An Intraday Examination of the Role of Priors in the Price Discovery Process

Baback Roodbar

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Abstract

The informational efficiency of financial markets is the most debated topic of financial economics. Asset price formation in the absence of new market relevant information is described as a puzzle unresolved by standard economic theory. This thesis asks if this puzzle is simply a case of missing information. If there is market relevant information in existence, which has been identified by market agents, but not discerned by economists.

Traders/Investors have prior expectations for the outcome of future market relevant information events (subsequently termed '*priors*'). Such *priors* relate to the scope, scale, timing and probability of an upcoming information event. These *priors* play a significant role in the price formation process upon the arrival of the expected information event.

Priors are updated frequently by individual investors concurrently with information flows which may change the individuals' expectation of the upcoming high scope information event. Such changes to *priors* alter the fundamental valuation of a given asset and can be considered completely in line with rational expectation hypotheses. The subtle changes to the *priors* of a few market agents alone is not enough to result in a large-scale price formation process. However, an information event sufficiently absorbed by a large number of market agents, which results in an alteration to *prior's* en masse, will significantly alter the weighted average valuation of a given asset sufficiently that a large-scale price formation process should be observable.

This research identifies a database of market relevant information, in the form of market rumours, broadcast by market agents and commentators. This information by nature is not published or archived by the incumbent and regulated financial information sources such as Reuters and Bloomberg, thus potentially missed by research economists.

Empirical results of this thesis show that at intraday observations of market price, large scale and persistent volatility events are observable at the time of rumour broadcast. The instantaneous increase in volatility during the first minute of rumour arrival is up to 211%, while the cumulative increase in volatility over a 60-minute window is as much as 2614%. Such large-scale volatility events had previously been attributed to '*noise'* or private information flows.

Further findings show that large excess returns in the run-up to central bank announcements can be attributed to market rumours dispersion. Such pre-announcement excess returns had been observed in the past but unexplained in the literature. Results show that trading on the pre-announcement rumour for 10 days per year can generate almost 100% greater return than holding the market portfolio on all other days of the year.

The thesis also documents the existence of a new price formation process undocumented in the literature. Empirical results identify the existence of large excess returns in the day following European Central Bank (ECB) announcements but only when the day is a Friday. This is termed '*the ECB conditional Friday effect'*.

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Chapter 1. Introduction

Economic theory dictates that financial market prices should remain at equilibrium unless new market fundamental information becomes available. This new information may become available to the public or be privately acquired by an individual or a small group of market agents. The information may be scheduled, that is, the time of its release is known by the public but its content/scale of information is unknown prior to its arrival. The information may also be unscheduled, that is, the arrival and the content, scale and scope of the information is unknown ex-ante.

The magnitude of the correction toward the new equilibrium occurring as a result of an information event should be directly related to the amount by which the new information changes the fundamental valuation of the market traded asset. Fundamental valuation may change due to the scope (e.g. central bank policy announcement), the content (e.g. interest rate policy), the scale (e.g. deviation from current interest rates), and the probability content (e.g. forward guidance) of the information event. Further, the magnitude of price deviation from equilibrium also depends on the degree to which new information deviates from expectations (e.g. deviation from analyst forecasts).

The complete and instantaneous incorporation of new market relevant information into market price is considered to be an efficient price formation process. Further, the deviation of market price from equilibrium without the detection of new fundamental information is considered to be an inefficient price formation process. This economic principle is formalised as the Efficient Market Hypothesis by Fama (1965).

It is the observation of large deviations of market prices from equilibrium in the absence of new information that lead the strongest critiques of the notion of informationally efficient financial markets. It is the central focus of this thesis to investigate market price deviations from equilibrium occurring in absence of new market information, such price formation processes are often deemed ‘puzzles’ of financial economics. The central question posed in commencement of this research is whether such price formation processes occur independently and are therefore ‘puzzles’, or, does an information set exist which is detected by market agents but not yet identified by academics? Further, is such an information set sufficiently influential to alter the fundamental valuation of market traded assets? As a result, can a price formation process be detected upon the arrival of new information of this kind?

Eugene Fama's (1965) Efficient Market Hypothesis (EMH) is among the most empirically analysed theories of economics. In its most strict form, Fama's hypothesis contends that for a financial market to be considered efficient, available information, private or public about the past, present or future must be priced. A more relaxed version of his hypothesis (Fama (1991)) contends that a market can be considered 'semi-strong' efficient if all known public information is priced. The least strict form of the EMH considers a market to be 'weakly' efficient as long as current prices reflects all information priced in the past. The large-scale interest in testing this hypothesis is unsurprising given that an efficient financial market is one of the cornerstones of a functioning market driven economy. Inefficiencies in the financial markets of such economies can be catastrophic, as evident during the recent financial crisis which had led to a prolonged period of economic decline, followed by stagnation in most major developed economies. The financial crisis, after all, at its most fundamental level, can be considered a result of informational inefficiency in financial markets.

The informational efficiency of financial markets has proponents and opponents in abundant measures. Empirical examination of financial market price during times of new public and private information arrival is abundant. Results of such analysis predominantly show support for the EMH, with evidence pointing to weak form efficiency (lack of autocorrelation persistence and profitability for technical traders, Jensen (1978)), semi-strong form efficiency (new public information is immediately priced, Andersen and Bollerslev (1997)) and strong form efficiency (private information is priced as evidenced by order flow, Li et al. (2009)).

Proponents point to excessive price variation, both in the first and second moment, in the absence of new fundamental information as evidence of informational inefficiency in the financial markets. Price formation processes such as the January Effect (Rozeff and Kinney (1976)), Monday Effect (Kamara (1997)), asset price bubbles (Shiller (2003)), over and under reaction to new public information (De Bondt and Thaler (1985)) and the price to earnings ratio effect (Fama and French (1995)) are considered as repudiations to the notion that financial markets are informationally efficient.

More recently policymakers and academics have turned their attention to financial market 'functionality' (see ECB (2012)) and O'Hara (2003)). Financial market functionality is fundamentally dependent upon a complete price discovery process and sufficient liquidity provisions. Liquidity provision is defined as a market agent's ability to buy and sell assets without, individually, having a large impact on price (Hasbrouk (2009)). A complete price discovery process is defined as the integration of new public and private information,

instantaneously, in price (O'Hara (2003)). Therefore, for a market to be considered functional, it should also be informationally efficient under the strictest definition of the EMH.

According to this definition of financial market functionality, the abundant price formation puzzles identified by proponents of the EMH would suggest that a large number of financial markets may be defined as dysfunctional. Such price formation puzzles, are solved incrementally with wider access to market relevant public and private information databases and the availability of intraday and ultra-high frequency observations of market price.

Alternative trading windows such as intraday price observations and overnight trading periods have been examined to show that increasing amounts of excess price variability can be attributed to new public information arrival (Andersen and Bollerslev (1997)). The nature of new public information, in terms of scale, relevance and surprise has also been tested to account for increasing amounts of excess price variability (Faust et al. 2007)). The structure of public information arrival has also been examined. For instance, unscheduled monetary policy announcements have been shown to have a significantly greater impact on price than scheduled announcements (Kuttner (2001)). A large number of financial markets have been examined, at various frequencies of price observation during heterogeneous public information events, to unravel the structure of the instantaneous and cumulative price response (see among others, Andersen et al. (2003)).

Proponents of efficient markets lend support from the existence of private market relevant information to explain the remaining unexplained price formation processes. Recently, the existence of price formation resulting from private information, has been documented by using order flows (see among others O'Hara (2003), Evans and Lyons (2002) and Li et al. (2009)). Such periods of private information driven order flow have been characterised as increasing the inherent informational risk in the market, thus leading to excess return premiums required to compensate market participants. A risk premium driven price formation process seems plausible and this price discovery process has gained traction in the recent literature. However, questions have been posed as to whether private information flows can completely explain the existence of large scale return and volatility events. After all, the value of private information to market agents is maximised if they trade incrementally on such information and do not shock the market with orders capable of causing large scale price formation events (Cespa and Foucault (2013)).

Progressively, price formation puzzles, investigated with more sophisticated datasets and methodologies are converging to the definition of a complete price discovery processes.

However, significant large scale price formation processes exist in the financial markets that cannot as yet be fully explained by the arrival of new fundamental information detected by academics (Andersen et al. (2007), Groß-Klußmann and Hautsch (2011)).

This thesis contributes toward the price discovery literature by providing further support to the idea that informationally driven price formation processes are recurrent and a key feature of financial markets. The fundamental assertion of this thesis leans on the notion that market agents have *priors* (Fleming and Remolona (1999)). Traders/Investors form prior expectations for given outcomes of future market relevant information events (subsequently termed '*priors*'). Such *priors* relate to the scope, scale, timing and probability of an upcoming information event. These *priors* play a significant role in the price formation process upon the arrival of the expected information event. A realised information event which significantly deviates from the weighted average expectation (e.g. analyst forecasts) is shown to have a greater impact on market price than one which is largely in line with the weighted average/consensus expectation (see among others, Kuttner (2001), Faust et al. (2007)). Similarly, the price impact is of greater magnitude if the realised information event is of fundamental scope. An example of this would be scheduled central bank policy announcements (Andersen et al. (2007)).

Priors are updated frequently by individual investors concurrently with information flows which may change the individuals' expectation of the upcoming high scope information event. Such changes to *priors* may alter the fundamental valuation of a given asset and can be considered completely in line with rational expectations hypotheses. The subtle changes to the *priors* of a few market agents alone is not enough to result in a large-scale price formation process. However, an information event sufficiently absorbed by a large number of market agents, which results in an alteration to *prior's* en masse, will significantly alter the weighted average/consensus valuation of a given asset sufficiently so that a large-scale price formation process should be observable.

This thesis posits that such expectation altering information events occur frequently and when such information is pertaining to large scope macroeconomic news events, the price impact could be large scale. The impact could be of such scale that the resulting price formation process may be deemed a puzzle, if the expectation altering information events go undetected.

The assertion in this thesis is that a Bayesian updating process of traders' prior expectations is taking place in the pre-announcement period, prior to large scope macroeconomic news events. Such updating is posited to be as a result of new information, perhaps public, which has been

detected by market agents but not by academics. The information is therefor, not private but also not public in the regulatory sense. That is, it is not published and/or archived by mandated outlets such as Bloomberg or Reuters. Should the content of such information change the weighted average expectation of market agents, about the scale, probability or timing about the forthcoming large scope central bank announcement, then pre-announcement price formation process should be observable.

This thesis identifies a dataset of *prior* altering information events and shows empirically that contemporaneous and persistent large-scale intraday price volatility is dependent on the arrival of such information events at intraday observations of price. Further, this dataset is employed to solve an existing price formation puzzle identified by Lucca and Moench (2015). The central bank pre-announcement positive drift in returns previously identified as a pre-announcement risk premium can be explained with the existence of *prior* updating information events. This research also identifies a unique, central bank announcement conditional day-of-the-week effect. This price formation process could be considered a pricing puzzle however, applying the central hypothesis of this thesis to this price formation process allows for an intuitive explanation based on the notion of expectations updating.

The remainder of the thesis presents the central theoretical hypothesis, along with empirical evidence in support.

Chapter 2 investigates a new source of market relevant informational flow that is discerned by market agents but not yet identified by academics. The advent of social networks has enabled the identification of 'market rumours' and this has rarely been the subject of discussion within the price discovery literature, as until the introduction of Twitter and similar financial micro-blogging sources, these elements whilst known to market participants were not available as a database for investigators. It is this largely neglected category of information which is of most interest to this study. These rumours are essentially chatter, broadcast by market agents and commentators on the microblogging website Twitter.com. The information is therefore public and archived, timestamped and fully observable to both academics and market agents.

I suggest that rumours about expected future market events, circulating publicly, are *prior* altering information events. Rumours by nature are difficult to pinpoint in time and rational expectations theory would suggest rumour information to be of little fundamental importance to the pricing of assets. It is therefore understandable that this type of information has been overlooked in the past. However, it is fair to posit that if rumours sufficiently alter the perceptions held by market participants of a given future market event, they become fundamental to the pricing mechanism. Rumours of forthcoming European Central Bank (ECB)

actions, dubbed ‘ECB sources’, which are broadcasted regularly by ‘in the know’ market commentators are observed. All such broadcasts are timestamped to within one-minute accuracy which alleviates the difficulty of pinpointing the arrival of a rumour in time. Moreover, the unique nature of Twitter as a broadcasting mechanism is that, commentators are not subject to stringent financial regulatory body mandates and in-house substantiation filtration systems. This fundamentally differentiates Twitter from incumbent financial news broadcasters, such as Bloomberg and Reuters, which have in the past been the source of new timestamped market information for studies testing the asset price impact of new information (see, among others Li et al. (2015)).

The arrival of 63 ‘ECB sources’ rumours broadcast on Twitter is pinpointed, to within one-minute accuracy, during a 420-day sample period of one-minute frequency spot Euro-US dollar exchange rates. I show, using Anderson and Bollerslev’s (1998) Flexible Fourier form regression, that there is a significant increase in the volatility of exchange rate returns following the arrival of 25 out of 63 ‘ECB sources’ rumours. The empirical results suggest that in the foreign exchange markets, market participants actively seek rumour information pertaining to market relevant ECB announcements. The consideration of such actionable information in the price formation process makes it possible to explain a greater proportion of asset price volatility.

In Chapter 3, I explore the potential effect of rumours on financial market price formation in the central bank pre-announcement period. Results show that stock market excess returns are significantly large and positive in the 24-hour trading period immediately before scheduled monetary policy announcements. These excess returns are particularly observable in recent years, between 2011 and 2015, during which the European Central Bank (ECB) has exercised policy measures considered to be accommodative. This finding is in line with observations of a similar pattern in pre-announcement price formation found by Lucca and Moench (2015) for trading windows prior scheduled FOMC (Federal Open Market Committee). However, given the findings of the previous chapter I ask: Is the central bank pre-announcement anticipatory effect simply as a result of new public information flows which have previously gone undetected?

I expand the data set from Chapter 2 to six years of observations for ‘ECB sources’ stories broadcast on Twitter and corresponding stock and currency intraday return observations. Employing the same model as Lucca and Moench (2015), pre-ECB return windows are isolated and tested for excess returns above other non-pre-ECB trading periods. Empirical results show that average excess returns earned on the stock market index, in the 24-hour trading window immediately prior the 55 ECB Governing Council’s scheduled policy announcements are

statistically significant and substantially higher than all other days. The implication is that the pre-announcement drift is also observable in European markets pre-ECB windows. This contrasts with Lucca and Moench (2015) findings that show the pre-announcement drift is only observable for scheduled FOMC announcements, with no specific pattern occurring for other central banks. I conjecture that this is simply due to the sample period under scrutiny. Their sample period concludes in 2011, whereas the sample period here is from November 2010 through November 2015. It is fair to suggest that the major changes in the ECB's balance sheet, policy mandate and expansion of policy tools from 2011 onwards may be, in part, the reason behind their divergence in results.

Importantly, further empirical results show that the pre-announcement drift is rumour conditional and less puzzling than previously assumed. This result is in line with the most compelling case put forward by Lucca and Moench (2015) for explain the 'drift'. In fact, they suggest that investors could be subject to more complex information flows than those detected in standard theory. In this chapter, I assert that such information flows include the arrival of new publicly available information in rumour form pertaining to forthcoming policy actions. These rumours have the standard theoretical effect of an ensuing risk adjusted price formation process

In Chapter 4, I explore the currency market price formation process in the central bank post-announcement period. Findings show that the immediate EUR/USD exchange rate response to European Central Bank (ECB) schedule policy announcements is in line with the standard economic theory formalised through the Efficient Market Hypothesis (see Fama (1970)). The Euro area currency experiences large negative excess returns in the immediate (5-minute) period following Central Bank Monetary Policy announcements which are deemed to be mostly accommodative throughout the sample period under scrutiny. This finding is unsurprising, given that it is simply the anticipated financial market response to new and relevant, public information.

The main finding of this Chapter, however, is in stark contrast to that professed by standard asset pricing theories. I document large, significant negative excess returns on the EUR/USD spot exchange rate on the day following scheduled ECB policy decision announcements. This pricing anomaly only takes place on Friday trading days which follow scheduled ECB announcements taking place on Thursdays. When the day-of-the-week following an ECB announcement falls on a Thursday then no pricing anomaly can be observed. I define this ECB Friday pricing anomaly as the 'ECB conditional Friday effect'. Overall, these findings present a price formation anomaly which is conditional on a prevailing scheduled ECB policy decision

announcement and that the trading day following the announcement must fall on a Friday. Several explanations are explored for this conditional price formation process.

The initial intuition is that such a uniform post-ECB negative drift must be a result of new public information arrival. However, findings in this chapter show that scheduled public information events observed on days following scheduled ECB announcements, are heterogeneous in macroeconomic data type and report both Euro negative and positive information. Thus, I conclude that the intuitive reasoning based on standard asset pricing theory cannot be used to explain the ECB conditional Friday price formation process.

Due credence is also given to a second argument; that this ECB conditional Friday effect is one linked to findings presented in market microstructure literature. This literature finds that Friday afternoons in multiple markets experience higher levels order flows, volume and short selling (see among others, Ralando et al. (2012)). In this context, the hypothesis could be that large-scale profit taking and closing of positions occurring after a larger impact public information event are the determinants of the ECB conditional Friday effect. The magnitude of the average excess negative return on the EUR/USD following scheduled announcements is over 20 basis points. Therefore, this argument is also dismissed given that post-ECB scheduled announcement immediate market reaction is likely to be short positions in the EUR/USD, the covering of which would result in an opposite directional Friday price effect than that observed in the empirical results.

The most intuitively persuasive reason for the ECB conditional Friday effect is simply a risk-weighted liquidation of long positions in the Euro prior to Friday market close. The intuition being that traders, cautious of weekend news relating to an already dovish ECB during a predominantly policy easing cycle, would not be willing to stay long the currency over the weekend following ECB announcements. Further, ECB Governing Council members, who are mandated to a quiet period prior to scheduled announcements, tend to make frequent comments and clarification to the world press during the days following ECB meetings. Following predominantly dovish ECB announcements in the sample, such comments may be deemed by traders to be likely to have a Euro negative impact on post-weekend market open. Therefore, a conclusion can be drawn that traders, long the currency on post-ECB Fridays, are likely to make a risk-weighted decision to cut their positions. And, traders short the currency, are likely to make the risk-weighted decision to remain short. This conclusion comes with a caveat; that the strength of this argument is very much linked to the intuition underpinning rational risk-weighted investor/trader behaviour. Thus, the ECB conditional Friday effect is, in part, still a pricing puzzle worthy of further investigation. Chapter 5 concludes this thesis.

Chapter 2. Trade the Rumour

2.1 Introduction

The excess volatility puzzle is one of the foremost unanswered questions in financial economics. The Efficient Market Hypothesis in all its guises has offered theoretical and empirical backing to the notion that security prices vary as a result of new information arrival. A large number of studies, however, have shown that such flows of market relevant information cannot fully explain the large volatility observed in financial markets. Many scholars, however, argue that such excess of volatility can be explained by the existence of private information (see, among others, French and Roll 1989). A competing explanation comes from behavioural finance, and it is based on the idea of irrational investors as a solution to the 'excess volatility puzzle'. The existence of excess volatility, within this school of thought, is ascribed to the existence of noise, technical and speculative investors (see, among others, De Long at al. 1990). Both of these competing paradigms struggle to offer tangible evidence of the determinants of excess of volatility. 'Noise' and private information are, in fact, particularly difficult to pinpoint in time, source, scale and scope.

