsilon_t^* \end{pmatrix} \tag{A.26}$$

with $E_t\{\varepsilon_t \varepsilon_t^*\} = \begin{bmatrix} \sigma_\varepsilon^2 & \rho(\varepsilon_t, \varepsilon_t^*) \\ \rho(\varepsilon_t, \varepsilon_t^*) & \sigma_{\varepsilon^*}^2 \end{bmatrix}$.

Given the processes of $\widehat{z}, \widehat{z}^*$, equations (A.10) through (A.26) are sufficient to characterise the equilibrium in the world economy for the system of variables $\{\widehat{C}, \widehat{Y}, \widehat{R}_s, \widehat{i}, \widehat{\Pi}_H, \widehat{mc}, \widehat{q}, \widehat{C}^*, \widehat{Y}^*, \widehat{R}_s^*, \widehat{i}^*, \widehat{\Pi}_F^*, \widehat{mc}^*, \widehat{q}^*, \widehat{x}_{F,t}, \widehat{S}, \widehat{e}\}$.

Appendix B

This appendix offers a brief description of the solution of the system in Chapter 2. The solution procedure consists in reducing the system to get a vector of exogenous variables, $z_t \epsilon \Re^m$ and a vector of exogenous variables, $x_t \in \Re^{r+s}$. The exogenous variables correspond to the random shocks, $\widehat{z}, \widehat{z}^*$. The endogenous variables' vector can be partitioned into a $r-$dimensional vector x_t of endogenous predetermined variables at time t (endogenous states) and a $s-$dimensional vector y_t of endogenous variables no predetermined. In our system, we identify x_t, y_t and z_t as

$x_t = (\widehat{\pi}_{H,t}, \widehat{\pi}_{F,t}, \widehat{\pi}_t, \widehat{\pi}_t^*, \widehat{s}_t, \widehat{q}_t, \widehat{q}_t^*, \widehat{x}_{F,t})$

$y_t = (\widehat{C}_t, \widehat{C}_t^*, \widehat{Y}_t, \widehat{Y}_t^*, \widehat{\Omega}_t, \widehat{\Omega}_t^*, \widehat{r}_{s,t}, \widehat{r}_{s,t}^*, \widehat{i}_t, \widehat{i}_t^*)$

$z_t = (z_t, z_t^*)$

The solution consists in finding the recursive equilibrium law of motion such that

$$\begin{aligned} x_t &= Px_{t-1} + Qz_t \\ y_t &= Rx_{t-1} + Sz_t \end{aligned}$$

We look for matrices P, Q, R and S, so that the equilibrium described by these rules is stable. Stability requires that the eigenvalues of P be inside the unit circle. Uhlig (1999) summarises the complete system to a matrix quadratic equation and solves the problem by turning it into a generalised eigenvalue and eigenvector problem. He establishes the link between the eigenvalues and eigenvectors of the problem and the matrices P, Q, R and S. The Matlab computer codes used to compute the calculations presented in Chapter 2 are based in Uhlig's programs. These programs are available at: http://cwis.kub.nl/~few5/center/STAFF/uhlig/toolkit.dir/toolkit.htm.

Appendix C

This appendix solves for the steady state allocation when the value of net foreign shares in steady state is different from zero in Chapter 2. In this appendix, we introduce asymmetries between domestic and foreign economies in steady state. As in our benchmark scenario, we characterise a prefect foresight steady state with CPI inflation rates equal to zero.

The steady state values of the nominal interest rates and stock exchange returns do not change in steady state, but now equation (2.4) together with equation (2.8) imply that $\overline{x}_F = \overline{x}$ in steady state. The steps to calculate the new steady state are exactly the same as those in Appendix A. The main changes in the equations are herein described.