In this chapter, I define a tangible alternative source of excess financial market volatility, a part of the puzzle previously unaccounted for by economists but discerned by market participants. More specifically, I pinpoint the source, timing, scale and scope of sixty-three financial market rumours relating to upcoming European Central Bank (ECB) policy actions and announcements. I assert that such rumours are neither private in scope nor noise in relevance. I define financial market rumours as actionable information, broadcast on Twitter, by multiple market commentators. I suggest this is information to be considered for trade execution, given a probabilistic change in market participant's expectations of future ECB policy decisions, thus leading to a change in market consensus.

As long as enough number of market participants discerns a particular rumour as having a high enough probability to occur, then a period of market volatility should be observable. The empirical findings of this chapter show that out of 63 ECB rumours under scrutiny, 25 result in a significant and positive impact on foreign exchange volatility. The instantaneous increase in volatility during the first minute of rumour arrival is up to 211%, whereas the cumulative increase in volatility over a 60-minute window is as much as 2614%.

The Efficient Market Hypothesis (EMH) suggests that financial asset prices reflect all information relevant to the value of a given traded security. In its strongest form, the EMH

dictates that relevant information, regardless of whether it is in the public domain, or held privately, will be reflected in market price. Given this assertion, asset price fluctuations should reflect the arrival of new information about relevant market events that have already occurred or are expected to occur in the future. This notion has resulted in a large body of research testing the informational efficiency of financial markets. A large number of studies have investigated the market impact of the arrival of macroeconomic news (Andersen et al. 2000, Cutler et al. 1989, Menkhoff 2010, Berry and Howe 1994, Andersen and Bollerslev 1997, Cai et al. 2001, Chang and Taylor 2003, Bauwens et al. 2005, etc.). One strand of this literature focuses on the directional change in asset prices following news arrival, while the remainder measure asset price volatility following news arrival (Li et al. 2015). The latter is of greater relevance to this study. At lower frequency daily observations, French and Roll (1986), Barclay et al. (1990) and Ito et al. (1998), find that a relatively small amount of daily asset price volatility can be attributed to the arrival of new public information. They all conjecture the existence of private information among 'informed market agents', as the reason behind the remaining unexplained asset price volatility. However, any evidence of the existence of such private information is ambiguous, as opposed to being pinpointed in time with a given source.

The availability of higher frequency intraday data has yielded more insightful results. Andersen et al. (2000), Cutler et al. (1989), Menkhoff (2010), Andersen and Bollerslev (1997), Cai et al. (2001) and Chang and Taylor (2003), all find that a larger proportion of price variability can be attributed to the arrival of new information. There remains a consensus, however, that volatility attributable to the arrival of new public information is low when compared to that of their respective samples. Andersen and Bollerslev (1997), in particular, discover a distinct periodic intraday volatility pattern where the magnitude of return variability is consistently correlated with variations in market activity. They suggest, in line with French and Roll (1986), that the greater variability in returns during periods of heightened market activity is evidence of price adjustments due to the existence of private information.[1] More recently, scholars have increasingly focussed on studying the formation of price prior the arrival of new information. Bauwens et al. (2005), Andersen et al. (2007), and Groß-Klußmann and Hautsch (2011) have found heightened levels of volatility in stock, bond and currency markets prior to the arrival of new scheduled and unscheduled public information. Bauwens et al. (2005), draw upon these findings to give further empirical support to the notion that private information triggers price

[1] Periodic volatility patterns during periods of heightened market activity can also occur as a result of market microstructure factors such as systematic periods of increased order flows (Groß-Klußmann and Hautsch 2011).

adjustments prior to market information becoming public. Despite this growing body of literature, questions remain over the plausibility of the notion that a sizable majority of excess price variation occurs due to private information arrival. After all, by nature, private information is likely to filter relatively slowly into price and not to produce large price deviations - as suggested by price discovery authors (see, among others, Andersen and Bollerslev 1997 and Bawuens et al. 2005). While it is fair to acknowledge the existence of private information and a resultant price formation process, the idea that private information is the main - or one of the main determinants - of financial market volatility, is not entirely plausible.

The literature testing the informational efficiency of financial markets has traditionally divided new information into four broad categories. The first consists of the arrival of new scheduled public information named structured information. Information of this type becomes available in the market at a pre-specified time. New structured public information is generally about market events that have occurred in the past. An example of this type of information would be macroeconomic data released by a government body.

The second is the arrival of new unscheduled information named unstructured information. This type of information does not have a pre-specified arrival time, and it is generally about market relevant events that have already occurred. An example of this type of information would be the announcement of a profit warning.

The third type consists of privately held information, which is assumed to circulate among a small group of 'in the know' market agents. Information of this type is generally about a market relevant event due to take place in the future or which has already taken place, but of which the public are unaware. An example of this type of information would be insider knowledge of an upcoming takeover.

The fourth type consists of market rumours. The financial market impact of this type of information has been explored to a lesser extent. This is in part due to the ambiguous nature of rumours and difficulty in acquiring timestamped historical datasets of rumour arrival. Pound and Zeckhauser (1990) were among the first to consider the price effect of market relevant rumours by considering takeover stories published in financial newspapers. They found that speculative stories of potential mergers and acquisitions published in the Wall Street Journal result in significant changes in the 'price trends' for the acquired firm's equity, during the pre-acquisition windows. Similar findings of rumour conditional equity price variation have been presented by Zivney et al. (1996), Gao and Oler (2012) and Chou et al. (2015). More recently, Ahern and Sosyura (2015) carry out more in-depth analysis of similar rumours published in the

mainstream financial U.S. press. They find stock prices of rumoured takeover targets are rumour conditional and that such price movements are unconditional of the accuracy of the reported rumour. There is, therefore, substantial empirical evidence pointing to a rumour conditional stock price effect.

The above literature finds evidence that rumours pertaining to firm-specific factors - such as takeovers, earnings reports, hiring and firing – have a role in the price formation process. This finding is in part supportive of the findings in this chapter. At an elementary level, they all show that rumours, irrespective of realised accuracy have a market price impact. However, the findings presented in the literature fail to show the real-time price formation effect of rumours. This is usually due to rumour datasets not containing timestamps to a high enough frequency. Moreover, the rumours studied are all pertaining to firm-specific factors and it would be valid to suggest that the role of firm-specific rumours is limited given that they amount to idiosyncratic noise in the wider market context, which based on fundamental financial theory, can be diversified away in any long run return window.

There is very limited research into the systematic influence of rumours on macro-markets. Oberlechner and Hocking (2004) show - using questionnaire and interview data - that traders implement currency market transactions based on informal communications with 'in the know' journalists and sources. The intuition is that market relevant rumours carry an informational risk premium. Their intuition and survey findings are in line with the empirical results of this chapter; however, in the absence of an empirical sample of timestamped market relevant rumours, it is difficult to identify any associated real-time price discovery process. Kosfeld (2005) builds on Banerjee's (1993) theoretical model to show that if the diffusion of a rumour is wide enough, through word of mouth, then such rumours can cause a significant 'price run-up'. The model builds on the assumption that rumours transmit more effectively in networks that are small and local rather than large and global. I would argue that this theoretical model can be expanded to include a more global outreach for a given rumour since the existence of social media outlets has been shown to lead to rapid rumour diffusion (Nekovee et al. (2007)). The rapid global transmission combined with the macroeconomic information content of ECB Twitter rumours would suggest that systematic risk factors are at play – so that during rumour diffusion the market should command risk premia.

In this chapter, I focus on a new source of systematic informational flows that is relevant to macro-markets. The advent of social networks has enabled the identification of 'market rumours' and this has rarely been the subject of discussion within the price discovery literature.

In fact, up until the introduction of Twitter and similar financial micro-blogging sources, such rumours whilst known to market participants were not available as a database to investigators. It is this largely neglected category of information, which is of most interest to this study.[2]

Results show that real-time price discovery in the foreign exchange markets are associated with the real-time arrival of ECB relevant rumours. This finding provides fundamental evidence that market relevant rumours - conveying a potential change to future expectations of systematic risk factors - carry risk premium in macro-markets. This previously undetected price formation process incrementally increases the proportion of excess volatility that can be explained.

I suggest that rumours about expected future market events, circulating publicly, are information of this type. Rumours by nature are difficult to pinpoint in time and rational expectations theory would suggest rumour information to be of little fundamental importance to the pricing of assets. It is therefore understandable that this type of information has remained overlooked in the past. I argue, however, that if rumours sufficiently alter the perceptions held by market participants of a given future market event, they become fundamental to the pricing mechanism. This assertion will be discussed in greater depth in section 2.2. A domain is available where market relevant rumours can be pinpointed in time by using Twitter. The social networking platform, Twitter, is a medium through which market commentators and participants exchange opinions and information about market relevant events. I identify rumours of forthcoming ECB actions, dubbed 'ECB sources', which are broadcasted regularly by 'in the know' market commentators. All such broadcasts are timestamped to within one-minute accuracy, which alleviates the difficulty of pinpointing the arrival of a rumour in time. Moreover, the unique nature of Twitter as a broadcasting mechanism is that commentators are not subject to stringent financial regulatory body mandates and in-house substantiation filtration systems. This fundamentally differentiates Twitter from incumbent financial news broadcasters such as Bloomberg and Reuters, which have in the past been the source of new timestamped market information for studies testing the asset price impact of new information (see, among others Li et al. 2015).

I pinpoint the arrival of 63 'ECB sources' rumours broadcast on Twitter, to within one-minute accuracy, during a 420-day sample period of one-minute frequency spot Euro-US dollar exchange rates. Using Andersen and Bollerslev's (1997b) Flexible Fourier form regression, I show that there is a significant increase in the volatility of exchange rate returns following the

[2] Given the above discussion, the statement by Andersen and Bollerslev (1998): *"If private information is at least in part ruled out, supporters of the Efficient Market Hypothesis must concede the existence of fundamental market information detected by market actors but not by economists"* still remains relevant today.

arrival of 25 out of 63 ‘ECB sources’ rumours. Empirical results suggest that in the foreign exchange markets, market participants actively seek rumour information pertaining to market relevant ECB announcements. The consideration of such actionable information in the price formation process makes it possible to explain a greater proportion of asset price volatility.

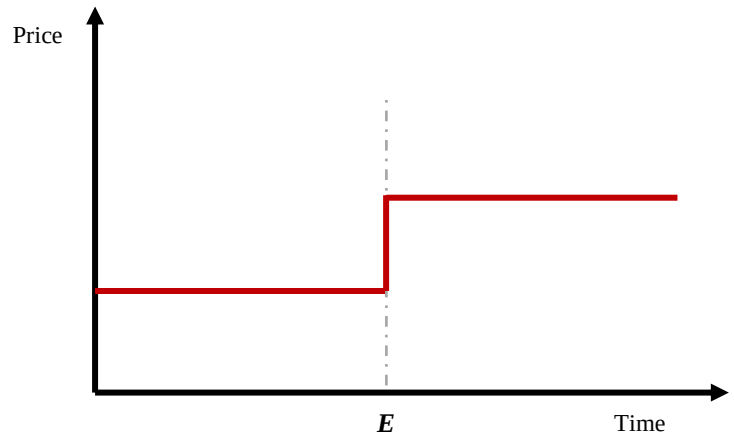
The remainder of the chapter is structured as follows. Section 2.2 defines the theoretical framework that provides the rationale for market rumours to be a source of information fundamental to the process of price formation in efficient markets. Section 2.3 provides details of market and information data. Section 2.4 assesses the robustness of the methodological approach I adopt by means of Monte Carlo simulation. Section 2.5 discusses the empirical results, while section 2.6 concludes the chapter.

2.2 Rumours and Price Formation: A Paradigm

In this study, I show empirically that rumours play a significant role in the price formation process. The question remains, however, if market rumours can be considered information events fundamental to the efficiency of financial markets. Are market rumours a type of information fundamental to the calculation of asset price? Do market agents change their calculations of asset prices based on new rumours? Can the market, therefore, be considered efficient if prices re-adjust at the time of new rumour information arrival?

I answer these questions in the context of strong form EMH, which asserts that an efficient financial market will price all available relevant information, public and private, about market events that have already occurred or are expected to occur in the future. Market rumours by nature are information events predominantly indicating the size, scope, timing and probability of future market events. The arrival of a market rumour could plausibly change the nature of investor forecasts of future events. Depending on the quality of the source of a given rumour, market agents may reasonably alter the probability they attach to the possible outcomes of a specific future event. It is therefore perfectly reasonable for investors to alter their pricing of an asset based on the reliability and timing of a given rumour. The second question remains over the motivation for market agents to change their market positions based on a rumour contingent alteration to their forecast. To answer this question, I refer to Figure 2.1, which provides simple illustrations of price formation leading up to a future event *E*. Figure 2.1a illustrates a semi-strong efficient market, where market agents react only to public information at the time of event *E*.

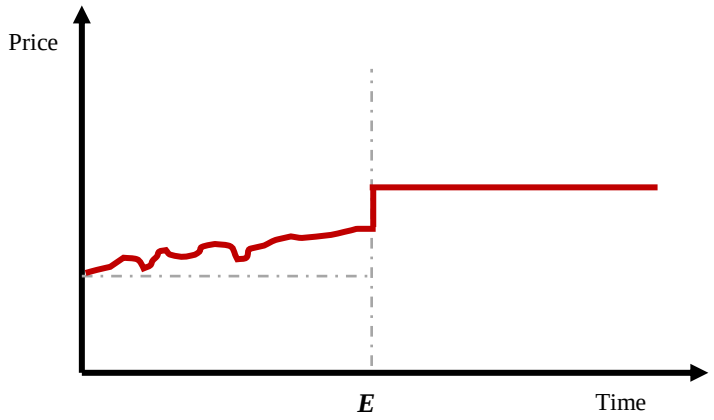
Figure 2.1a



The size, scope and probability of this event become known only at time *E*, and the profits generated by the price adjustment would only be earned by those reacting immediately. The price formation process illustrated in Figure1a is purely theoretical and not observable in financial markets.

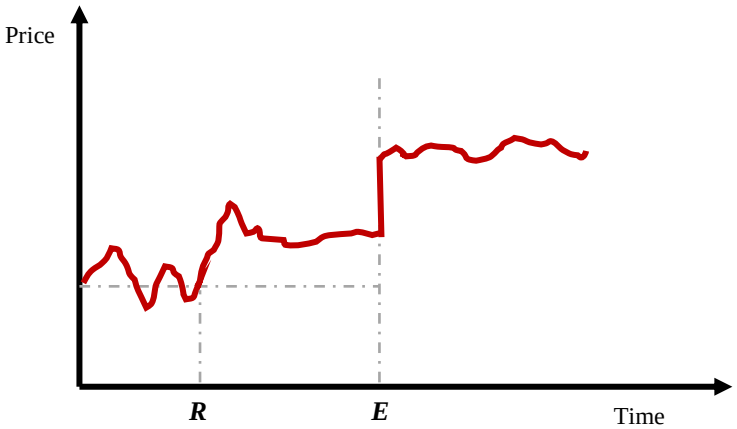
A price formation process with increasing investor price forecast accuracy and private information diffusion is illustrated in Figure1b. Price variation is observed in this scenario up to event *E*.

Figure 2.1b



The timing, size, scope and probability of a future event in a strong form efficient market is partly known and priced by 'in the know' market agents. Market agents with the best forecasts or private information prior to event *E* will profit most. This simple illustration is converging to the reality of financial market price formation.

Figure 2.1c



In reality, however, Figure 2.1c is more representative of pre-event price formation. Price formation is a dynamic process where forecasts alter frequently due to continuous market information flows. The timing, size, scope and probability of upcoming event *E* changes based on heterogeneous forecasts and beliefs. Cumulative market participant forecasts form a market consensus, which at any given time determines price.

If the arrival of a rumour *R* (Figure1c) sufficiently changes the forecasts of a large enough group of market agents to a new homogenous forecast, then a resultant volatility event may be expected. Given that market agents attach a certain probability to the rumour being true they stand to profit by taking action based on the change to their forecasts. The profit may be contemporaneous at time *R* or based on a time advantage over market agents who react at time *E*. With the obvious profit motive of market agents in mind, it is perfectly rational for market agents to change their position based on the probability they attach to the rumour being true. Such a probabilistic calculation is simply a risk-weighted trading decision, one that would be deemed rational in an efficient market.

To demonstrate this, I define I_t as a vector of all variables determining the exchange rate of a given currency pair prior to an event *E*. The outcome of such an event could alter the composition, magnitude and probability attached to any given element of vector I_t. I would, however, expect I_t to remain fixed between *t=0* and *t=E,* without the arrival of unscheduled market relevant information. This vector includes the known quantities of exchange rate determinants such as, the rate of inflation, trade balances, interest rate differential, as well as information about central bank announcements/actions, which determine investor's expectations about the future values of said variables. Further, I denote $\hat{I}_t$ as a vector containing the consensus estimates of all market participants of each element of I_t between *t=0* and *t=E*. Equilibrium foreign exchange rate at any time $t \in [0; E]$ can be written as $FX_t = \emptyset(I_t, \hat{I}_t)$. I can obtain the approximate change in the foreign exchange rate within this time window (*t=0* to *t=E*) by linearizing $\emptyset$ and time differencing the result, so that:

$$\Delta FX_t \cong \emptyset_1' \Delta I_t + \emptyset_2' \Delta \hat{I}_t$$

where Δ is the difference operator between $t = 0\ to\ t = E$, and $\emptyset_1' = \frac{\partial \emptyset}{\partial I_t}$ and $\emptyset_2' = \frac{\partial \emptyset}{\partial \hat{I}_t}$. By supposition, none of the foreign exchange rate determinants can change during the window, thus $\Delta I = 0$ and $\Delta FX = \emptyset_2' \Delta \hat{I}_t$. Any marginal effect on the exchange rate is given by an element of the vector $\emptyset_2'$, as a result of a change to an element of the market consensus vector $\hat{I}$. Changes to market consensus without material changes to vector *I*, detectable as excess volatility, can be deemed a repricing of risk by the market, due to either undetected information events or noise.

I assert that a rumour event *R*, can be seen as an undetected information event. Provided that *R* delivers information about the probability, scale, scope or timing of upcoming event *E*, and that it sufficiently alters market consensus elements of vector $\hat{I}$, a marginal effect on the exchange rate should be observable following the arrival of the rumour at $t=R$. The magnitude of such a change should be proportional to $\emptyset_2' \Delta \hat{I}_t$ as a result of the arrival of *R*. In section 2.5.5, I show that this marginal effect is observable in terms of significant periods of exchange rate volatility following the arrival of ECB rumour information events.

2.3 Data description

2.3.1 Euro-US dollar exchange rate data

The Euro-US dollar currency market is the largest in the world by number of transactions per day. It opens 2200 GMT Sunday and is subject to a 24-hour trading day until 2200 GMT Friday. Pre-market (weekend) trading is available through some exchanges, however trading volume is relatively illiquid when compared to standard non-weekend trading (Chaboud et al. 2014). The markets opening hours overlap geographic trading days in Tokyo, Sydney, Frankfurt, London and New York; the most active financial centres. This 24-hour trading day allows the investigation of price formation during the full weekly information cycle.