The budget constraints in the steady state become

$$\overline{Y}\overline{\frac{P_H}{P}} = \overline{C} - \frac{\overline{x}}{\theta - \overline{x}}\overline{C}^* \quad ; \quad \overline{Y}^*\overline{\frac{P_F^*}{P^*}} = \frac{\theta}{\theta - \overline{x}}\overline{C}^* \tag{C.1}$$

Equations (A.2) and (A.3) become

$$\overline{C} - \frac{\overline{x}}{\theta - \overline{x}}\overline{C}^* = \left(\overline{\frac{P_H}{P}}\right)^{1-\theta}\left[(1-b)\overline{C} + b\overline{C}^*\right] \tag{C.2}$$

$$\overline{C}^* = \frac{\theta - \overline{x}}{\theta}\left(\overline{\frac{P_F^*}{P^*}}\right)^{1-\theta}\left[(1-b)\overline{C}^* + b\overline{C}\right] \tag{C.3}$$

Equation (A.4) still holds. Combining (C.2), (C.3) and (A.4) we obtain the relationship between domestic and foreign consumption

$$\overline{C}^*\omega_1 = \overline{C}\omega_2 \tag{C.4}$$

where $\omega_1 = \theta b - \frac{(1-b)^2}{b}\overline{x} - (1-b)(\theta - \overline{x})$ and $\omega_2 = \overline{x}(1-b) + b(\theta - \overline{x}) - \theta(1-b)$. Notice that in general $\omega_1 \neq \omega_2$, which implies that home consumption does not equal foreign consumption in steady state equilibrium. Only when the holdings of foreign shares are zero, i.e., when $\overline{x} = 0$, $\omega_1 = \omega_2 = 1$ and then $\overline{C} = \overline{C}^*$. Thus, the steady state calculated in Appendix A is a special case of the more general scenario presented in this appendix.

Combining (C.1)-(C.4) and (A.4) with the equilibrium in labour markets as we did in Appendix A, we are able to obtain the steady state value for home consumption

$$\overline{C} = \left(\frac{\theta-1}{\theta}\right)^{\frac{1}{\sigma+\phi}} \left(\frac{1}{\omega_3}\right)^{\frac{1}{\sigma+\phi}}$$

where $\omega_3 = (1-b)^{\frac{1+\phi}{1-\theta}} \left(1 - \left(\frac{\overline{x}}{\theta-\overline{x}}\frac{\omega_1}{\omega_2}\right)^{\phi}\right) + b^{\frac{1+\phi}{1-\theta}} \left(\frac{\theta-\overline{x}}{\theta}\right)^{\phi} \left(\frac{\omega_1}{\omega_2}\right)^{\phi+\sigma}$. Plugging $\overline{C}$ in (C.4) we obtain the value of $\overline{C}^* = \frac{\omega_2}{\omega_1}\overline{C}$.

Due to the fact that PPP holds, recall that $\overline{\frac{P_F^*}{P^*}} = \overline{\frac{P_F}{P}}$, which can be used in (A.4) to obtain the value of $\overline{\frac{P_H}{P}}$. Opposite to the results in Appendix A, notice that in this scenario, $\overline{\frac{P_H}{P}}$, $\overline{\frac{P_H}{P}}$ and $\overline{S} \equiv \overline{\frac{P_F}{P_H}}$ are not equal to one in steady state. In particular,

$$\overline{\frac{P_F}{P}} = \overline{C}^{*\frac{\sigma+\phi}{1+\phi}} \left(\frac{\theta}{\theta-\overline{x}}\right)^{\frac{\phi}{1+\phi}} \left(\frac{\theta}{\theta-1}\right)^{\frac{1}{1+\phi}}$$

$$\overline{\frac{P_H}{P}} = \left(\frac{1}{1-b}\right)^{\frac{1}{1-\theta}} \left[1 - b\left(\overline{\frac{P_F}{P}}\right)^{1-\theta}\right]^{\frac{1}{1-\theta}}$$

Plugging the values of $\overline{C}$, $\overline{C}^*$, $\overline{\frac{P_F}{P}}$ and $\overline{\frac{P_H}{P}}$ in (C.1), we can obtain the values of $\overline{Y}$ and $\overline{Y}^*$. Finally, the values of the real profits and the real share prices are given by

$$\overline{\frac{\Omega}{P}} = \frac{\overline{Y}}{\theta}\overline{\frac{P_H}{P}} \quad ; \quad \overline{\frac{q}{P}} = \frac{\beta}{1-\beta}\frac{\overline{Y}}{\theta}\overline{\frac{P_H}{P}}$$

The correspondent starred equations hold for the foreign level of profits and equity shares in steady state.

Next we focus on the description of the novelties in the log-linear system.

First, home and foreign inflation equations are now affected by the level of terms of trade in steady state and they become

$$\widehat{\pi}_{H,t} = \widehat{\pi}_t - s_1 \Delta \widehat{S}_t \tag{C.5}$$

$$\widehat{\pi}^*_{F,t} = \widehat{\pi}^*_t + s_2 \Delta \widehat{S}_t \tag{C.6}$$

where $s_1 = \frac{b\overline{s}^{1-\theta}}{1-b+b\overline{s}^{1-\theta}}$ and $s_2 = b\left(\frac{\overline{P_F/P}}{\overline{s}}\right)^{1-\theta}$.

Second, the log-linear form of the cost function (2.4) becomes

$$\widehat{\Psi}_t = -\psi\left(\widehat{x}_{F,t} - \overline{x}_F\right) \tag{C.7}$$

where $\widehat{x}_{F,t} = \log\left(\frac{\widehat{x}_{F,t}}{\overline{x}_F}\right)$. The current account dynamics can be written as

$$\begin{aligned}\beta\widehat{x}_{F,t} - \widehat{x}_{F,t-1} &= -\widehat{\Psi}_{t-1} + \frac{1-\beta}{\pi_5}\widehat{\Omega}_t^* + \frac{\overline{Y}}{\overline{Y}^*}\frac{\theta}{\overline{x}_F}\frac{1}{\overline{s}}\widehat{Y}_t - \frac{\overline{C}(1-\beta)}{\pi_5}\widehat{C}_t \\ &\quad + \frac{\overline{Y}}{\overline{Y}^*}\frac{\theta}{\overline{x}_F}\frac{s_1}{\overline{s}}\widehat{S}_t\end{aligned} \tag{C.8}$$

where $\pi_5 = \overline{x}_F \frac{\overline{Y}^*}{\theta}\frac{\overline{P}_F^*}{\overline{P}^*}$ and we observe that the magnitude of the equilibrium of foreign shares $\overline{x}_F$, the terms of trade in equilibrium $\overline{s}$ and the initial asymmetries between countries $\frac{\overline{Y}}{\overline{Y}^*}$ affect the evolution of foreign shares holdings.

Equations (C.1)-(C.8) reveal that the magnitude of the steady state values of $\overline{s}$ and $\overline{x}_F$ directly enter and affect the evolution of variables in the system.

Appendix B

Appendices for Chapter 4

Appendix D: Macroeconomic Data

This appendix presents the macroeconomic releases used in the empirical analysis in Chapter 4.

D.1 Positive Euro-Zone News Releases

Date	Time	Type of Announcement
4 July	11:00	EC Service Index, Business Climate Index
4 July	11:00	Euro-Zone PPI
5 July	11:00	Euro-Zone Labour Costs preliminary
13 July	11:00	Euro-Zone GDP rev. (QoQ)
18 July	11:00	Euro-Zone CPI
27 July	11:00	Euro-Zone Trade Balance (Eur bln)
30 July	11:00	Euro-Zone Current Account (Eur bln)
2 August	11:00	Euro-Zone PPI
3 August	09:03	EC Purchasing Managers Index (level)
3 August	11:00	EC Service Index and Composite Index
20 August	11:00	Euro-Zone IP
30 August	12:45	ECB announces interest rates (cut)
Tuesdays in August	14:00	ECB Financial Statement and Balance

Notes: All times refer to London time.

Unless otherwise stated, the announcements are reported as a month over month percentage change.

ECB Financial Statement & Balance corresponding to the previous week. The announcement dates are 7, 14, 21 and 28 August. A priory we did not have the median expectations, but it turns out that they always have a positive impact in the Eurex market, and therefore they were included in the positive dummy variable.