I source EUR-USD exchange rate data from Bloomberg professional services. I have chosen to utilise 1-minute interval exchange rate data to accommodate the investigation of post-rumour price formation in greater detail. The data supplied consists of exchange rate quotes for a period spanning from September 29, 2013 to May 08, 2015 (84 weeks, 420 days), totalling in 604,800 observations. Quote data is available for weekend trading hours (2200 GMT Friday to 2200 GMT Sunday) however, I choose to omit these observations due to reasons given above. Further, I omit half trading days and major holidays during which trading is considerably less active. These omissions result in a final minute-by-minute data sample of 596,160 observations. There is a total of 414 trading days, individually made up of 1440 1-minute intraday returns. I define intraday returns ($R_{t,n}$) in terms of trading day t=1,2,...,414 and minute interval n=1,2,…,1440. Where price is defined as $P_{t,n}$, minute by minute returns are calculated as follows:

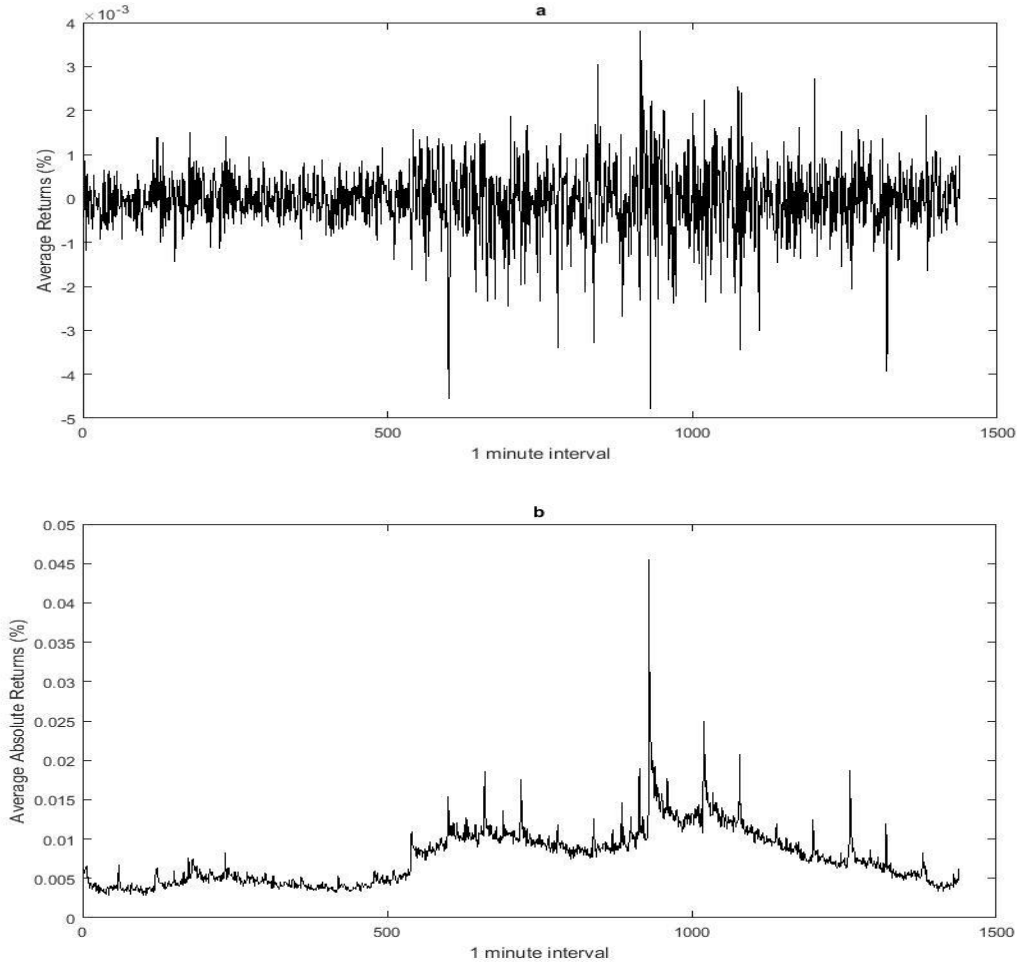
$$R_{t,n} = \log(P_{t,n}) - \log(P_{t,n-1}) \quad [2.1]$$

The collection of daily EUR-USD data is also required for inclusion in the baseline Flexible Fourier form regression to account for the highly persistent volatility factor as observed by Andersen and Bollerslev (1997b). The inferred daily volatility in daily frequency observations of spot EUR-USD exchange rates, as determined by EGARCH estimates, controls for the observable highly persistent volatility in exchange rate. A detailed discussion of this procedure will be outlined in section 2.4. I source this daily data, spanning from January 2012 to June 2015 for a total of 910 observations, via Bloomberg professional services. Daily data (R_t) is then filtered to omit related observations removed from the intraday sample (898 observations). Descriptive statistics for both daily and intraday frequency samples are presented in Table 2.1.

Table 2.1
Descriptive statistics for full sample daily and intraday minute-by-minute EUR-USD exchange rate returns.

	Mean	Median	St. Dev.	Skew	Kurtosis	Min	Max	Observations
R_t	-4.55×10^{-4}	-1.45×10^{-4}	0.0052	-0.138	2.84	-0.021	0.024	898
$R_{t,n}$	-2.64×10^{-7}	0	1.43×10^{-4}	0.235	192.47	-0.0088	0.0094	596,160

Figure 2.2
(a) EUR-USD intraday 1-minute average (one trading day) raw returns $R_{\cdot,n}$. (b) EUR-USD intraday 1-minute average (one trading day) absolute returns $|R_{\cdot,n}|$.

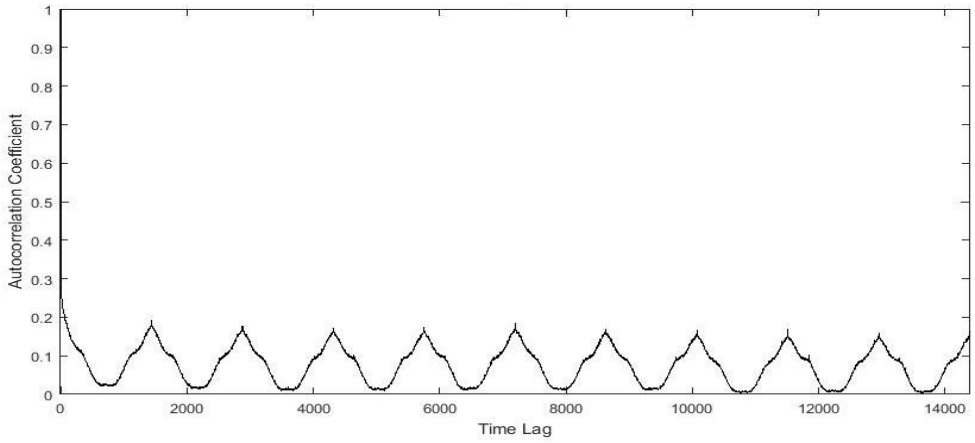


2.3.2 Intraday patterns of the Euro-USD series

It is clear from Table 2.1 that with a skewness of 0.235 and kurtosis of 192.47 the EUR-USD minute-by-minute raw returns are not normally distributed across the sample. This is consistent with previous studies by Chaboud et al. (2014) and Andersen and Bollerslev (1997b), who make use of intraday currency 1-minute and 5-minute data respectively. Furthermore, it can be observed that when sample returns are averaged for the trading day, there are distinguishable increases in return variability during specific times of the trading day. This greater variability is somewhat apparent, although centred around zero, for raw returns but is profoundly clear for absolute returns. This unique feature of intraday data was initially identified by Andersen and

Bollerslev (1997a) and has been consistently observed by a number of other scholars (see, e.g., Bauwens et al. 2005, Dominguez 2003, and Chaboud et al. 2014). Figure 2.3 illustrates the average interval raw and absolute returns across the trading day.

Figure 2.3
Ten day correlogram for absolute EUR-USD returns $|R_{t,n}|$.



The regular intraday pattern observed for absolute returns suggests persistent spikes in volatility at regular times for the trading day across the sample. These spikes in price variability coincide with prominent geographical financial centres opening and their respective scheduled public information releases of macroeconomic data and Central Bank news. This chapter defines the trading day as commencing 2200 GMT when the average absolute 1-minute returns are low relative to the trading day. There are small periodic increases in absolute returns as Asian financial centres begin their respective trading days. There is a notable rise to a higher level of 0.011% for the Frankfurt opening, and a further rise to 0.016% for the start of the London trading day. There are further spikes in absolute returns at 0900 GMT (660^{th} interval) and 1000 GMT (720^{th} interval) which represent regular macroeconomic data releases. The most distinguishing feature of the daily pattern is that of the 930^{th} trading interval at which points absolute returns spike to 0.046%. This represents East coast US financial centres opening and the release of scheduled macroeconomic data such as the US employment report. Further distinguishable spikes represent a second scheduled macroeconomic data point, US stock markets closing and times during which the Federal Open Market Committee (FOMC) releases information.

The intraday pattern in absolute returns discussed above has been reported to result in a persistent U-shaped autocorrelation effect throughout the sample (see, e.g., Andersen and Bollerslev 1998, and Bauwens et al. 2005). I report similar findings in Figure 2.3, which depicts

the 10-day correlogram for absolute returns. Standard volatility models developed for analysis of lower frequency daily, weekly and monthly data, by design, are not appropriate given the persistent autocorrelation in observations (Payne 1996). This is the principal reason I offer for selecting the methodology outlined in section 2.4.

2.3.3 Information event data

There are two sources of financial market information for this chapter; Bloomberg professional services and Twitter. Information events sourced via the former facilitate the inclusion of times during which scheduled and unscheduled public information arrives. For scheduled events, a unity value is included as a dummy variable for the event window commencing at the minute the information is released via Bloomberg. The inclusion of said event windows allow for the testing of the papers' main hypothesis while controlling for any volatility jumps attributable to scheduled public information events. From Bloomberg professional services, I collect timestamped data for 20 categories of scheduled public information releases, totalling in 429 events of this type for the period September 29, 2013 to May 08, 2015. Further, 250,000 unscheduled public information arrivals (news headlines) are collected via Bloomberg for the same period. The times of such news headlines are cross-referenced with the sample of timestamped rumour information. Any rumour observations which either repeat such Bloomberg information arrivals or occur concurrently are eliminated from the sample.[3]

Details of public information data is provided in Table 2.2. For the purpose of this chapter, I collate scheduled public information in twenty categories, FOMC rate decisions, ECB rate decisions, FOMC meeting minutes release, speeches given by prominent ECB and FOMC Committee members, US employment reports, Category 1 economic data (US GDP, US CPI, US ISM manufacturing data, US consumer confidence, German ZEW economic confidence data, German IFO economic confidence data and Eurozone CPI) and Category 2 economic data (US retail sales data, US Durable Goods, US Manufacturing PMI, German Employment Report, European PMI manufacturing, German Industrial Production and German Factory Orders). A relevance indicator provided by Bloomberg determines the constituent economic data events included in the latter two categories.[4] In further research there is scope to include additional control variables, particularly those relating to the microstructure of the EUR/USD market.

Preliminary analysis of the EUR-USD market shows that of the largest 25 absolute returns for the sample, 10 occur concurrently within the arrival of news associated with the ECB (see Table 2.3). It is therefore appropriate, that I focus on highly relevant market rumours relating to forthcoming ECB actions or changes in remit. Such highly relevant market rumours are appropriate examples of actionable information discerned by market actors but not yet

[3] The inclusion of further control variables such as sentiment indicator could potentially augment this research. However, for simplicity and to avoid possible endogeneity problems, I have chosen to exclude such indicators.

[4] It is worth noting that for Eastern Standard Time (New York) the change to daylight savings time occurs sooner and ends later than in Western Europe. This can cause some disparity when observing US related information events. I control for these disparate periods when constructing public information dummy variables.

Table 2.2
Scheduled public information arrival for period September 29, 2013 to May 08, 2015.

Announcement	Regular Time (GMT)	Bloomberg Relevance Indicator	Number of Observations
FOMC Rate Decision	1900/1800	97.6	13
ECB Rate Decision	1245	97.7	18
FOMC Minutes	1930/1830	97.6	12
ECB Speakers	Various	N/A	46
FOMC Speakers	Various	N/A	52
US Employment Report	1330	99.2	20
US CPI (Cat 1)	1330/1230	94.4	19
US GDP (Cat 1)	1330/1230	96.8	19
US ISM (Cat 1)	1500/1400	96.0	19
German ZEW (Cat 1)	1000	98.3	19
German IFO (Cat 1)	0900	96.6	19
Eurozone CPI YoY (Cat 1)	1000	95.3	19
US Consumer Confidence (Cat1)	1330/1230	95.2	19
US Durable Goods (Cat 2)	1330/1230	92.1	19
US Retail Sales (Cat 2)	1330/1230	91.3	19
US Manufacturing PMI (Cat 2)	1445/1345	90.0	19
German Employment Report (Cat 2)	0855	90.0	19
Eurozone Manufacturing PMI (Cat 2)	0800 to 0900	90.0	19
German Industrial Production (Cat 2)	0700/1100	93.2	20
German Factory Orders (Cat 2)	0700/1100	91.5	20

investigated by economists. Rumours of this type are quoted as 'ECB sources' stories. These rumours are regularly reported by 'in the know' financial market commentators via Twitter.

ECB sources stories are particularly prevalent within a one-week window of the ECB's Governing Council meeting that takes place on a monthly basis. I can gauge the popularity of the ECB sources story by the number of times the quoted rumour is repeated. It is relatively simple to search Twitter archives for the phrase 'ECB sources'. I select ECB rumour events where the quoted story is repeated by more than 50 'in the know' financial market commentators. I then perform an advanced search for the full quoted story i.e. *"ECB Sources: ECB is working on a discussion chapter to execute government bond buying. 3 different options",* and pinpoint the time of the first broadcast of the quote. In total, I collect times for the first broadcast of 63 ECB rumour events. Some 'sources' stories gain so much traction among financial commentators that they are then reported via Bloomberg professional services. Details of the 63 'ECB sources' events are given in Appendix A1.

The applied threshold of 50 repeats of a given rumour is determined arbitrarily, but nonetheless is reasonable method of preventing the selection of stale rumours and those which are largely

ignored by financial market commentators. Since the rumours are collected manually, the threshold also serves as a means of eliminating selection bias. In effect reducing problems associated with hand selected information samples by automating selection. There is scope in future research to perform sensitivity analysis to gauge a more precise threshold for a market rumour to be considered ‘actionable’.

2.4 Methodology

To infer any meaningful exchange rate volatility effect due to the arrival of new information, I need to account for the intraday pattern in absolute returns found in the previous section. I make use of the Andersen and Bollerslev's (1997b) empirical model as it is the most closely aligned with the aim of detecting the exchange rate return variability linked with the arrival of new information. This model has been developed specifically for the purpose of controlling for the intraday diurnal pattern persistent in intraday data. By design, the model is flexible and can be adapted to control for latent daily volatility clustering, low-frequency calendar effects and the arrival of heterogeneous public information other than the principal rumour information in question. The model has been applied by several authors in the literature to study the volatility effects of the arrival of new information on equity, currency, bond and their respective futures markets (see, e.g. Bauwens et al. 2005, Andersen and Bollerslev 1998, Bollerslev et al. 2000, Andersen et al. 2000, Dominguez 2003 and Cai et al. 2001).

In order to 'smooth' out intraday periodicity we must think in two frequencies of time; day t and interval n within day t. Thus, $R_{t,n}$ is the market return at interval n of day t (e.g. 2200 GMT would be n=1 for a given day, t). The model can be specified as follows;

$$R_{t,n} - \bar{R}_{t,n} = \sigma_{t,n} \cdot s_{t,n} \cdot Z_{t,n} \qquad [2.2]$$

where $\bar{R}_{t,n}$, is the mean market return, which is defined as a sample mean of 1-minute returns. $Z_{t,n}$, is a normally distributed error term with mean zero and unit variance, whereas the term $s_{t,n}$ captures the intraday periodic component discussed in section 2.3.2. Finally, $\sigma_{t,n}$ captures the latent interday conditional heteroscedasticity component which remains persistent. It is the joint presence of this latent interday component and the intraday periodic patterns documented in Figure 2.2b that result in the u-shaped pattern observe in the correlegram of absolute returns (Andersen and Bollerslev 1997b). Related intraday estimates of the highly persistent interday conditional heteroskedasticity can be defined as:

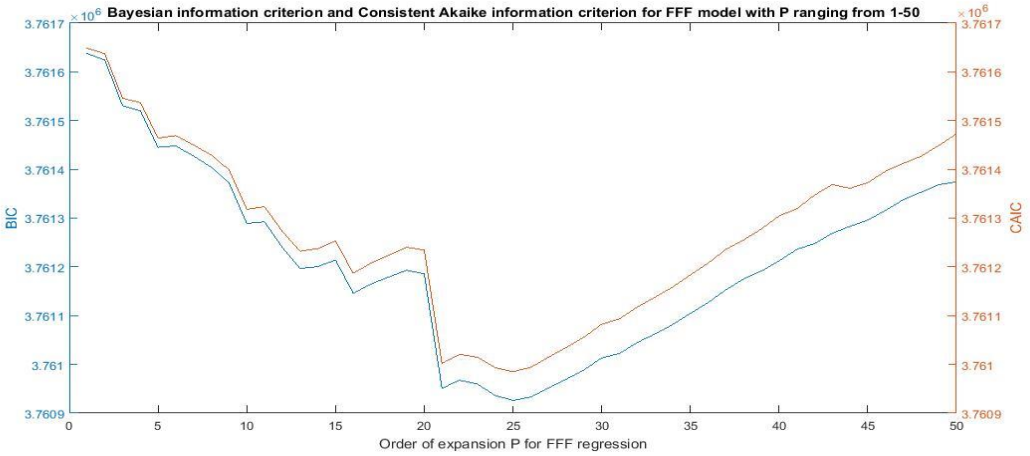
$$\hat{\sigma}_{t,n} = \hat{\sigma}_t / N^{1/2} \qquad [2.3]$$

where N is the number of intervals in each day (1440) and $\hat{\sigma}_t$ is estimated using an generalised autoregressive conditional heteroscedasticity (GARCH) type model. Intraday estimates of the latent interday volatility component achieved through equation 2.3 are under the assumption that this volatility component remains constant throughout the day. Although this assumption

is not necessarily correct, it has been shown to have no impact on the overall robustness of the FFF regression nor does it affect the consistency of the regression estimates[5].

In order to fully specify a functional model from the general representation outlined in equation (2.2), the components are log-transformed and squared.

Figure 2.4
Bayesian and Consistent Akaike information criterion calculated for Flexible Fourier form regressions where order of expansion P, takes values from 1-50.