D.2 Negative Euro-Zone News Releases

Date	Time	Type of Announcement
3 July	11:00	Euro-Zone Sentiment Index (level)
3 July	11:00	Consumer & Business Confidence (level)
4 July	11:00	Euro-Zone Retail Sales
5 July	12:45	ECB announces interest rates (no change)
19 July	11:00	Euro-Zone Labor Costs rev.
20 July	11:00	Euro-Zone IP
26 July	09:00	Euro-Zone M3
1 August	11:00	Euro-Zone Retail Sales
2 August	11:00	Euro-Zone Sentiment Index, (level)
2 August	11:00	Consumer & Business Confidence (level)
2 August	12:45	ECB announces interest rates (no change)
17 August	11:00	Euro-Zone CPI
23 August	11:00	Euro-Zone Current Account (Eur bln)
28 August	09:00	Euro-Zone M3

On the 3 August at 11:00, final GDP (QoQ) is announced, but expected value equals announced value. 3 July and 1 August, 11:00, the Euro-Zone unemployment rate is released and its expected value is equal to the actual value. In the three cases, no surprise is included in the analysis.

D.3 Positive British News Releases

Date	Time	Type of Announcement
5 July	09:30	Housing Starts
12 July	11:00	BCC Quarterly Economic Survey
24 July	15:30	Conference Board: Leading and Coincident Indexes (levels)
26 July	09:30	BBA Mortgage Lending and Consumer Credit Figures
30 July	09:30	Net Consumer Credit
2 August	12:00	BoE cuts interest rates (level)
6 August	09:30	Industrial Production and Manufacturing Production
8 August	10:30	BoE Quarterly Inflation Report
9 August	09:30	Housing Starts
13 August	09:30	PPI Output and PPI Input
14 August	09:30	RPI
15 August	09:30	Average Earnings and Unit Wage Costs
16 August	09:30	Retail Sales
20 August	09:30	Visible Trade Balance (GPB bln)
21 August	09:30	Business Investment Figures (Q2)
30 August	09:30	M4 and New Consumer Credit

D.4 Negative British News Releases

Date	Time	Type of Announcement
2 July	09:30	M0
5 July	12:00	BoE announces interest rates (no change)
6 July	09:30	Industrial Production and Manufacturing Production
9 July	09:30	PPI Output and PPI Input
17 July	09:30	RPI
18 July	09:30	Average Earnings, Unit Wage Costs and Unemployment Change
19 July	09:30	M4, Visible Trade Balance and Budget Deficit
20 July	09:30	Retail Sales
25 July	11:00	CBI Quarterly Industrial Trends
30 July	09:30	M4
2 August	09:30	CIPS Construction Report
15 August	09:30	Unemployment Change (thousands)
20 August	09:30	Budget Deficit (PSNCR) (GPB bln)
23 August	09:30	Conference Board: Leading and Coincident Indexes (level)

UK GDP (QoQ) was announced at 09:30h on 27 July and 22 August. Expected value equals to actual value and therefore, the announcements are not included here. The Unemployment Rate, the expected value equals the actual figure. Therefore, we include the unemployment change instead of the unemployment rate.

The minutes of the MPC meeting were released at 09:30h on 5, 18 July and 8, 15 August. Beforehand, we do not know the sign of these releases. However, in section 4.6, these days are included in the announcement days subsample. Exactly the same situation corresponds to the release of the CIPS Service Reports and the Changes in Official Reserves, which were announced at 09:30h on 4 July and 3 August.

D.5 Positive German News Releases

Date	Time	Type of Announcement
5 July	08:50	Employment
5 July	11:00	Factory Orders
9 July	11:00	Industrial Output
17 July	15:00	Zew Survey (Economic Sentiment)
19 July	14:22	Factory Orders
24 July	14:10	German CPI (after landers published its own CPI)
24 July	15:53	Industrial Output
1 August	08:35	Purchasing Managers Index (level)
7 August	08:28	Unemployment Change (thousands)
7 August	11:00	Industrial Output
13 August	14:00	Capital Account and Foreign Bond Purchases
21 August	15:00	Zew Survey (Economic Sentiment)
22 August	09:00	IFO, Business Climate Index
23 August	16:05	German CPI (after landers published its own CPI)
31 August	16:00	Purchasing Managers Index (level)

D.6 Negative German News Releases

Date	Time	Type of Announcement
2 July	08:30	Purchasing Managers Index (level)
2 July	14:30	Industrial Output
5 July	08:25	Unemployment Change (thousands)
12 July	09:12	CPI (final)
12 July	12:15	Capital Account and Foreign Bond Purchases
20 July	08:26	Construction Orders
23 July	09:00	IFO, Business Climate Index
31 July	08:05	VDMA Plant and Machinery Orders
6 August	11:00	Factory Orders
7 August	08:50	Employment
17 August	09:09	New Car Registration
29 August	10:22	VDMA Plant and Machinery Orders
29 August	14:30	Conference Board Leading and Coincident Index

Appendix E. Robustness Analysis. Effects of the IFO Release

This appendix presents the robustness analysis for Chapter 4.

There is evidence that the effect of macroeconomic announcements depends on the context in which investors interpret the announcement, not just the news itself (McQueen and Roley (1993) and Connolly et al. (2003)). Due to the short length of the data set used in this research, the results may be affected by the announcement of the IFO or German Business Climate Index on the 22 August. We pay particular attention to the IFO release because it is macroeconomic release that has most effect on the stock exchanges during the period we analyse. In this appendix the analysis of sections 4.6 and 4.7 is repeated to asses if the results are robust enough for the inclusion of the IFO release in the news series.

The economic background was the following: on the 18 July, Alan Greenspan, the Chairman of the U.S. Federal Reserve had discussed the state of the U.S. economy and the Fed policy during his testimony to the U.S. Congress. He warned that the American economy was showing no sign of rebound and said that the Fed was prepared to cut short-term interest rates again. The Bank of England cut its interests rates by a quarter of a point on the 2 August. The situation in continental Europe was that the European Economic indicators looked quite gloomy and the stock exchanges were falling. Investors expected a movement by the European Central Bank at the next Monetary Policy Committee meeting on the 30 August. A low IFO figure would be seen as a 'sign' in favor of the intervention of the ECB. Given this background and the estimated effects of the IFO announcement, such an announcement is not considered to have a 'standard' effect on stock market dependencies.

In order to better analyse the effect of such an announcement, in this appendix the estimates of the parameters of Tables 4.5 and 4.6 are reported whilst the IFO announcement in the German news releases series is not included. Similarly, the estimated parameters of Table 4.7 are given when the IFO announcement is incorporated.

First, Table E.1 displays the effects of positive German surprises without including the IFO release on stock indices returns. The parameter estimates in this table are directly comparable with those $\theta_{gp,t}$ reported in Table 4.5. If we compare the estimates between both tables, two main points are worth noting: On the one hand, the qualitative results of the effects of the positive German news releases on stock indexes do not change, namely, positive German releases significantly affect domestic and foreign stock returns. On the other hand, the cumulative coefficient and the F-statistics testing the significance of the sum of the lagging coefficients is lower, but still significant (in Table E.1 $\theta_{gp,-1...-10} = 0.714, 0.274$ and 0.107 respectively in the three equations). This second result is not surprising as we are substracting the effect of the IFO surprise from the total effect of the positive German releases.

Second, Table E.2 illustrates the effects of positive German news on the lead-lag relationship between the DAX and the other indices without including the IFO release. The parameter estimates in this table are directly comparable with those $\beta^1_{gp,t}$ reported in Table 4.6. If we compare the estimates between both tables we also observe that the qualitative results do not change in the new estimation. Our results show mixed evidence on the effect of news on the lead-lag relationship between futures markets. At the time of positive German news releases, the lead of the DAX returns over the Eurostoxx 50 strengthens (the cumulative coefficient $\beta^1_{gp,-1...-10} = 0.163$ is positive and significant in the $R_{Eur,t}$ equation), while the lead of the DAX returns over the FTSE 100 weakens (the cumulative coefficient $\beta^1_{gp,-1...-10} = -0.157$ is negative and significant in the $R_{FTSE,t}$ equation). It would be interesting to examine if these findings are systematic effects or they are due to the particular period used in our analysis.

Finally, Table E.3 reports the contemporaneous cross-market correlations between the DAX and the other futures returns at the time of positive German releases when the IFO figure is included in the news series. It turns out that there is a major increase in the correlations between the DAX and the Eurostoxx 50 in the same minute when the IFO figure is released (comparing $\rho_{g,0} = 0.873$ in Table E.3 with $\rho_{g,0} = 0.646$ in Table 4.7 in the $R_{Eur,t}$ equation). This increase in the contemporaneous correlation in the same announcement minute may be due to the fact that European investors were waiting for this particular release and as soon as they saw the figure on the screens they started reacting to the new information. It is not surprising to observe that continental European investors were more aware of this release than British investors ($\rho_{g,0} = 0.379$ in the $R_{FTSE,t}$ equation).