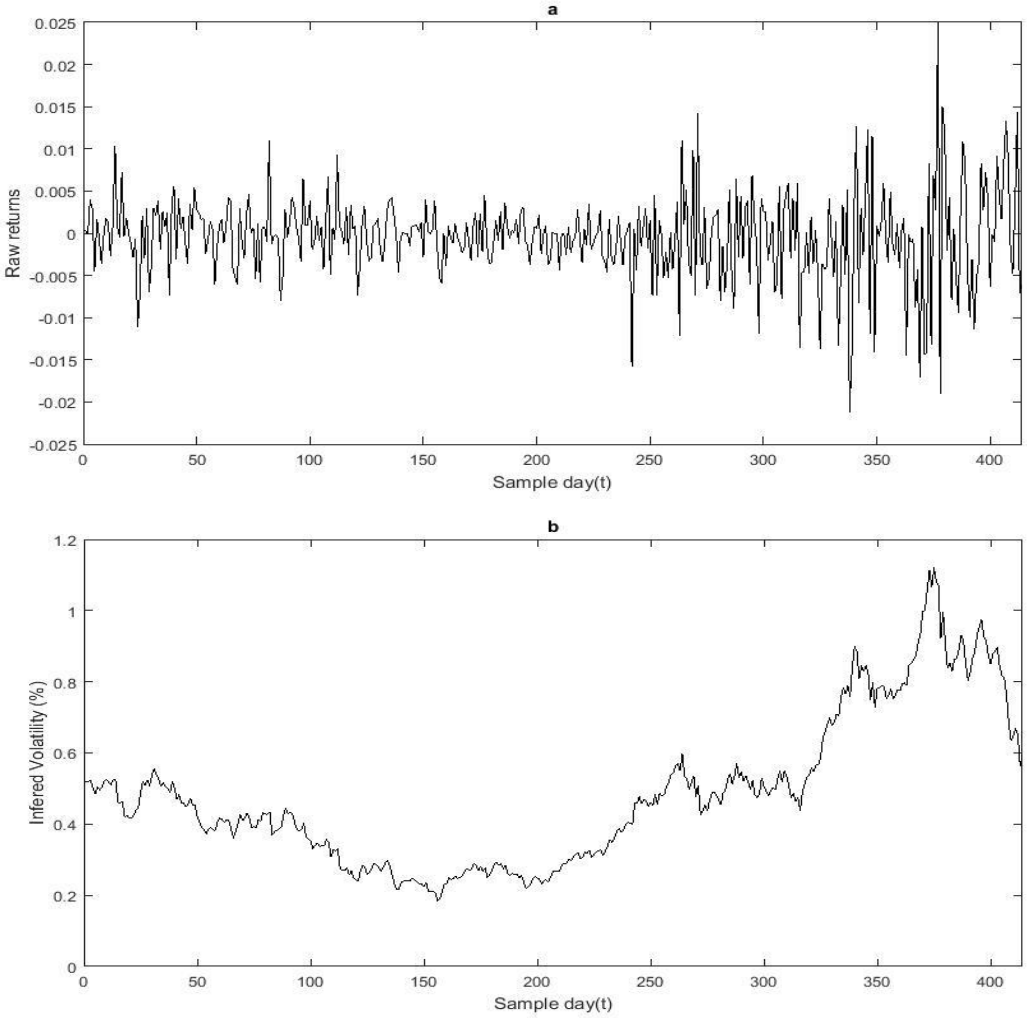
This allows for the isolation of the term $s_{t,n}$ as the sole explanatory component of normalised and debased 1-minute EUR-USD volatility process:

$$2\ln\left[\left|R_{t,n} - \bar{R}_{t,n}\right|\right] - \ln\hat{\sigma}_{t,n}^2 = c + 2\ln s_{t,n} + \varepsilon_{t,n} \qquad [2.4]$$

The final model is defined by Andersen and Bollerslev (1997b) as two-step flexible Fourier form (FFF) regression. The first step requires appropriate estimates of the sample mean $\bar{R}_{t,n}$, a GARCH estimate of the latent daily volatility component $\hat{\sigma}_t$ and the appropriate specification of the public information, intraday pattern and rumour event components of $s_{t,n}$. For the daily sample period, January 2012 to June 2015, I observe large exchange rate fluctuations (Figure 2.5a) particularly for the latter part of the 414 day, intraday sample period. Such periods of heightened volatility have been found to expose limitations of standard GARCH models (Engle (2001)). I therefore apply a GARCH (1, 1) and an exponentially weighted GARCH (EGARCH 1, 1) model to daily EUR/USD returns. The latter model is better formulated to capture the direction and persistence of volatility shocks in the daily sample. Figure 2.5b depicts the daily volatility estimates obtained from the EGARCH (1, 1) model.

[5] For further details see Andersen and Bollerslev (1997b).

Figure 2.5
(a) Raw daily returns for 414-day period from September 29, 2013 through May 08, 2015. (b) Conditional standard deviation inference from an EGARCH(1,1) model for daily EUR-USD returns for September 29, 2013 through May 08, 2015.



The second step of the FFF regression is the ordinary least squares (OLS) estimation of the equation provided below in its final form:

$$2\ln\frac{\left|R_{t,n}-\bar{R}_{t,n}\right|}{\hat{\sigma}_t/N^{1/2}} = c + \delta_{0,1}\frac{n}{N} + \delta_{0,2}\frac{n^2}{N} + \sum_{k=1}^{D}\lambda_k I_k(t,n) + \sum_{P=1}^{P}\left(\delta_{c,p}cos\frac{p2\pi}{N}n + \delta_{s,p}sin\frac{p2\pi}{N}n\right) + \varepsilon_{t,n} \qquad [2.5]$$

where the unknown parameters to estimate are; $\delta_{0,1}$, $\delta_{0,2}$, $\delta_{c,p}$, $\delta_{s,p}$, and λ_k, with p=1, .., P and k= 1, .., D. The $\sum_{P=1}^{P}\left(\delta_{c,p}cos\frac{p2\pi}{N}n + \delta_{s,p}sin\frac{p2\pi}{N}n\right)$ sinusoid parameter (Fourier series) controls for intraday seasonality component for each day *t*, of N intervals (1440). This allows for linear estimation of the volatility impact attributable to public information and rumour events *k*, for interval *n*, on day *t*, represented by $I_k(t,n)$. Normalising constants *n/N* and n^2/N are linear and quadratic trends within each day, where n=1,..,1440. *P* determines the order of expansion

(pitch) of the sinusoid components in the trigonometric variable. An order of expansion of 4-8 has been implemented in previous adoptions of this model (Andersen and Bollerslev 1997b, Bollerslev et al. 2000 and Dominguez 2003).

The order of expansion (*P*) appropriate for the FFF regression implemented with one-minute frequency data used in this analysis is likely to deviate from the above studies, given their use of 5-minute data. I determine the appropriate order of expansion by calculating the Bayesian and Consistent Akaike Information Criterion for equation (2.5) when *P* ranges from 1 to 50 (see Figure 2.4). The results of model comparison provided in Figure 2.4 shows that the optimum value for order of expansion of the Fourier series, is *P*=25. The periodic pattern can be converted to absolute returns, exclusive of dummy variables, as follows:

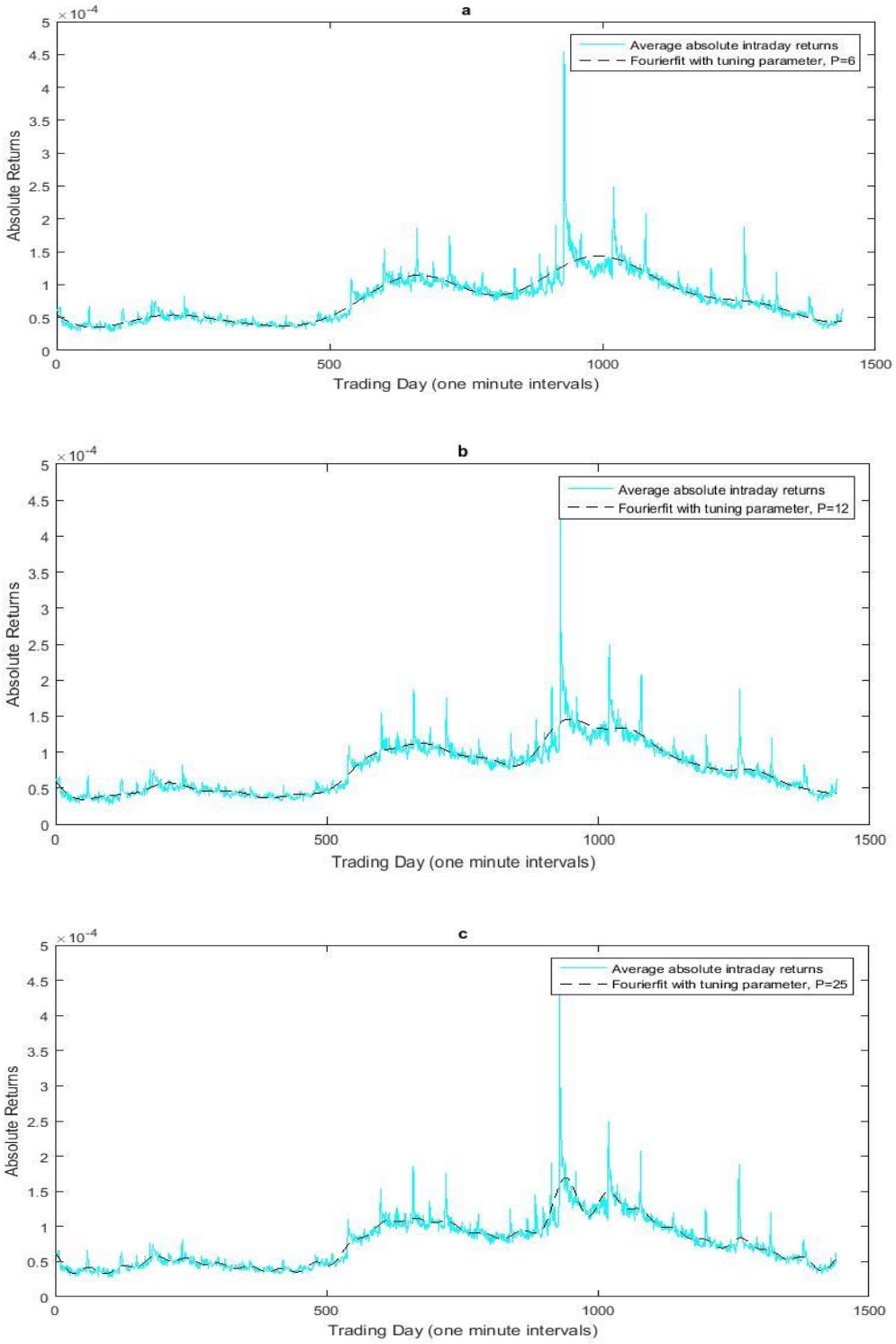
$$\left|R_{t,n} - \bar{R}_{t,n}\right| = N^{-1/2} \cdot \hat{\sigma}_t \cdot \exp\left(\frac{\hat{c} + \hat{\delta}_{0,1}\frac{n}{N} + \hat{\delta}_{0,2}\frac{n^2}{N} + \sum_{P=1}^{P}\left(\hat{\delta}_{c,p} cos\frac{p2\pi}{N}n + \hat{\delta}_{s,p} sin\frac{p2\pi}{N}n\right)}{2}\right) \cdot \exp\left(\hat{\varepsilon}_{t,n}/2\right) \qquad [2.6]$$

A comparative illustration is provided in Figure 2.6 between, 1-minute average trading day, realised absolute returns and fitted absolute returns implied by the FFF model and calculated in equation (2.6). Charts a, b and c demonstrate the improvement in fit when the tuning parameter *P* is increased from six to twelve and then to 25 – with the latter being the optimal order of expansion.

OLS estimation of the FFF regression outlined above will provide consistent parameter estimates for information and rumour events, given correct specification of the sinusoid term according to Andersen and Bollerslev (1998). The heteroscedasticity correction and log transformation in the first step of the sequential FFF approach enhance the efficiency of linear parameter estimates for public information and rumour event dummies in the second step. I double-check that this is the case by simulating 2000 trials of the above model using the Monte Carlo approach. I find all parameter estimates (OLS) in the second step FFF regression to be normally distributed, including all 25 $\delta_{c,p}$ and $\delta_{s,p}$ coefficients. This simulation exercise suggests that the finite sample properties of the above OLS estimates do not depart from the standard asymptotic properties.[6]

[6] The empirical results from the above Monte Carlo simulations are presented in Appendix A2.

Figure 2.6
Comparative illustration: Fit of the Fourier component, with tuning parameter P=6, 12 and 25, of the FFF model to the average absolute one-minute EUR-USD returns across the 24-hour trading day. (a) Graphs the fit of the Fourier component with tuning parameter P=6 of the FFF model, to the average absolute one-minute EUR-USD returns across the 24-hour trading day. (b) Graphs the fit of the Fourier component with tuning parameter P=12 of the FFF model, to the average absolute one-minute EUR-USD returns across the 24-hour trading day. (c) Graphs the fit of the Fourier component with tuning parameter P=25 of the FFF model, to the average absolute one-minute EUR-USD returns across the 24-hour trading day



The effectiveness of this model has been reviewed by Harju and Hussain (2011). They suggest that the non-linear transformation performed using the trigonometric component may result in time varying non-zero values in $\varepsilon_{t,n}$ for times when $I_k(t,n)$ takes unity value (during information event windows). In their evaluation of the FFF procedure they suggest an integrated approach to the FFF model, where sequential estimates of ARCH effect and non-linear transformation are combined in one step, which provides more efficient parameter estimates of linear event dummies. The improvements in model efficiency are however found to be marginal by measure of mean absolute error (MAE), mean squared errors (MSE) and Diebold–Mariano test (DM test). [7]

The biggest improvement to model efficiency occur by swapping between GARCH (1, 1) and a HYGARCH (1, d, 1) in the first sequential heteroscedasticity correction step. By measure of mean squared errors, Harju and Hussain (2011), find an improvement of 2% for a sequential FFF model which is subject to HYGARCH (1, d, 1) heteroscedasticity correction in the first stage. Given that their suggested improvement yielded marginal improvements to the efficiency of estimates and no significant change in estimation outcome, I have chosen to follow the stepwise process adopted by Andersen and Bollerslev (1997b). This is partly for simplicity, but more importantly, to allow for a more direct comparison of event studies exclusive of market rumours (Andersen and Bollerslev (1997b and 1998), Bollerslev et al. 2000 and Dominguez 2003), and this research.

Overall, the supporting evidence from the Akaike and Bayesian Information Criterion for the first step procedure for equation (2.5), along with additional results of the Monte Carlo simulation of the second step procedure, I conclude the FFF model is an appropriate tool for the purpose of this study.

[7] By measure of mean absolute error (MAE) and mean squared errors (MSE), an integrated FFF model exhibits an improvement over a sequential FFF model by 1.3% and 0.6% respectively (Harju and Hussain, 2011).

2.5 Empirical findings

2.5.1 Preliminary analysis

I begin by tabulating the 25 largest absolute one-minute returns over the full sample period. I then cross-reference the times and dates of these abrupt changes in exchange rate with the sample of public and actionable information data set. The same matching exercise was followed by Fleming and Remolona (1999), Andersen, Bollerslev and Cai (2000) and Bollerslev, Cai and Song (2000) in analysis of return variability in stock, bond and currency markets during public information arrival. Their results show concurrently, that the largest 25 absolute returns of their respective markets of interest occur during times of public information arrival. I carry out the same exercise for find that of the 25 largest absolute returns, 21 occur during times of public information arrival. These last, together with their matched information/rumour event, are reported in Table 2.3.

Twenty of the largest jumps in exchange rate can be attributed to scheduled public information and one to the unscheduled announcement of the approval of an economic assistance package for Greece. These 21 events are corroborated, certified and reported by the accredited newswire Bloomberg. Such information has in the past been referred to as fundamental financial market information; relevant, 'rational' public market information reported by an authorised newswire. Four of the 25 largest absolute EUR-USD returns for the full sample period occur during times of 'actionable' information arrival. Three of these events are rumours of forthcoming ECB action reported by 'in the know' commentators broadcasting on Twitter. The fourth is the reporting of the arrival of Russian troops in Crimea by independent Twitter users.

While this matching exercise is somewhat subjective, the results reported in Table 2.3 suggest that 'actionable' rumours discerned by market agents could have a sizable impact on market price. These matching results provide the basis for the hypothesis that the availability of Twitter as a medium for rumour diffusion would enable economists to identify a form of ambiguous - yet actionable - information that can be associated with significant fluctuations in market prices. I conclude this to be substantial preliminary support for the hypothesis that market rumours - i.e. information previously not discerned and categorised as private information or miss-identified as not fundamental - are of value to traders and they are a constituent factor of market price formation.

Table 2.3
Largest absolute 1-minute returns for EUR-USD spot exchange rate market from September 29, 2013 through May 08, 2015. For each of the 25 largest absolute returns, I indicate the information/rumour event, which may have contributed to returns.

Absolute Returns (%)	Timestamp (GMT)	Return Interval	Information/Rumour event
0.942	03/04/2015 1330	930	US Employment Report
0.878	07/11/2013 1245	885	ECB Rate Decisions
0.875	18/03/2015 2004	1384	FED Press Conference
0.823	06/03/2015 1331	931	US Employment Report
0.786	22/01/2015 1344	944	ECB Press Conference
0.761	22/01/2015 1340	940	ECB Press Conference
0.617	18/03/2015 1800	1260	FED Rate Decision
0.587	06/02/2015 1330	930	US Employment Report
0.571	20/02/2015 1735	1175	Euro group decide to extend financial assistance to Greece
0.564	18/03/2015 2005	1385	FED Rate Decision
0.535	05/12/2014 1330	930	US Employment Report
0.479	12/03/2015 1230	930	US Retail Sales
0.422	18/02/2015 1900	1260	FOMC Minutes
0.421	03/10/2014 1330	930	US Employment Report
0.404	04/09/2014 1245	885	ECB Rate Decisions
0.388	22/01/2015 1345	945	ECB Press Conference
0.375	07/02/2014 1330	930	US Employment Report
0.367	18/03/2015 2003	1383	FED Rate Decision
0.363	04/12/2014 1732	1172	ECB Sources (Twitter) German ECB members opposed to new balance sheet language
0.356	17/09/2014 1900	1260	FED Rate Decision
0.344	06/11/2014 1333	933	ECB Press Conference
0.342	28/02/2014 1000	720	Rumours of Russian troops in Sevastopol emerge on Twitter
0.340	20/11/2013 1520	1040	ECB Sources(Twitter) Governing council considering negative deposit rate of 0.1%
0.339	21/01/2015 1435	995	ECB Sources(Twitter): QE proposal calls for roughly €50 billion in bond buying per month
0.338	29/10/2014 1800	1260	FED Rate Decision

2.5.2 Intraday periodicity

The highly persistent intraday volatility pattern evident in one-minute absolute returns illustrated in Figure 2.2 is consistent with the findings of previous studies based on intraday data. For instance, Dominguez (2003), Andersen and Bollerslev (1998), Bollerslev et al. (2000) and Bawuens et al. (2005) all find evidence of intraday periodicity of this type for five-minute interval data and adopt the FFF regression approach to control for this. Their selection of smaller sets of tuning parameters (8, 4, 6 and 4 respectively) is appropriate for lower frequency five-minute data.[8]

[8] Andersen and Bollerslev (1998) is the only paper to include parameter results of the cosinor element of the FFF regression. They find all but one of the sinusoid parameters, the fourth sine variable, to be significant.

Table 2.4
Coefficient estimates for constant, normalising constants and Fourier components of the FFF regression of equation (2.5). Results set out for the complete FFF regression (inclusive of public information and ECB rumour event dummies), and for the same regression with both rumour and public information events excluded.

Parameter	FFF Regression	t-Stat	Rumours Excluded	t-Stat	Periodic Pattern Only	t-Stat
c	14.264	3.772	14.316	3.779	14.974	3.905
δ0,1	-116.791	-5.155	-117.174	-5.163	-121.526	-5.290
δ0,2	0.081	5.136	0.081	5.144	0.084	5.271
δc,1	-13.419	-5.851	-13.447	-5.852	-13.831	-5.947
δs,1	-1.874	-35.281	-1.864	-35.034	-1.815	-33.707
δc,2	-3.090	-5.389	-3.103	-5.401	-3.226	-5.547
δs,2	0.057	2.033	0.054	1.927	0.043	1.531
δc,3	-1.744	-6.837	-1.744	-6.827	-1.796	-6.946
δs,3	0.536	26.562	0.537	26.547	0.514	25.110
δc,4	-0.793	-5.517	-0.796	-5.529	-0.843	-5.784
δs,4	-0.758	-45.656	-0.762	-45.812	-0.717	-42.628
δc,5	-0.514	-5.571	-0.518	-5.600	-0.492	-5.255
δs,5	-0.057	-3.911	-0.051	-3.476	-0.041	-2.766
δc,6	-0.333	-5.166	-0.329	-5.092	-0.348	-5.315
δs,6	-0.057	-4.239	-0.058	-4.289	-0.084	-6.150
δc,7	-0.187	-3.898	-0.186	-3.879	-0.195	-4.015
δs,7	-0.080	-6.290	-0.079	-6.177	-0.052	-4.084
δc,8	-0.105	-2.813	-0.105	-2.802	-0.104	-2.746
δs,8	0.113	9.270	0.111	9.082	0.104	8.477
δc,9	-0.157	-5.211	-0.158	-5.245	-0.155	-5.065
δs,9	-0.002	-0.178	-0.006	-0.470	-0.016	-1.298
δc,10	-0.117	-4.664	-0.120	-4.782	-0.133	-5.222
δs,10	0.023	1.985	0.025	2.143	0.034	2.872
δc,11	-0.105	-4.850	-0.105	-4.867	-0.104	-4.774
δs,11	0.058	5.153	0.056	4.912	0.034	2.962
δc,12	-0.071	-3.731	-0.072	-3.801	-0.082	-4.249
δs,12	-0.067	-6.024	-0.065	-5.841	-0.055	-4.826
δc,13	-0.096	-5.652	-0.094	-5.539	-0.107	-6.186
δs,13	0.012	1.095	0.013	1.158	0.012	1.069
δc,14	-0.056	-3.571	-0.056	-3.576	-0.032	-2.010
δs,14	0.015	1.351	0.012	1.101	0.008	0.762
δc,15	0.012	0.853	0.012	0.821	-0.016	-1.101
δs,15	-0.077	-7.131	-0.075	-6.897	-0.082	-7.457
δc,16	-0.051	-3.752	-0.052	-3.794	-0.045	-3.271
δs,16	0.032	2.955	0.032	2.927	0.043	3.946
δc,17	-0.004	-0.286	-0.002	-0.175	0.009	0.678
δs,17	0.034	3.194	0.035	3.284	0.042	3.822
δc,18	0.037	2.986	0.037	2.960	0.031	2.476
δs,18	-0.011	-1.024	-0.012	-1.083	-0.037	-3.430
δc,19	-0.018	-1.506	-0.019	-1.566	-0.039	-3.210
δs,19	0.050	4.686	0.049	4.570	0.065	6.018
δc,20	0.010	0.863	0.010	0.889	0.029	2.434
δs,20	-0.032	-3.055	-0.032	-3.028	-0.027	-2.515
δc,21	0.063	.511	0.061	5.333	0.050	4.259
δs,21	-0.015	-1.440	-0.016	-1.499	-0.034	-3.161
δc,22	0.025	2.243	0.026	2.337	0.021	1.869
δs,22	0.021	1.999	0.022	2.113	0.035	3.312
δc,23	0.065	5.799	0.064	5.768	0.066	5.865
δs,23	-0.049	-4.652	-0.049	-4.684	-0.048	-4.508
δc,24	0.180	16.339	0.180	16.352	0.182	16.322
δs,24	0.024	2.260	0.024	2.246	0.021	1.955
δc,25	0.042	3.835	0.041	3.746	0.036	3.218
δs,25	-0.003	-0.325	-0.004	-0.364	-0.001	-0.064

For the purpose of this study, I find a tuning parameter of 25 to be the most appropriate for the one-minute frequency EUR-USD returns sample - as outlined in section 2.4. In Table 2.4 I set

out parameter estimates for the intraday periodicity control component of the FFF regression of equation (2.5). The second and third column report the parameter estimates for the full FFF regression inclusive of rumour and public information dummy variables. The remaining columns report parameter estimates obtained when the rumour event dummy variables and when the rumour and public information event dummy variables are excluded from the FFF regression[9]. The results show that most of the fifty sinusoid parameter estimates are significant and perform well in controlling for the highly persistent intraday periodicity in absolute EUR-USD returns. As with findings presented by Andersen and Bollerslev (1998), some Fourier series parameter estimates are insignificant. The inclusion of such terms is, however necessary for better smoothing of the intraday periodic component.[10] Most notably, results in Table 2.4 show that the inclusion of rumour and public information dummy variables reduces the number of significant sinusoid parameters and the respective size of their coefficient estimates. Andersen and Bollerslev (1998), Andersen et al. (2000), Dominguez (2003) and Bawuens et al. (2005) have all suggested and supported the idea that intraday periodicity is a manifestation of price variability resulting from the existence of private information. From these results, I can conclude that the inclusion of a relatively small number of rumour event variables is able to absorb some volatility dynamics previously captured by the intraday periodic components.

[9] The R^2 for FFF regression, Rumours Excluded and Periodic Pattern only are 0.1032, 0.0933 and 0.0895 respectively.

[10] For example, the inclusion of the insignificant ninth sine parameter ($\delta s,9$) facilitates the inclusion of the subsequent significant sinusoid parameters.

2.5.3 Volatility response structure

Macroeconomic public information and rumour events occur infrequently in the sample period relative to the large number of 596,160 EUR-USD return observations. I observe 63 rumour events and control for 20 categories of macroeconomic announcements the summation of which is 492 observations of information events. The relative infrequency of such events and persistent noise in high frequency intraday data - as noted in sections 2.3.2 and 2.4 - make coefficient point-estimation of independent events and corresponding time intervals following the events implausible (Andersen and Bollerslev 1998). The inclusion of an FOMC rate decision event as a single minute dummy variable in equation (2.5), for example, would result in an insignificant coefficient estimate given the aforementioned infrequency of such an event. To control for this feature of the dataset, one option is to extend event dummy variables to a longer time horizon, say 60 minutes following the event instead of one minute. This solution would improve the chances of capturing the volatility impact of an associated information event. This however, would provide only a broad-brush picture of the immediate impact of information arrival on the volatility of exchange rate. In this case, the coefficient estimates would only suggest some impact on volatility during the 60-minute event window. Empirical estimates of equation (2.5) with 60-minute dummy variables capturing rumour events are reported in Table 2.6.

Andersen and Bollerslev (1998) proposed an alternative methodology to gain a better insight into the instantaneous and cumulative impact of information events on price variability. They propose that volatility response in exchange rates following information arrival can be proxied with an average volatility pattern across all such events. They calibrate this pattern by fitting a third order polynomial to volatility observations during announcement event windows. The fitted volatility response pattern is then included in the FFF regression as explanatory variable to calculate the degree to which absolute returns during the event "load onto" this pattern. The implication of this is that, for each information event k and subsequent N_k time intervals, the $I_k(t,n)$ term in equation (2.5) is replaced with a calibrated volatility response pattern $\gamma(i)$ where $i = 0,1,2 \dots, N_k$. The volatility response pattern is calibrated by fitting an appropriate polynomial structure to the observed average volatility response in the immediate post announcement period for a specific type of market information event.

While Andersen and Bollerslev (1998) adopt a single volatility response pattern for macroeconomic information arrival, I calibrate four volatility response patterns specific to the type of macroeconomic information event and calibrate a further volatility response pattern

specific to rumour event windows. The intuition is that the volatility response pattern following information arrival differs depending on the speed of information arrival as well as the type of information content. For instance, during macroeconomic events such as the ECB rate decision where a press conference is held, information arrival is incremental. This is contrary to macroeconomic data release, where information arrival is immediate.

I calibrate volatility response patterns specific to ECB rumour events, ECB rate decision events, FOMC rate decision events, slow release public information events (FOMC minutes, FOMC and ECB prominent speakers) and fast release public information events (US Employment report, US GDP, US CPI, US ISM manufacturing data, US consumer confidence, German ZEW economic confidence data, German IFO economic confidence data, Eurozone CPI, US retail sales data, US Durable Goods, US Manufacturing PMI, German Employment Report, European PMI manufacturing, German Industrial Production and German Factory Orders).

The four volatility response patterns for macroeconomic announcements are calibrated by fitting a third order polynomial to the dummy variables attached to the event windows for the four categories of macroeconomic information. The polynomial restricts the volatility response window to 60 minutes for all macroeconomic information releases, except the ECB and FOMC rate decisions, for which the response window is extended to 120 minutes to accommodate the lengthy press conference that follows the decision announcement.

The third order polynomials calibrated for the volatility response following ECB (equation (2.7)) and FOMC rate decisions (equation (2.8)) are provided below:

$$\gamma_{ECB}(i) = 5.577[1-(i/120)^3] - 0.127\left[1-(i/120)^2\right]i + 0.00301[1-(i/120)]i^2 \quad [2.7]$$

$$\gamma_{FOMC}(i) = 8.856[1-(i/120)^3] - 0.228\left[1-(i/120)^2\right]i + 0.00412[1-(i/120)]i^2 \quad [2.8]$$

where $i = 0,1,2 \ldots,120$. I then specify the third order polynomials calibrated for the volatility response following slow release (SR) public information events (equation (2.9)) and fast release (FR) public information events (equation (2.10)) as follows:

$$\gamma_{SR}(i) = 3.850[1-(i/60)^3] - 0.218\left[1-(i/60)^2\right]i + 0.00733[1-(i/60)]i^2 \quad [2.9]$$

$$\gamma_{FR}(i) = 4.527[1-(i/60)^3] - 0.326\left[1-(i/60)^2\right]i + 0.0100[1-(i/60)]i^2 \quad [2.10]$$

where $i = 0,1,2 \ldots,60$.

The volatility response pattern for ECB rumour event windows is calibrated through a higher 7th order polynomial fitted to all parameters of equation (2.5) relevant for ECB rumour event windows. The choice of higher order polynomial allows for more flexibility in capturing greater fluctuations in the volatility pattern throughout rumour event windows. Intuitively, the ambiguous nature of market rumours could in fact result in a less cohesive price formation process. From experimentation and evidence presented in Figure 2.8 I can see that, contrary to 'fundamental' macroeconomic events, the volatility response following rumour events does not decay consistently across the event window. There is a distinct decrease, followed by an increase in volatility response for five one-minute intervals following the arrival of a rumour before volatility begins to decay again. A higher order polynomial allows for better calibration of this distinct pattern. The 7th order polynomial calibrated for the volatility response following ECB rumour events (equation (2.11)) is specified as follows:

$$\gamma_{Rumour}(i) = 2.75e^{-10}i^7 - 6.60e^{-8}i^6 + 6.25e^{-6}i^5 - 2.98e^{-4}i^4 - 0.0075i^3 + 0.096i^2 - 0.52i + 0.19 \quad [2.11]$$

where $i = 0,1,2 \ldots ,60$.

Given that the above volatility response patterns are pre-determined, an estimated coefficient $\lambda(k,i)$ loading onto this pattern during event *k*, enables the calculation of the immediate volatility impact of an information event. The immediate volatility response in absolute returns (from equation (2.6)) is given by $\exp(\hat{\lambda}_k \cdot \gamma(0)/2) - 1$, whereas the same response for the subsequent time intervals is given by $\exp(\hat{\lambda}_k \cdot \gamma(i)/2) - 1$. The cumulative response in absolute returns for the full event window is calculated as:

$$M(k) = \sum_{i=0}^{N_k} \left[\exp\left(\frac{\hat{\lambda}_k \cdot \gamma(i)}{2} \right) - 1 \right] \quad [2.12]$$

Further details of the structure of the outlined volatility response patterns are provided in the coming section.

2.5.4 Public information announcement effect

Figure 2.7 illustrates the shape of the estimated volatility response patterns calculated as $\hat{\lambda}(k,i) = \hat{\lambda}_k \cdot \gamma(i)$ for each of the 20 macroeconomic public information announcements. Figure 2.7a illustrates the volatility response patterns following ECB and FOMC rate decisions, where their different scale is determined by the degree to which absolute returns during such events load onto the decay structures of equations (2.7) - (2.8). Figure 2.7b depicts the volatility response patterns following slow release macroeconomic announcements. Also in this case, such patterns are determined by the degree to which absolute returns during such events load onto decay structure of equation (2.9). Figure 2.7c and 2.7d display the response patterns for the fast release macroeconomic data announcements where the volatility decay structure is specified in equation (2.10). The volatility persists at a higher level and for a longer time horizon during ECB and FOMC rate decisions. For slow release public information, the immediate volatility response is smaller but decays at a slower rate. The volatility response to fast release economic data announcements, is more immediate but volatility decays at a far faster rate.

Table 2.5 reports the empirical estimates of the loading coefficient $\hat{\lambda}_k$ for all 20 macroeconomic information announcements. Such coefficients are OLS estimates of equation (2.5) where the $I_k(t,n)$ dummy variable refers to the predetermined volatility response patterns associated with the relevant type of macroeconomic information, as determined by equations (2.7) - (2.10). All but two of the 20 public information announcements are significant at the 5% level. The announcements are ranked by order of largest instantaneous impact on absolute returns, calculated as $\exp(\hat{\lambda}_k \cdot \gamma(0)/2) - 1$.

To provide an example, the estimated FOMC rate decision loading coefficient implies that $\exp(\hat{\lambda}_k \cdot \gamma(0)/2) = \exp((0.729 \cdot 8.856)/2) = 25.23$ - this is tantamount to approximately 2423% $((25.23 - 1) \cdot 100)$ instantaneous increase in the one-minute absolute returns following FOMC rate decisions. The cumulative impact as outlined in equation (2.12) would be 678.64. Given that one-minute average absolute returns, during the 1800 to 2000 GMT time 120-minute horizon for FOMC rate decisions, are approximately equal to 0.008% and that average cumulative absolute returns for the trading days in the sample equals 11%, on days when FOMC rate decisions take place there is an average increase of approximately $(678.64 \cdot 0.008)/11 = 49.36\%$ in cumulative absolute returns.

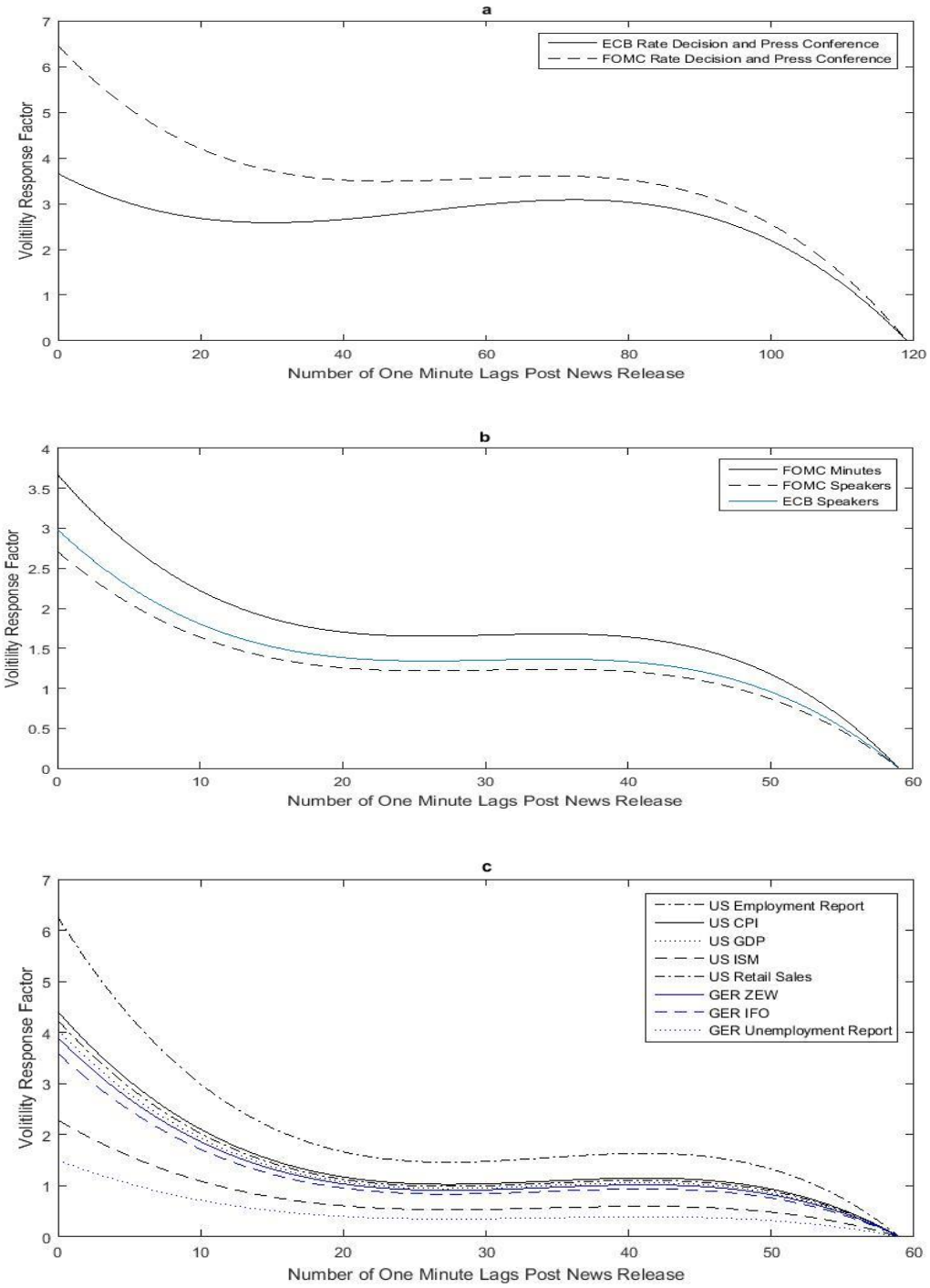
Table 2.5
Public information arrival effects on the volatility of 1-minute EUR-USD of exchange rate returns. ($R^2 = 0.0933$)

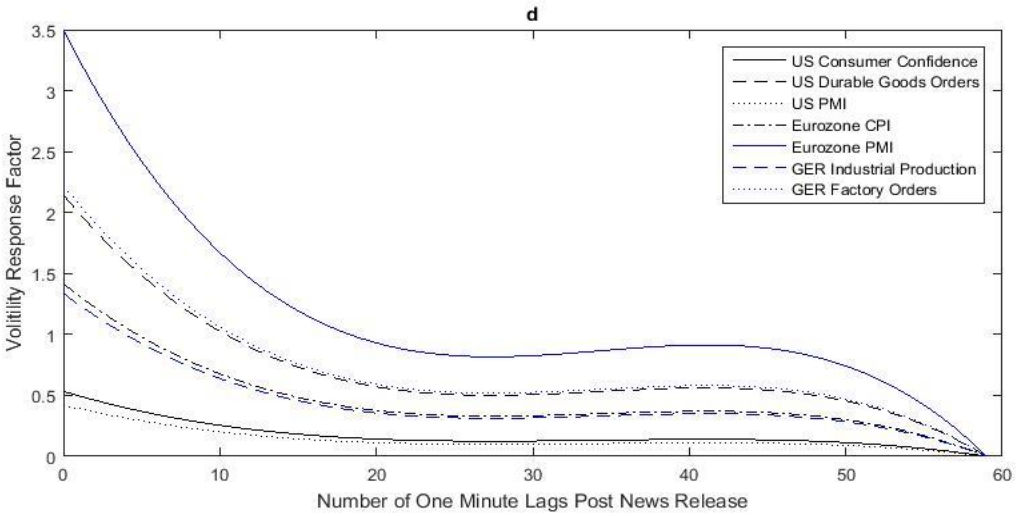
Public information announcements	**Coefficient $\hat{\lambda}(k)$**	**t-Stat**	**Instantaneous increase in volatility (%)**	**Effect on daily cumulative absolute returns (%)**
FOMC Rate Decision	0.729	36.551	2423.563	49.356
US Employment Report	1.382	19.819	2183.577	19.354
US CPI (Cat 1)	0.973	9.981	805.590	6.619
US Retail Sales (Cat 2)	0.935	10.779	730.839	9.602
US GDP (Cat 1)	0.894	9.155	656.767	8.890
German ZEW (Cat 1)	0.861	8.860	602.211	8.349
FOMC Minutes	0.955	22.424	528.481	6.675
ECB Rate Decision	0.656	21.486	523.766	35.534
German IFO (Cat 1)	0.792	8.188	501.201	5.737
Eurozone Manufacturing PMI (Cat 2)	0.772	7.973	474.424	5.510
ECB Speakers	0.776	9.454	345.261	6.619
FOMC Speakers	0.704	9.268	287.847	4.693
US ISM (Cat 1)	0.505	4.928	213.608	3.819
German Factory Orders (Cat 2)	0.491	5.214	203.625	2.364
US Durable Goods (Cat 2)	0.474	4.838	192.256	3.513
German Employment Report (Cat 2)	0.332	3.426	111.979	1.772
Eurozone CPI YoY (Cat 1)	0.313	3.216	102.876	1.349
German Industrial Production (Cat 2)	0.295	3.137	95.057	1.541
US Consumer Confidence (Cat1)	0.118	1.191	30.526	0.707
US Manufacturing PMI (Cat 2)	0.093	0.897	23.406	0.512

The results presented in Table 2.5 show that public announcements - 'fundamental' to the price formation process by proponents of the Efficient Market Hypothesis - do have a considerable immediate and cumulative impact on price variability. The relative infrequency of such events, however, means that a very small proportion of overall sample volatility can be attributed to such events. Nonetheless, these results show that FFF regression model in use is able to capture the effects of macroeconomic announcement events, and therefore it can be used as useful term of comparison for the results of the next section.