Overall, we find that the IFO surprise mostly affects the contemporaneous correlation pattern between the stock exchanges. Our main conclusions are robust to the inclusion or exclusion of the IFO release in our macroeconomic news series.

Table E.1: Effects of positive German news (excluding the IFO figure) on stock returns

	$R_{DAX,t}$		$R_{Eur,t}$		$R_{FTSE,t}$	
	Coef.	F-Stat.	Coef.	F-Stat.	Coef.	F-Stat.
$\theta_{gp,-1...-10}$	0.714**	2.273	0.274**	1.930	0.107***	1.584
	Coef.	Std. Error	Coef.	Std. Error	Coef.	Std. Error.
$\theta_{gp,0}$	0.112	0.130	0.051	0.102	0.176*	0.101
$\theta_{gp,-1}$	0.287**	0.130	0.266**	0.141	0.293**	0.130
$\theta_{gp,-2}$	0.064	0.185	0.168	0.162	−0.129	0.162

Note: See notes for Table 4.5.

Table E.2: Effects of positive German releases (excluding the IFO figure) on stock returns spillovers

	$R_{DAX,t}$		$R_{Eur,t}$		$R_{FTSE,t}$	
	Coef.	F-Stat.	Coef.	F-Stat.	Coef.	F-Stat.
$\beta^1_{gp,-1...-10}$	-0.022	0.763	0.163**	1.832	-0.157**	1.865
	Coef.	Std. Error	Coef.	Std. Error	Coef.	Std. Error
$\beta^1_{gp,0}$			0.045	0.071	-0.045	0.050
$\beta^1_{gp,-1}$			-0.024	0.074	-0.029	0.047
$\beta^1_{gp,-2}$			-0.008	0.070	-0.075	0.048

Note: See notes for Table 4.5.

Table E.3: Effects of positive German releases (including the IFO release) on contemporaneous correlation

	$R_{DAX,t} - R_{Eur,t}$	$R_{DAX,t} - R_{FTSE,t}$
$\rho_{g,+2}$	0.741	0.307
$\rho_{g,+1}$	0.630	0.410
$\rho_{g,0}$	0.873	0.379
$\rho_{g,-1}$	0.927	0.392
$\rho_{g,-2}$	0.761	0.373
$\rho_{g,-3}$	0.601	0.409
$\rho_{g,-4}$	0.875	0.480
$\rho_{g,-5}$	0.604	0.214^b
$\rho_{g,-10}$	0.776	0.395
$\rho_{g,-30}$	0.615	0.308
ρ^n	0.755	0.338

Note: See notes for Table 4.7.

Appendix C

Appendix for Chapter 5

Appendix F. Estimation Procedure

This appendix explains Tsay (1998) procedure to test for non-linearities and presents the estimation strategy used in Chapter 5.

Granger (1993) recommends employing a specific-to-general procedure when estimating non-linear time series models. His approach is widely used in the literature and consists of the following steps:

1. Specify a linear model to describe $\ln F_{t,T}$ and $\ln S_t$ in terms of the regressors, select the regressors and the lag order.

2. Test the null hypothesis of linearity against the alternative of non-linearity.

3. If linearity is rejected, estimate the parameters in the non-linear models, in our case, the SETAR and the TVECM models. This step involves two parts:

3.1. Select z_{t-d}, the variable that characterises the regime-switching and estimate the optimal threshold values c_1 and c_2.

3.2. Once z_{t-d}, c_1 and c_2, are known, recall that the system in (5.3) is linear in the remaining parameters. The system can be estimated by least squares regression conditional on c_1 and c_2.

4. Use the model for descriptive or forecasting purposes.

With respect to step 1, the cost of carry model in our case points to a linear Vector Error Correction Mechanism to describe the dynamic behaviour of the futures and index prices and to an Autoregressive Model to describe the dynamics of the basis.