Figure 2.7

(a) Estimated volatility response pattern for FOMC and ECB rate decision event windows. (b) Estimated volatility response pattern for slow release public information events. (c and d) Estimated volatility response pattern for fast release public information events.




d
US Consumer Confidence
US Durable Goods Orders
US PMI
Eurozone CPI
Eurozone PMI
GER Industrial Production
GER Factory Orders
Volitility Response Factor
Number of One Minute Lags Post News Release
0
0.5
1
1.5
2
2.5
3
3.5
0
10
20
30
40
50
60

2.5.5 ECB rumours arrival effects

I take two approaches in identifying the impact of ECB rumour events on the volatility of EUR-USD absolute returns. The first is to model each ECB rumour event as a sixty-minute dummy variable in equation (2.5). Here the $I_k(t,n)$ dummy variables (for *k=1, .., 63*), included in the full FFF regression take unity value for rumour event k for the sixty minutes after rumour arrival. In this case, the macroeconomic event dummy variables also take unity value for their respective event windows. The coefficient estimates $\hat{\lambda}_k$ for this approach captures the degree to which volatility is affected during the full sixty-minute rumour event window. The second approach consists of including each ECB rumour event as the sixty-minute volatility response pattern as specified by equation (2.11).[11] In this case, also the macroeconomic control variables are modelled through their volatility responses as specified by equations (2.7) - (2.10). The coefficient estimates $\hat{\lambda}_k$ for this second approach captures the degree to which absolute returns, during each rumour event window, load onto the pre-specified volatility response pattern.

Table 2.6 provides empirical results for the first approach. The rumour events are ranked by the magnitude of their coefficient estimates attached to the sixty-minute dummy variables. Of the 63 rumour events, 25 events result in a significant increase in the volatility of absolute returns. The largest increase is associated with the arrival of a rumour stating that the ECB Governing Council has drawn up a proposal which calls for quantitate easing to the magnitude of €50 billion on a monthly basis. To provide an example, the coefficient estimate of 3.475 for this rumour, implies an $\exp(3.475/2) - 1 = 209.05\%$ increase in the volatility of absolute returns for the respective event arrival.

The results presented in Table 2.6 show that the significant rumour events have a positive shock on absolute returns. In line with expectations, all of these rumours produce a positive impact on volatility, with no rumour having a significant and negative impact.

The above analysis based on the use of dummy variables provides little insight into how the volatility process during the event window evolves. I therefore move on to the second approach outlined that should allow greater insight into the immediate and ensuing volatility impact of rumour events.

[11] In this case, the $I_k(t,n)$ variables take the value of the volatility response pattern as specified in equation (2.11) for all the 63 rumour events.

Table 2.6
Rumours of European Central Bank action: effects on the volatility of 1-minute EUR-USD of exchange rate absolute returns for a sixty-minute event window per event. Details given for coefficient estimates of the 25 ECB rumour events found to be statistically significant. (R^2 = 0.1018)

ECB rumour events	**Coefficient $\widehat{\lambda_k}$**	**t-Stat**	**Inferred increase in volatility (%)**
ECB Sources: QE proposal calls for roughly €50 billion in bond buying per month	3.475	4.745	209.054
ECB Sources: Governing council considering negative deposited rate of 0.1%	3.102	4.237	173.531
ECB Sources: Existential threat to Euro if fiscal policy reform is not tackled	3.061	4.181	169.986
ECB Sources: Governing council may not have reached lower bound on key rate	2.894	3.953	156.389
ECB Sources: Central bankers to challenge Draghi on leadership style	2.644	3.611	138.006
ECB Sources: Governing council likely to refrain from new measures for next few months	2.609	3.563	135.594
ECB Sources: Said to allow 24 hours to make smaller ABS purchases	2.598	3.549	134.883
ECB Sources: New ECB action next week is unlikely	2.514	3.434	129.317
ECB Sources: ECB raising ELA for Greek banks to €71 billion	2.110	2.882	105.663
ECB Sources: ECB and Treasury building emptied under security concern	2.096	2.862	104.906
ECB Sources: Rate change unlikely. LTRO not on top of the communication agenda	2.079	2.839	104.021
ECB Sources: ECB to accept Greek bonds as collateral if deal is reached	2.026	2.759	101.293
ECB Sources: ECB won't accept Greek bond swap and wants full repayment	2.017	2.755	100.860
ECB Sources: ECB has approved additional €400 billion for Greek banks as emergency liquidity	1.860	2.540	93.239
ECB Sources: ECB cites barriers to QE. Need to let old measures work	1.799	2.456	90.418
ECB Sources: ECB to allow Greek banks ELA up to €60 billion	1.723	2.352	87.047
ECB Sources: Bundesbank still striving to put limits on ECB QE	1.716	2.344	86.765
ECB Sources: Bundesbank sources say they are willing to accept significant stimulus package	1.652	2.180	84.038
ECB Sources: Weidmann opposed to today's rate cut	1.574	2.113	80.810
ECB Sources: No major policy change expected in January	1.537	2.099	79.335
ECB Sources: ECB buying Spanish short dated covered bonds	1.401	2.091	74.108
ECB Sources: Markets over interpreting possibility of QE. No consensus but intense debate	1.385	2.068	73.543
ECB Sources: Preparing package of measures, including cuts to all 3 rates for June meeting	1.324	1.976	71.312
ECB Sources: Governing council prefer additional time to assess current measures	1.277	1.972	69.672
ECB Sources: G.C discussing ABS purchases worth up to €500 billion which could start this year	1.268	1.970	69.351

Table 2.7 reports empirical results of the loading coefficient $\hat{\lambda}_k$ for rumour events k. The coefficient estimates are based on OLS estimation of equation (2.5) where the $I_k(t,n)$ variables

refer to the predetermined volatility response patterns associated with the ECB rumour event windows, as specified in equation (2.11). Of the 63 event windows following ECB rumour arrival, 20 events are found to have significant loading coefficient $\hat{\lambda}_k$.

The rumour events are ranked by order of biggest instantaneous impact on absolute returns calculated as $\exp(\hat{\lambda}_k \cdot \gamma(0)/2) - 1$. To provide an example, the estimated loading coefficient for the ECB rumour; "*ECB Sources: QE proposal calls for roughly €50 billion in bond buying per month"* implies $\exp(\hat{\lambda}_k \cdot \gamma(0)/2) = \exp((3.692 \cdot 0.615)/2) = 3.11$. This is equivalent to approximately 211% $((3.11 - 1) \cdot 100)$ instantaneous increase in the one-minute absolute return interval following the arrival of this rumour.

The cumulative impact obtained by applying equation (2.12) is as large as 262.41. Given that one-minute average absolute returns, during the 1430 to 1530 GMT event window for this rumour, are approximately equal to 0.013% and that average cumulative absolute returns for the trading days in the sample equals 11%, the arrival of this ECB rumour has an average increase of approximately $(134.95 \cdot 0.013)/11 = 15.95\%$ in cumulative absolute returns.

The twenty rumour events found to significantly load onto the volatility response patterns of equation (2.11) are the same as those found to have the most significant coefficients in Table 2.6 - when the rumour event window was a basic 60-minute dummy variable for each event. This would suggest that rumour events with the biggest volatility impact load onto the predetermined volatility response pattern more effectively.

Figure 2.8 depicts the shape of the estimated volatility response patterns calculated as $\hat{\lambda}(k, i) = \hat{\lambda}_k \cdot \gamma(i)$ for the 5 ECB rumour event windows with the biggest loading coefficients. Such patterns are dependent on the degree to which absolute returns during ECB rumour events load onto the decay structures given by equation (2.11).

The volatility decay structure following rumour arrival is more complex than that of macroeconomic information. There are instantaneous jumps in the volatility of absolute returns in the first minute interval following rumour arrival.

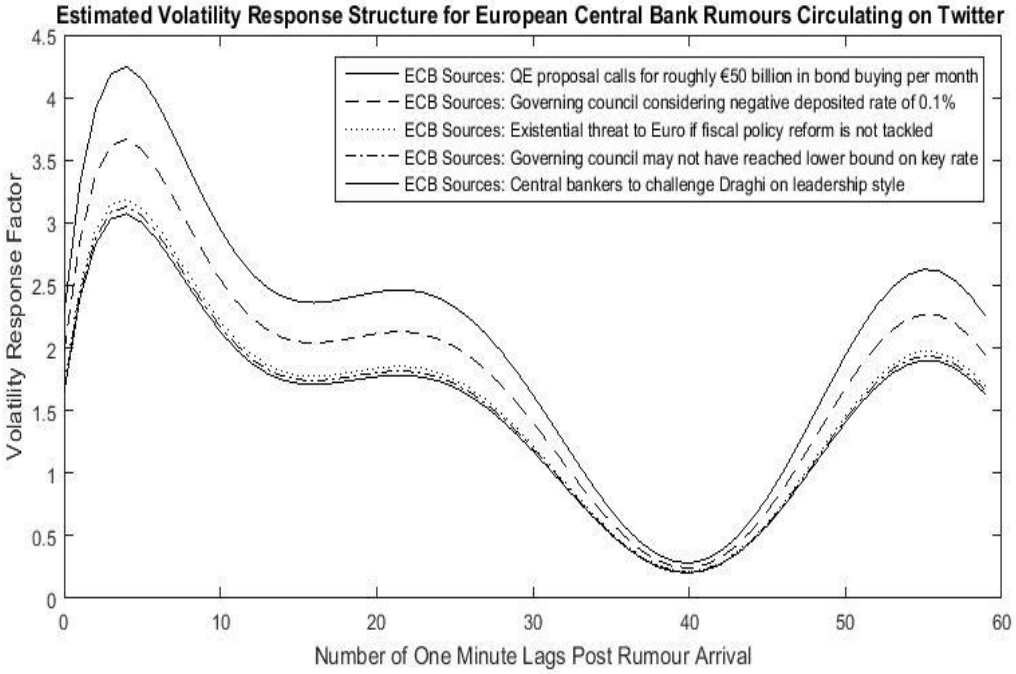
Such jumps are then followed by a sharp increase is volatility that reaches its peak at the 6th minute interval. At this point the volatility declines gradually before increasing again following the 40th one-minute interval. For flexibility, by design, the 7th order polynomial set out in equation (2.11) does not reach zero. This is justified given that volatility persistence is evident, form Figure 2.8, up to the 60th minute and beyond.

Table 2.7
Rumours of European Central Bank action: effects on the volatility of 1-minute EUR-USD exchange rate absolute returns. Details given for the 20 Rumour events which are found have significant 'loading' coefficient $\hat{\lambda}(k,i)$ estimates for the volatility decay structure set out by equation (2.11). (R^2 = 0.1032)

ECB rumour events	**Coefficient $\hat{\lambda}(k)$**	**t-Stat**	**Instantaneous increase in volatility (%)**	**Increase in daily cumulative absolute returns (%)**
ECB Sources: QE proposal calls for roughly €50 billion in bond buying per month	3.692	4.544	211.199	15.949
ECB Sources: Governing council considering negative deposited rate of 0.1%	3.190	3.926	166.647	13.166
ECB Sources: Existential threat to Euro if fiscal policy reform is not tackled	2.775	3.415	134.711	10.415
ECB Sources: Governing council may not have reached lower bound on key rate	2.720	3.347	130.774	9.363
ECB Sources: Central bankers to challenge Draghi on leadership style	2.671	3.287	127.350	9.796
ECB Sources: Governing council likely to refrain from new measures for next few months	2.624	3.230	124.089	9.523
ECB Sources: Said to allow 24 hours to make smaller ABS purchases	2.512	3.092	116.500	8.894
ECB Sources: New ECB action next week is unlikely	2.249	2.768	99.674	7.519
ECB Sources: ECB raising ELA for Greek banks to €71 billion	2.185	2.688	95.760	6.689
ECB Sources: ECB and Treasury building emptied under security concern	2.184	2.688	95.712	6.685
ECB Sources: Rate change unlikely. LTRO not on top of the communication agenda	2.177	2.680	95.318	6.656
ECB Sources: ECB to accept Greek bonds as collateral if deal is reached	2.154	2.650	93.904	4.535
ECB Sources: ECB won't accept Greek bond swap and wants full repayment	2.110	2.597	91.333	6.359
ECB Sources: ECB has approved additional €400 billion for Greek banks as emergency liquidity	2.086	2.567	89.919	5.292
ECB Sources: ECB cites barriers to QE. Need to let old measures work	2.067	2.544	88.829	4.274
ECB Sources: ECB to allow Greek banks ELA up to €60 billion	2.067	2.539	88.793	6.646
ECB Sources: Bundesbank still striving to put limits on ECB QE	1.935	2.382	81.313	5.620
ECB Sources: Weidmann opposed to today's rate cut	1.911	2.351	79.961	4.672
ECB Sources: No major policy change expected in January	1.895	2.332	79.063	5.876
ECB Sources: Bundesbank sources say they are willing to accept significant stimulus package	1.792	2.206	73.510	3.498

Figure 2.8

Estimated volatility response pattern for ECB rumour event windows. Five Rumour events with the largest volatility response factor are graphed below.



All in all, the empirical findings detailed in this section show that there is a significant increase in the volatility of EUR-USD absolute returns for 60-minute event windows during which ECB rumours arrive and circulate on Twitter. The rumour events with the biggest volatility impact follow quite similar volatility response patterns - producing jumps in absolute returns as large as 211% and increases in cumulative daily absolute returns as large as 15%. These findings point to the existence of a form of actionable market information able to explain a significant share of the large volatility in the EUR-USD spot exchange rate.

As a further test of the central hypothesis, I carry out empirical estimates of equation (2.5) for a split sample of days with rumour and days without rumour. Due to the existence of days with multiple rumours, this is tantamount to 58 days (83,520 observations) with rumours and 356 days (512,640) without rumours. The R^2 for the sample with and without ECB rumours calculate to 0.1032 and 0.0933 respectively. This is tantamount to a 10.61% improvement in explaining excess volatility with the discernment of ECB rumours.

2.6 Conclusions

This chapter identifies market relevant rumours as a form of public information that has been largely overlooked by price discovery literature. I present a new database of previously undetected public information that is able to explain a substantial share of the excess volatility observed on foreign exchange markets. I therefore assert that such rumours are actionable information as - by changing market consensus upon broadcast - they have substantial impact on the volatility of the EUR-USD exchange rate. More specifically, I pinpoint the arrival of 63 rumours of forthcoming ECB action, as broadcast via Twitter, to within 1-minute accuracy. I show that 25 of such rumours have a pronounced impact on the volatility of 1-minute EUR-USD of exchange rate returns for a 420-day sample period. The instantaneous increase in volatility during the first minute of rumour arrival is up to 211%, while the cumulative increase in volatility over a 60-minute window is as much as 2614.

The findings of this chapter demonstrate the existence of financial market relevant information seemingly discerned by market agents but overlooked by economists. The identification of rumour information events as a determinant in the price formation process offers new opportunities to understand the shares of volatility in financial markets left unexplained by the arrival of scheduled and unscheduled public information as broadcast via incumbent financial market news sources such as Bloomberg and Reuters. Furthermore, the hypothesis attributing market volatility to private information can be, to some extent, scaled down in the light of the existence of market rumours previously misidentified as private information that can be classified as public information.

Our empirical results highlight a number of implications for both central banks and market regulators. The existence of such 'actionable information' suggests that an unofficial channel of communication exists between central banks and market participants. This may be a transmission mechanism through which sensitive information can be incrementally passed onto the market in order to prevent overwhelming volatility events. Alternatively, the existence of such rumours may be in direct violation of the central banks intent, in which case the acknowledgement and repudiation of such rumours is of vital importance for the central bank. For the market regulator there are implications in terms of informational efficiency. It is plausible to argue that the existence of 'actionable rumours' via Twitter increases the informational efficiency of financial markets. The network of 'in the know' market commentators provides market participants with a source of free market relevant information at the point of delivery – the same type of information that is often highly expensive to retrieve

in real time via incumbent newswires. In principle, such a reduction in the cost of information might mitigate informational asymmetries, making informed trading less costly and therefore reducing the role of speculative trading. This assertion remains valid with the caveat that rumours are actionable and not ‘noise’. The efficient distinction between ‘actionable rumours' and ‘noise' can depend on the market agent’s ability to discern reliable ‘in the know’ commentators. Further, the lack of regulatory jurisdiction over Twitter needs to be addressed given the degree to which information disseminated through Twitter can impact market prices, as I have shown in this chapter. The deliberate distribution of false market-relevant news via Twitter may result in significant volatility events beneficial to the distributor.

Appendix A

Appendix A1

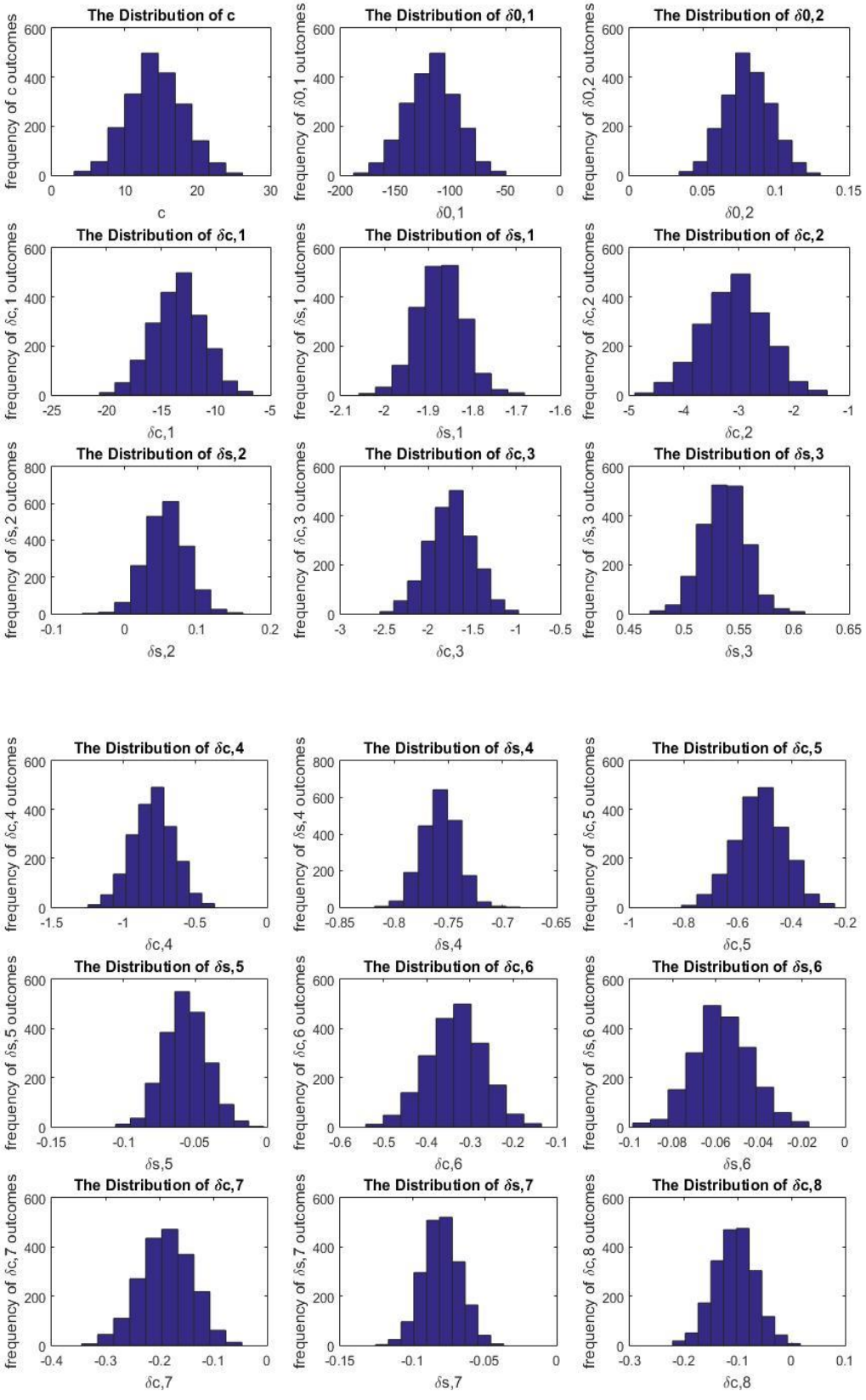
List of 'ECB sources' stories quoted by more than 50 Twitter accounts.

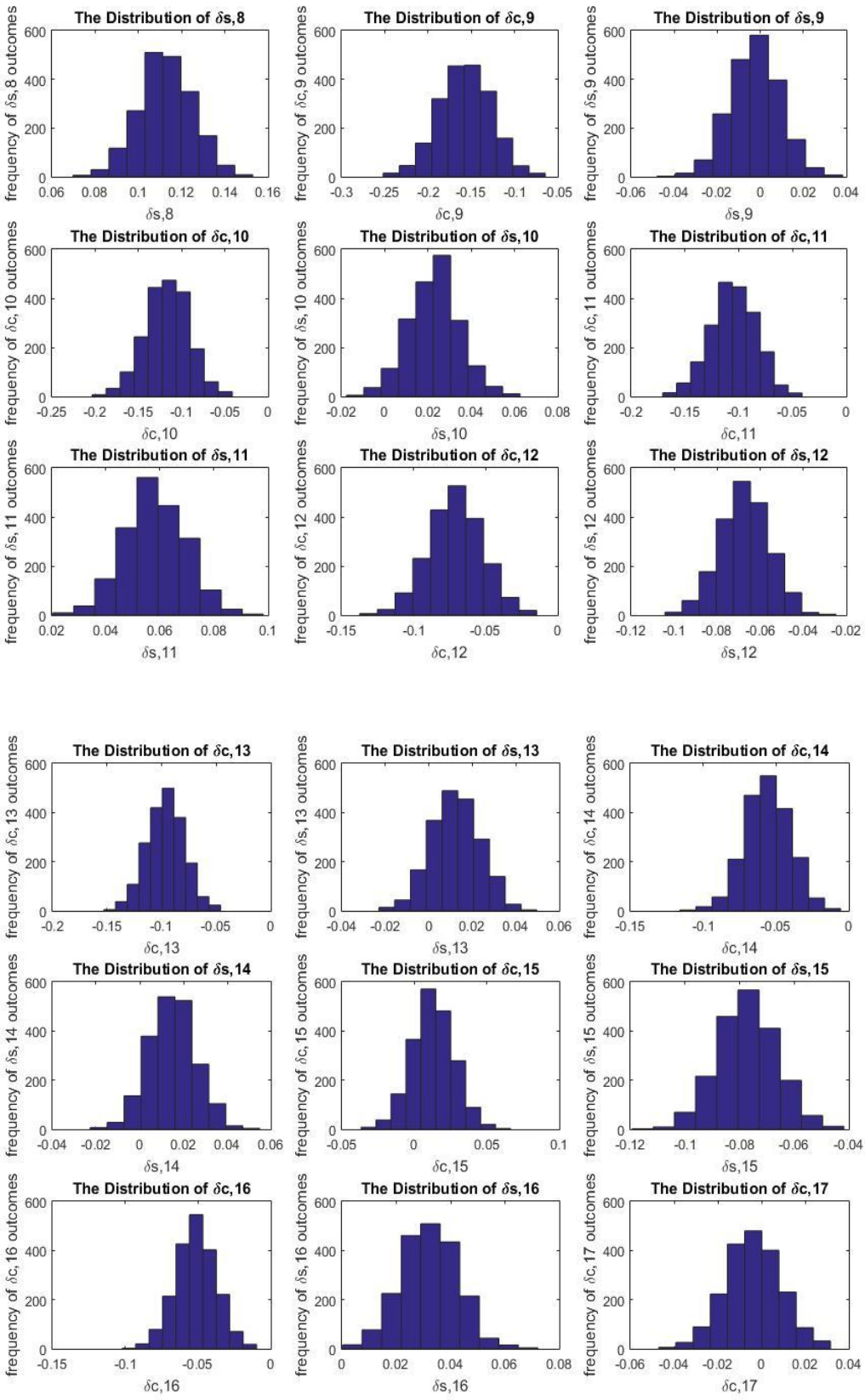
Timestamp	ECB Rumour Quote
01/10/2013 1320	ECB Sources: New LTRO may not yield benefit if launched now
22/10/2013 1433	ECB Sources: ECB to Impose 8% capital buffer on Eurozone banks
25/10/2013 1115	ECB Sources: Governing council hesitant over negative rates
29/10/2013 1423	ECB Sources: No realistic prospect of refinancing or deposit rate cut
06/11/2013 1449	ECB Sources: Rate change unlikely. LTRO not on top of the communication agenda
07/11/2013 1605	ECB Sources: Weidmann opposed to today's rate cut
11/11/2013 1047	ECB Sources: Considering package of stimulus for December meeting
20/11/2013 1514	ECB Sources: Governing council considering negative deposited rate of 0.1%
26/11/2013 1449	ECB Sources: 25 basis point rate cut and negative repo rate discussed
06/01/2014 1530	ECB Sources: No major policy change expected in January
28/01/2014 1139	ECB Sources: Governing council content with current monetary policy stance
04/02/2014 0649	ECB Sources: Draghi looking closer at ending SMP sterilization
05/02/2014 0953	ECB Sources: No consensus among Governing Council members on action tomorrow
26/02/2014 0910	ECB Sources: No consensus among governing council members for March policy move
13/03/2014 1423	ECB Sources: ECB and Treasury building emptied under security concern
19/03/2014 1039	ECB Sources: Spanish banks face property reviews for ECB check-up
02/04/2014 0909	ECB Sources: Markets over interpreting possibility of QE. No consensus but intense debate
24/04/2014 1141	ECB Sources: No consensus among governing council members for May policy action
13/05/2014 1104	ECB Sources: Bundesbank sources say Bubba willing to accept significant stimulus
14/05/2014 0827	ECB Sources: Preparing package of measures, including cuts to all 3 rates for June meeting
20/05/2014 1102	ECB Sources: Considering 6 week meeting schedule to help write minutes, take policy decisions
02/06/2014 1651	ECB Sources: ECB to lead revamp of global FX code of conduct
04/06/2014 0641	ECB Sources: Draghi is likely to signal rate cut this week, won't necessarily be last
16/06/2014 1341	ECB Sources: Governing council likely to refrain from new measures for next few months
26/06/2014 1434	ECB Sources: Governing council may not have reached lower bound on key rate
22/07/2014 1251	ECB Sources: June rate cut affecting markets exactly the way Governing council want
27/08/2014 1510	ECB Sources: New ECB action next week is unlikely
28/08/2014 0010	ECB Sources: ECB policy action unlikely without inflation slump
29/08/2014 1127	ECB Sources: No consensus among governing council members on QE next week
04/09/2014 1137	ECB Sources: G.C discussing ABS purchases worth up to €500 billion which could start this year
08/09/2014 0757	ECB Sources: Policy measures could amount to €500 billion
21/10/2014 1025	ECB Sources: ECB buying Spanish short dated covered bonds
27/10/2014 1231	ECB Sources: ECB cites barriers to QE. Need to let old measures work
27/10/2014 1451	ECB Sources: Current stimulus may lack desired scale. QE an option
31/10/2014 1512	ECB Sources: Existential threat to Euro if fiscal policy reform is not tackled
03/11/2014 1023	ECB Sources: ECB considering improvement to LTRO if economy deteriorates, too early to say
04/11/2014 1513	ECB Sources: Central bankers to challenge Draghi on leadership style
06/11/2014 1055	ECB Sources: Governing council members did NOT confront Draghi at council dinner
14/11/2014 1534	ECB Sources: Said to allow 24 hours to make smaller ABS purchases
26/11/2014 1249	ECB Sources: Governing council prefer additional time to assess current measures
04/12/2014 1633	ECB Sources: German ECB members opposed to new balance sheet language

19/12/2014 1012	ECB Sources: Considering making weaker Eurozone countries bear greater risk burden in QE plan
06/01/2015 0639	ECB Sources: ECB is working on a discussion paper to execute government bond buying.
09/01/2015 0951	ECB Sources: €500 billion plan showed to Governing council members but no decision made
09/01/2015 1114	ECB Sources: ECB considering risk sharing mix for QE plan
16/01/2015 1640	ECB Sources: QE timing, size and scope yet to be decided
19/01/2015 1445	ECB Sources: Bundesbank still striving to put limits on ECB QE
21/01/2015 1430	ECB Sources: QE proposal calls for roughly €50 billion in bond buying per month
03/02/2015 0957	ECB Sources: 3 Greek banks have tapped ECB ELA window
03/02/2015 1420	ECB Sources: ECB won't accept Greek bond swap and wants full repayment
04/02/2015 1927	ECB Sources: ECB believes Greece may run out of cash as early as March
05/02/2015 1347	ECB Sources: ECB to allow Greek banks ELA up to €60 billion
10/02/2015 1202	ECB Sources: ECB to accept Greek bonds as collateral if deal is reached
17/02/2015 1645	ECB Sources: ECB member resisting support from ECB for Greek banks
18/02/2015 1642	ECB Sources: ECB divided over extra funds for Greek banks
18/02/2015 2011	ECB Sources: Greek banks asked for €5 billion extra in ELA funding
19/02/2015 0709	ECB Sources: ECB has extended ELA to Greek banks from €65 billion to €68.3 billion
02/03/2015 1442	ECB Sources: Staff projections may show 2017 inflation target return, signal end to QE Sep 2016
09/03/2015 0827	ECB Sources: ECB has started QE programme
19/03/2015 0925	ECB Sources: ECB has approved additional €400 billion for Greek banks as emergency liquidity
25/03/2015 1400	ECB Sources: ECB raising ELA for Greek banks to €71 billion
01/04/2015 1921	ECB Sources: ECB raised emergency funding cap by €700 million for Greek banks
17/04/2015 1914	ECB Sources: ECB examines possibility of I.O.U currency in case of default

Appendix A2

Histograms of parameter estimates from Monte Carlo simulation of the second step procedure. The following histograms are derived from 2000 trial simulations of the FFF regression. There are 53 histograms for each of the parameter estimates specified in equation 2.5 for the normalising constants and cosinor control parameters. The histograms show that parameter estimates converge to that predicted by the OLS estimation of equation 2.5 presented in table 2.4.

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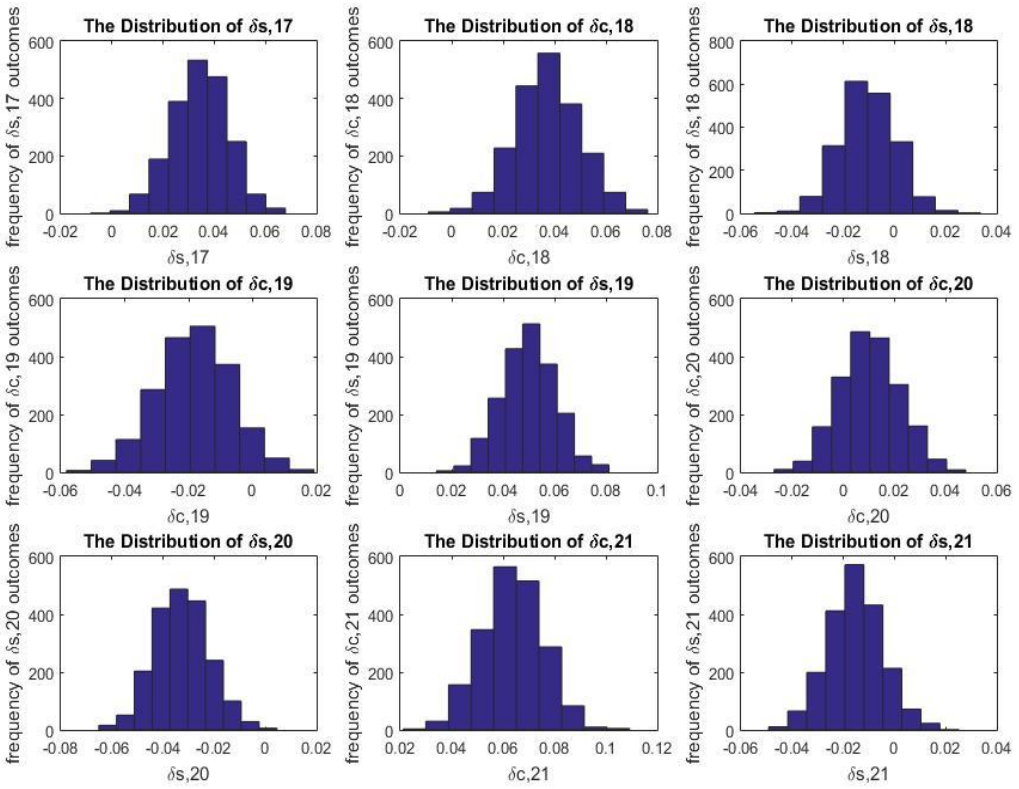
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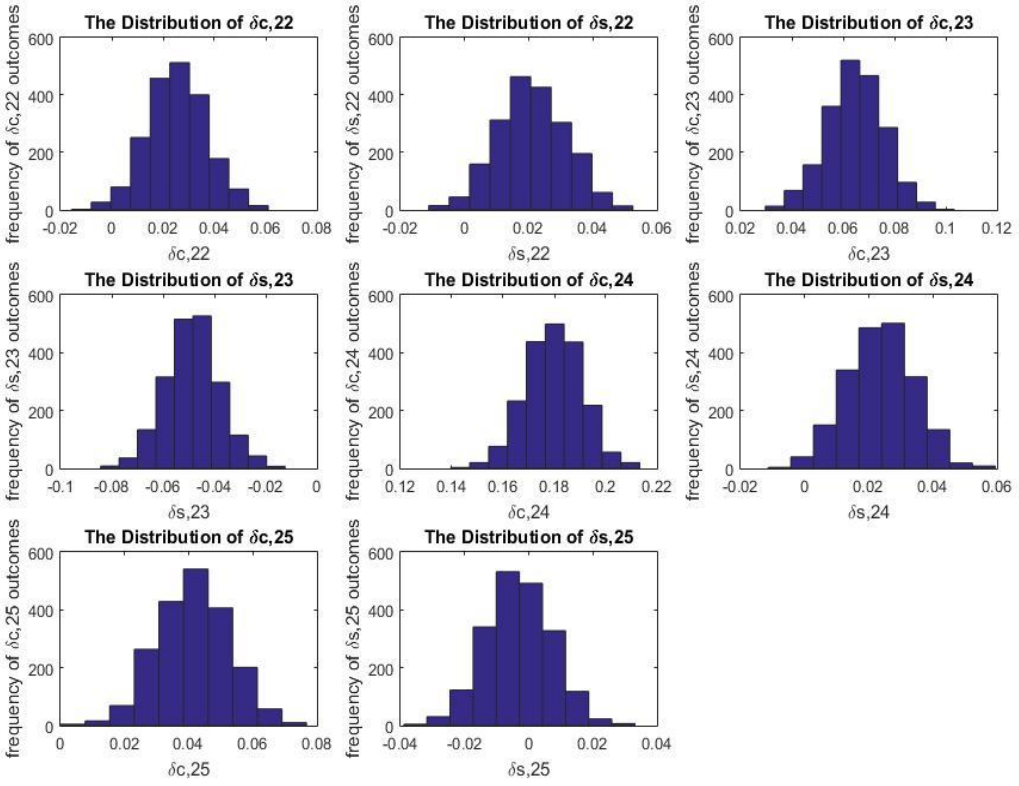
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Chapter 3. Buy the Rumour, Sell Before the Fact

3.1 Introduction

In this chapter, I explore the potential effect of rumours on financial market price formation in the central bank pre-announcement period. I find stock market excess returns are statistically significantly large and positive in the 24-hour trading period immediately before scheduled monetary policy announcements. These excess returns are particularly observable in recent years, between 2011 and 2015, during which the ECB (European Central Bank) has exercised policy measures considered to be accommodative. The initial conjecture drawn from this finding is that such pre-announcement excess returns are simply a result of anticipatory speculation. This is in line with observations of a similar pattern in pre-announcement price formation found by Lucca and Moench (2015) for trading windows prior scheduled FOMC (Federal Open Market Committee) announcements. However, given the findings of the previous chapter, the following question is examined: Is the central bank pre-announcement anticipatory effect simply the result of new public information flows which have previously gone undetected?

Based on the findings of the previous chapter, this chapter provides a simple but effective explanation of Lucca and Moench's (2015) pre-FOMC drift puzzle. Chapter 2 results suggest that market relevant rumours broadcast by 'in the know' financial market commentators on Twitter have a significant real-time impact on the volatility of exchange rate returns. I observe substantial instantaneous jumps in volatility at times of rumour arrivals. Furthermore, results show that realised excess volatility ex-post rumour broadcast, is highly persistent and decays slowly. The overall finding being that the observations of the timed effect of market relevant rumour can explain sizable proportions of overall excess volatility. Based on these findings, it would be reasonable to pose the following question: can rumour occurrences, during pre-announcement trading hours, explain the pre-central bank drift and therefore solve the pre-announcement puzzle.