With some necessary changes, we use the multivariate test statistic to detect threshold non-linearity in step 2 and the model building in step 3 suggested by Tsay (1998), who also derives the asymptotic distribution of the test and discusses its performance. These steps are described in the next subsections.

F.1 Non-linearity Test and Arranged Autoregression

For notational convenience, we write the system in (5.3) in a regression framework

$$y_t = X_t'\Phi + \varepsilon_t \qquad t = h+1, ..., N \tag{F.1}$$

where $y_t = (\Delta \ln F_{t,T}, \Delta \ln S_t)'$, $X_t = (1, \Delta \ln F_{t-1,T}, ...\Delta \ln F_{t-p,T}, ...\Delta \ln S_{t-1}, ...,$ $\Delta \ln S_{t-p}, z_{t-d})'$ is a $(kp+q+1)$ dimensional regressor, k is the number of dependent variables, p is the lag order, q is the number of exogenous variables. In our system $k = 2$, $q = 1$ and corresponds to z_{t-d} and p is determined in the estimation. Φ denotes the parameters matrix and $\Omega = E(\varepsilon_t'\varepsilon_t)$. Finally, $h = max(p, d)$. Given the observations $\{y_t, X_t, z_{t-d}\}$, our goal is to detect the threshold non-linearity of y_t. In other words, we want to test the null hypothesis of linearity against the alternative of non-linearity.

Given the threshold variable, z_{t-d}, the arranged regression becomes useful when the cases of data $\{y_\pi, X_\pi, z_{\pi-d}\}$ are sorted according to the threshold variable z_{t-d}.[1] In this arranged regression, the dynamics of the dependent variable, y_t, are not changed. What changes is the ordering by which the data enters the regression setup, i.e., the row order if one places the regression in a matrix framework. The important feature of the arranged regression is that it transforms the threshold model into a change-point problem.

Tsay (1998) uses the predictive residuals and the recursive least squares method to detect the model change in (F.1).[2] The basic idea behind it is easy: if y_t is linear, then the recursive least squares estimator of the arranged regression (F.1) is consistent so that the recursive residuals approach white noise. Consequently, the predictive residuals are uncorrelated with the regressors X_π. If y_t follows a threshold

[1] We use the subscript π instead of t in the arranged regression to remark that it is not a time subscript.

[2] In recursive leasts squares, the equation is estimated repeatedly, using larger subsets of the sample data. If the first m_0 observations are used to form the first estimate of Φ_{m0}. The next observation is then added to the data set and $m_0 + 1$ observations are used to compute the second estimate of Φ_{m0+1} and so on till N.

model, the recursive residuals are correlated with the regressors, X_π.

The recursive residuals $\widehat{\varepsilon}_\pi$ of equation (F.1) can be obtained efficiently by the recursive least squares algorithm.

Next, consider the regression

$$\widehat{\varepsilon}_\pi = X_\pi^{'}\Psi + w_\pi \qquad \pi = m_0 + 1, ..., N - h \tag{F.2}$$

Our problem of interest is to test the null hypothesis of linearity $H_0 : \Psi = 0$ versus the alternative $H_1 : \Psi \neq 0$ in regression (F.2). The employed test statistic is

$$C(d) = [N - h - m_0 - (pk + q + 1)] * \{\ln(\det(S_0)) - \ln(\det(S_1))\} \tag{F.3}$$

where the delay d means that the test depends on the threshold variable z_{t-d}, $det(S)$ denotes the determinant of matrix S and S_0 is the estimate of the residual variance under H_0. w_π is the residual variance of the auxiliary regression (F.2), namely

$$S_0 = \frac{1}{N-h-m_0}\sum_{\pi=m_0+1}^{N-h} \widehat{\eta}_\pi^{'}\widehat{\eta}_\pi \quad ; \quad S_1 = \frac{1}{N-h-m_0}\sum_{\pi=m_0+1}^{N-h} \widehat{w}_\pi^{'}\widehat{w}_\pi$$

Tsay (1998) demonstrates that under the null hypothesis that y_t is linear and some regularity conditions, $C(d)$ is asymptotically a chi-square random variable with $k(pk + q + 1)$ degrees of freedom.

Alternatively, for a SETAR model, Hansen and Seo (2001) suggest a more specific test for the null of a linear AR(I) model against the alternative of a two regime SETAR model. We prefer the test suggested by Tsay (1998) for two reasons: first, Tsay (1998) proposes a more general, nonlinear multivariate test instead of a univariate test. Moreover, as far as we know, there are no formal tests of linearity against three-regime switching models. Second, the Tsay (1998) test does not depend on the parameters of the alternative model or encounters the problem of undefined parameters under the null hypothesis as for instance, the threshold values c_1 and c_2 are not defined under H_0.

F.2 Optimal Threshold Variable and Values

The next step is to estimate the threshold model in equations (5.3) and (5.4) assuming that the lag order, the number of regimes and the threshold variable are known. However, the delay parameter, d, and the threshold values, c_1 and c_2, are also part of the parameters of the model. To estimate the model, it is useful to recall that for a *fixed* threshold lag d and threshold values c_1 and c_2, the model is linear in the remaining parameters Φ and Ω. Estimates conditional on d, c_1 and c_2 are obtained by least squares regression of y_t on $X_t(d, c_1, c_2) = X_t * S_{j,t}$, where $S_{j,t} = 1$ for each of the corresponding regimes j defined in (5.4) and $S_{j,t} = 0$ otherwise. The residuals in each regime j are $\widehat{\varepsilon}_t^{(j)}(d, c_1, c_2) = y_t^{(j)} - (X_t * S_{j,t})'\Phi^{(j)}$.

Their variance is $\widehat{\sigma}^{2,(j)}(d, c_1, c_2) = \frac{1}{N_j}\sum_{t=1}^{N_j} \widehat{\varepsilon}_t^{(j)\prime}\widehat{\varepsilon}_t^{(j)}$, where N_j is the number of observations in regime j. Further, we denote the sum of square residuals of the system by

$$S(d, c_1, c_2) = S^{(1)}(d, c_1, c_2) + S^{(2)}(d, c_1, c_2) + S^{(3)}(d, c_1, c_2)$$

where $S^{(j)}(d, c_1, c_2)$ is the trace of $N_j\, \widehat{\sigma}^{2,(j)}(d, c_1, c_2)$. Then, the estimates of d, c_1 and c_2 can be obtained by minimising this sum of squared residuals

$$(\widehat{d}, \widehat{c}_1, \widehat{c}_2) = \underset{d, c_1, c_2}{\arg\min} S(d, c_1, c_2) \tag{F.4}$$

where $d \in D$ and c_1, c_2 belong to the empirical range of z_{t-d}.

In practice, we use the Akaike Information Criterion (AIC) to select the model. The AIC has been used in the literature to select threshold autoregressive models, for instance see Tong (1990). When p, q and the number of regimes are fixed, the AIC is asymptotically equivalent to selecting the model that has the smallest generalized residual variance using the conditional least squares method. In practice, we proceed in the following way: first, we use the test results of (F.3) for different threshold variables to select the delay parameter, d, resulting in further simplification.[3] Second, we use a grid search method to select the threshold values c_1 and c_2 which

[3]This way of selecting d is based on the idea that the test is most powerful when d is correctly specified. See Tsay (1998).

minimise the AIC criterion. In particular, given, p, q, d and the number of regimes, $s = 3$, the AIC criterion of a multivariate threshold model such as the one specified in equations (5.3) and (5.4) when the innovations follow a multivariate normal is

$$AIC(p,q,d,s) = \sum_{j=1}^{s}\{N_j \ln(\widehat{\sigma}^{2,(j)}) + 2k(pk+q+1)\} \tag{F.5}$$

F.3 Estimation of the SETAR and the TVECM

As we have already noted in the previous subsection, once d, c_1 and c_2 are fixed, equations (5.2) and (5.3) are linear in the remaining parameters, δ, α, Φ and Ω. Estimates of these parameters can be easily obtained by least squares regressions conditional on d, c_1 and c_2. In other words, a linear model describes the relationship between the variables within each regime. Specifically, to model the dynamics of the basis we estimate an AR(I) for each regime and to describe the dynamic relationships of the futures and index returns we estimate a VECM for each regime. Notice that across regimes, the parameters in the models can be different. See Tsay (1998) and Franses and Dijk (2000) for more detailed explanations of the estimation strategy of non-linear models.

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