I expand the data set from the previous chapter to six years of observations for 'ECB sources' stories broadcast on Twitter and corresponding stock and currency intraday return observations. Employing the same model as Lucca and Moench (2015), I isolate pre-ECB return windows and test for excess returns above other non-pre-ECB trading periods. Empirical results here, show that average excess returns earned on the stock market, in the 24-hour trading window immediately prior the 55 ECB Governing Council's scheduled policy announcement in the sample, are positive, statistically significant and substantially higher than all other days. The

implication is that the pre-announcement drift is also observable in European markets pre-ECB windows. This contrasts with Lucca and Moench (2015) findings that show the pre-announcement drift is only observable for scheduled FOMC announcements and no other central banks. I conjecture that this is simply due to the sample period in question. Their sample period concludes in 2011, whereas the sample period here is from November 2010 through November 2015. I suggest that the major changes in the ECB's balance sheet, policy mandate and expansion of policy tools from 2011 onwards may be, in part, the reason behind the divergence in results.

Then I carry out the same analysis for a corresponding sample of EUR/USD exchange rate returns to test for a potential pre-announcement exchange rate drift. The EUR/USD exchange rate is the most actively traded spot currency market in the world, the economic valuation of which is fundamentally linked to investor expectations of the future monetary policy decisions of central banks in the E.U and U.S. Findings show no pre-ECB drift for the currency market over various specifications of return windows. I also find no statistically significant drift when the sample is split to account for any potential divergence in the anticipatory effect between periods of policy tightening and easing.

Having established the existence of a pre-ECB announcement drift in the DAX index (Deutscher Aktienindex), yet no existence of pre-ECB drift in the EUR/USD exchange rate, I test for the effect of rumours on the pre-announcement anticipatory effect.

I survey a five-year dataset (November 2010 through November 2015) of 'ECB sources' (Appendix 3.1) and isolate 'in the know' rumour broadcasts on Twitter which occur in any 36-hour window prior scheduled ECB Governing Council policy announcements. In total, there are 30 pre-ECB windows where a relevant rumour has been observed on Twitter and 25 windows for which no rumours are detected[12]. By re-estimating Lucca and Moench's (2015) model, with a rumour/no-rumour conditional pre-ECB explanatory factor I show that the pre-ECB drift is in fact rumour conditional. I show that for pre-ECB return windows where rumours are observed, average excess returns earned on the DAX above all other days are large and statistically significant. Further, average excess returns are orders of magnitude smaller and statistically insignificant on pre-ECB windows where there are no observations of 'ECB sources' stories. This finding is consistent for a variety of pre-ECB return windows and for full and split samples.

[12] For the slightly longer currency market sample window of 56 schedule ECB Governing Council announcements we observe 31 pre-ECB windows with rumours and 25 without.

I repeat the rumour/no-rumour specified model again, for the corresponding currency market sample. I find no drift when the full return sample is tested of both rumour and rumour-less pre-ECB return windows. When the full sample of EUR/USD exchange rate returns are split between policy tightening and easing periods, the pre-ECB drift is highly significant and rumour dependent. Results show that pre-ECB return windows with observations of a rumour, produce average excess returns which are statistically significant and positive for the tightening cycle and, statistically significant and negative for the easing cycle. Meanwhile for pre-ECB windows where no rumours are observed, excess returns are not statistically different from zero.

Empirical results show that the pre-announcement drift is rumour conditional and less puzzling than previously assumed. This finding is in line with the most compelling case put forward by Lucca and Moench (2015) for explaining the 'drift'. They suggest that investors could be subject to more complex information flows than those detected in standard theory. In this chapter, I assert that those information flows include the arrival of new publicly available information in rumour form pertaining to forthcoming ECB policy action. These rumours have the standard theoretical effect of an ensuing risk adjusted price formation process.

The remainder of this chapter is organised as follows. Section 3.2 discusses the pre-announcement effect in more detail and formally reviews the relevant literature covering this topic. Section 3.3 outlines in more detail the rumour driven price formation process in the pre-announcement window and relevant literature. Section 3.4 presents a review of the ECB's mandate, policy tools, recent monetary policy decisions and meeting schedule. Section 3.5 provides a description of the datasets used. Section 3.6 sets out the methodological approach. Section 3.7 discusses the empirical findings. Section 3.8 presents the concluding remarks.

3.2 Pre-Announcement Price Formation

Scheduled financial market relevant macroeconomic public information events have been shown to have variable influence on the price formation process for a cross section of international securities markets (see Andersen et al. (2003), French and Roll (1986) and Mitchell and Mulherin (1994) among others). The price impact is however, considerably more apparent and larger in magnitude when the subject of the macroeconomic public information announcement is a major data release (CPI, GDP and Employment reports) or central policy directive (Andersen and Bollerslev (1997)). Further, the market variation is larger still, if the content of the announcement departs significantly from expectations (see Kuttner (2001) and Faust et al. (2007)). The ex-post macroeconomic public information announcement price discovery process is well documented. The ex-ante macroeconomic public information announcement price formation process has not been fully explained yet. Volatility jumps (Bauwens et al. (2005)) and liquidity slumps (Riordan et al. (2013)) have been noted as price formation properties in stock, currency and bond markets during pre-announcement return windows for scheduled macroeconomic public information events. Pre-announcement volatility has been largely attributed to private information flows (Li et al. (2015)). Order flow irregularities found during pre-announcement windows where public information is under embargo agreements, has been identified as further evidence of pre-announcement trading based on asymmetric information (Bernile et al. (2016)). Overall though, returns earned (the first moment of price) in such pre-announcement windows have been found to be statistically and economically insignificant (Lucca and Moench (2015)).

However, pre-central bank policy announcement returns have been found to differ from other schedule macroeconomic public information announcements. For instance, Lucca and Moench (2015) find that the pre-FOMC announcement price formation departs from most pre-announcement price discovery studies. More specifically, they find significant consistent large excess returns prior to scheduled FOMC meetings. This pre-announcement effect, which they refer to as ‘drift’, is also in contradiction to the expected pre-announcement price formation process as defined by fundamental theories of financial economics. According to the standard asset pricing theory, excess returns earned on the market should be zero during pre-announcement periods when there are no observations of new market relevant information. Scholars have proposed a number of theories to explain such price formation anomalies, including the high volatility/low liquidity market maker premium (Campbell and Hentschel (1992) and Amihud (2002)), systematic risk premium due to the oversensitivity to central bank policy decisions (Bernanke and Kuttner (2005)) and informational frictions (Tetlock (2011)).

Factors associated with such theories are accounted for and ruled out by Lucca and Moench (2015). They find no evidence of significant variation in volatility and trading volume when compared to other return windows. Informational asymmetry is largely dismissed due to the mandated FOMC 'blackout period'[13]. Although this finding is contradicted with recent findings presented by Berline et al. (2015), who show significant order flow disparity during the pre-central bank announcement period which are assumed to lead to significant abnormal profits. They infer that such order flows must be associated with asymmetrically informed traders. Moreover, the systematic risk premium argument is contradicted by their findings which show that pre-FOMC excess returns substantially exceed the almost zero average excess returns earned on all post-FOMC windows studied. It is these contradictions that lead Lucca and Moench (2015) to label the pre-FOMC drift a 'puzzle'. The pre-FOMC excess returns are categorised as unconditional realised earnings and Lucca and Moench 2015 focus their analysis on the searching for a risk based explanation of both the pre-announcement earning and the lack of post-announcement excess returns.

This study contributes to the existing literature by using a previously untapped database of central bank relevant rumours observed on Twitter, to provide an explanation of the above puzzle. More specifically, I show that pre-ECB announcement excess returns, are positive, significant and rumour conditional. Moreover, the pre-announcement rumours I observe on Twitter are mostly market positive in tone, potentially explaining the consistent positive direction of excess returns. I also conjecture that post-announcement earnings are subdued due to the ex-ante risk adjusted price formation process anecdotally referred to as '*buying the rumour and selling the fact'*. That is, the information content of the announcement has been in part, priced when market agents trade on the rumour in the pre-announcement window. This argument is supported with a simple comparative look at rumours and respective realised policy outcomes. The ECB's policy decisions predominantly lead to the maintenance of the status quo rather than to take action, thus resulting in a negative market reaction following positive rumour driven drift. This coupled with large positive excess returns when new measures are announced plausibly cancel out to an almost zero ex-post stock market excess return.

[13] The 'blackout period' is a mandatory quiet period prior FOMC meetings during which member are barred from speaking about their opinions of the policy development process.

3.3 Rumour Driven Price Formation

Pound and Zeckhauser (1990) were among the first to consider the price effect of market relevant rumours by considering takeover stories published in financial newspapers. They found that speculative stories of potential mergers and acquisitions published in the Wall Street Journal result in significant changes in the 'price trends' for the acquired firm's equity during the pre-acquisition windows. Similar findings of rumour conditional equity price variation have been presented by Zivney et al. (1996), Gao and Oler (2012) and Chou et al. (2015). More recently, Ahern and Sosyura (2015) carry out more in-depth analysis of similar rumours published in the mainstream financial U.S. press. They find that the majority (circa 67%) of firm specific rumours printed at source do not lead to a realised true outcome. Their findings show that stock prices of rumoured takeover targets are rumour conditional and that such price movements are unconditional of the accuracy of the reported rumour. There is, therefore, substantial empirical evidence pointing to a rumour conditional stock price effect.

The above literature finds evidence that rumours pertaining to firm specific factors such as takeovers, earnings reports, hiring and firing, have been found to play some role in the price formation process. This finding is in part supportive of the findings in this and the previous chapter. At an elementary level, they all show that rumours, irrespective of realised accuracy have a market price impact. However, the findings presented in the literature fail to show the real-time price formation effect of rumours. This is usually a by-product of rumour datasets which are not timestamped to a high enough frequency. Moreover, the rumours studied are all pertaining to firm specific factors and it would be valid to suggest that the role of firm specific rumours is limited given that they amount to idiosyncratic noise in the wider market context, which based on fundamental financial theory, can be diversified away in any long run return window.

There is very limited research into the systematic influence of rumours on macro-markets. Oberlechner and Hocking (2004) show, using questionnaire and interview data, that traders implement currency market transactions based on informal communications with 'in the know' journalists and sources. Their intuition and survey findings are in line with the empirical results of this thesis, however in the absence of an empirical sample of timestamped market relevant rumours, it is difficult to identify an associated real-time price discovery process. The intuition is that market relevant rumours carry an informational risk premium. Kosfeld's (2005) build on Banerjee's (1993) findings to show that if the spread of a rumour is wide enough, through word of mouth, then such rumours can cause a significant 'price run-up'. The model is built on the assumption that rumours transmit more effectively in locality and not in global informational

networks. I would argue that this theoretical model can be expanded to include a more global outreach for a given rumour since the existence of social media outlets have been shown to lead to rapid rumour diffusion (Nekovee et al. (2007)). The rapid global transmission combined with the macroeconomic information content of ECB Twitter rumours, would intuitively suggest that a systematic risk factor is at play so that a market return premium must be commanded.

In the second chapter of this thesis results showed real-time price discovery in the foreign exchange markets associated with the real-time arrival of central bank relevant rumours. This finding provides fundamental evidence that market relevant rumours, as broadcast on Twitter, if discerned by market agents, convey a certain amount of new information which is then at least in part priced.

In this chapter, I find evidence showing that investors can earn significant excess returns (the first moment of price) on both stock and currency markets in correspondence of rumours relating to forthcoming macroeconomic news. The pre-ECB drift can be characterised, based on the results of this chapter, as a rumour conditional systematic risk premium. This finding asserts the importance of financial market rumours as a price determining factor, for which risk premium should be demanded based on rational expectations theory.

3.4 European Central Bank Policy and Governing Council Meetings

The European Central Bank (ECB) Governing Council is the independent monetary policy setting body for the Eurosystem. The Governing Council consists of six members of the Executive Board and the governors of the national central banks of all Eurozone (euro area) countries. They are mandated to supervise the banking system in the Eurosystem and to set the monetary policy for the euro area. The latter is the primary mandate of concern for this chapter. The council convenes twice per month. At one of these meetings the council discuss the ancillary tasks associated with the ECB and Eurosystem. Whereas, at the other, the council convenes to assess economic and monetary changes and takes monetary policy decision. The monetary policy decision had, up until January 2015, been taken once a month and announced to the financial press under embargoed conditions to be broadcast at 1345 CET on the day of a Governing Council meeting[14]. The monetary policy decision is followed by a press conference at 1430 CET, where the president and vice president of the Executive Board explain to the world press the decisions taken during the monetary policy meeting. These meetings and announcements are scheduled in advance, the times and dates of which are known to traders and investors. The ECB has historically convened for unscheduled meetings and ensuing associated announcements resulting from such meetings, however by definition such unscheduled meetings are of little interest to the research presented in this chapter since they don't tend to command sufficient associated rumour/chatter. Further, such meetings have occurred relatively infrequently, accordingly any comparative analysis of pre-ECB schedule/unscheduled announcement return windows would suffer from small sample bias. Governing council members also frequently give interviews and provide comments to the world press, however for a 7-day window prior key meetings they observe a compulsory quiet period (formerly termed "purdah") during which Governing Council members must have no communication with market participants or the press. I see it as intuitive that during such quiet periods, rumours may carry more traction. The analysis in this chapter by construction, utilises this quiet period, particularly the 36-24-hour window immediately before scheduled announcements.

Given that the financial market sample length is selected based on the availability and widespread use of Twitter from November, 2010 through November, 2015, the ensuing discussion will focus on ECB policy implementation during this sample window.

[14] Since January 2015 the Governing Council takes monetary policy decisions once every six weeks rather than every month. The announcement procedure and timing has remained the same.

The ECB's statutory monetary policy mandate has, since its inception, been to set key interest rates and to supply reserves with the primary objective of maintaining stable inflation expectations. From the onset of the financial crisis and subsequent European debt crisis, this mandate has evolved to include alternative non-standard policy tools beyond rate setting and money supply. The mandated objective of managing inflation expectations has also evolved to include objectives of boosting economic growth, maximising employment and sovereign bond market stability (see Eser and Schwaab (2016), Lenza et al. (2010) and Eser et al. (2012)) by means of non-standard policy tools. The first of these non-standard policies, such as the Securities Market Programme (SMP) were introduce under the presidency of Jean Claud Trichet. During the latter year of his presidency (October 2010 through October 2011), accommodative policy tools were adopted alongside the upward adjustment of key interest rates to curb sovereign debt market instability while anchoring inflation above the ECB's medium-term target of 2%. I consider this period to be a period of relative policy tightening, particularly for the EUR/USD currency market given the interest rate fundamentals at play.

Mario Draghi's tenure began in November, 2011 with a significant shift in the ECB's policy stance with a reduction to the key interest rate by 25 basis points. The years since have included further interest rate reductions, as well as the introduction of further accommodative monetary policy tools. These non-standard policy measures, along with the bank's balance sheet have been significantly expanded during the presidency of Mario Draghi from November, 2011 through November, 2015. I consider this period to be a policy easing cycle during which I expect some differences in the market price formation. This expectation is based on the findings presented by Andersen et al. (2007) which show a notable difference in the price formation process during alternative business cycles. The findings show that both stock and currency market excess returns earned during pre-ECB announcement windows differ considerably during tightening and easing cycles.

3.5 Data Description

3.5.1 DAX Stock Index Data

The Deutscher Aktienindex (DAX) is a stock market index consisting of the 30 largest German companies trading on the Frankfurt Stock Exchange. The exchange opens 0900 CET and closes 1730 CET. The market trades during, prior and post ECB monthly policy announcements and news conferences. It is widely considered to be the benchmark stock index for the largest economy in the Eurozone and one of the most actively traded indices globally. I consider the DAX to be a good indicator of equity market price formation prior ECB policy decisions due to the relative size and the prominence of the index in the Eurozone economy. Further, given the macroeconomic implications of ECB policy decisions, systemic risk factors associated with such policy decisions should be part of the price formation process in the Eurozone's largest national benchmark index.

I source the DAX index data from OLSENDATA (www.olsendata.com), one of the largest global suppliers of historical intraday data. I have chosen to utilise 5-minute interval observations of index level data to accommodate the creation of different length trading windows to investigate price formation during the periods prior to ECB announcements. The data supplied consists of index level quotes for a period spanning from November 05, 2010 to September 16, 2015 (245 weeks, 1225 trading days), totalling in 124,950 observations. The sample is filtered to exclude non-trading days, partial trading days and public holidays. The sample period is specifically chosen to coincide with the availability of Rumour data sourced from Twitter.com. Descriptive statistics for the log returns in percentage points for this sample are provided in Table 3.1 below:

Table 3.1
Descriptive statistics for full sample intraday five-minute DAX returns (%).

	Mean	St. Dev	Skewness	Kurtosis	Min	Max	Obs.
DAX 5-minute Returns	3.499×10^{-4}	0.1284	-1.012	84.06	-3.854	3.396	124,950

The analysis focuses primarily on DAX returns around scheduled ECB Governing Council meetings, the associated policy decisions announcement and press conference. The DAX sample spans a period during which 55 ECB Governing Council meeting policy decisions are announced. The intraday 5-minute interval data is chosen to accommodate the formation of various trading periods prior the policy announcement and press conference window. The cumulative five-minute returns are calculated for the 24-hour period from 1300 CET on the day

before a scheduled ECB policy decision announcement until 1300 CET on the day of the announcement or 45 minutes before the scheduled policy decision announcement. By construction cumulative returns calculated during this time period do not include ECB Governing Council decision outcomes, thus allowing the investigation of the rumour impact and the anticipatory effects associated with ECB announcements. For the purpose of completeness, I also compute and investigate samples of returns for the close-close period for the trading day 24-hours prior the ECB announcement window, as well as partial trading day cumulative returns for the Close-1300 CET trading window before ECB announcements.

Table 3.2
Descriptive statistics for the cumulative excess returns (%) on the DAX index for all computed daily and partial day samples

Sample	Mean	St. Dev.	Skewness	Kurtosis	Min	Max	Obs.
Pre-ECB Announcement Window							
DAX Open-Close	0.0847	1.233	1.213	5.884	-2.579	4.416	55
DAX 1300-1300	0.5016	1.184	-0.1091	3.770	-2.534	3.390	55
DAX Close-1300	0.5510	0.7300	0.0083	4.675	-1.924	2.315	55
Other (Non-Pre-ECB days)							
DAX Open-Close	0.0321	1.309	-0.3165	5.569	-6.237	5.443	1169
DAX 1300-1300	0.0132	1.341	-0.5702	6.601	-6.936	7.238	1169
DAX Close-1300	0.0342	1.029	-0.4116	6.1791	-5.755	4.450	1169

I use Bloomberg to collect data on the risk-free rate throughout the entire November 05, 2010 to September 16, 2015 sample. To capture any potential impact on risk adjusted investment decisions from the variability in the risk-free asset returns, I use the daily rate on three-month German bills to calculate the log excess returns for each tested sample. Table 3.2 provides descriptive statistics for the pre-ECB windows and for all other non-pre-ECB trading periods. *DAX Open-Close* is the log excess returns on the DAX index. *DAX 1300-1300* is the cumulative log excess returns on the DAX index from 1300 CET on date $t-1$ to 1300 CET on date t. *DAX Close-1300* is the cumulative log excess returns on the DAX index from the closing price on date $t-1$ to 1300 CET on date t.

3.5.2 Euro-US Dollar Exchange Rate Data

The Euro-US dollar currency market is the largest in the world by number of transactions per day. It opens 2300 CET Sunday and is subject to a 24-hour trading day until 2300 CET Friday. Pre-market (weekend) trading is available through some exchanges, however trading volume is relatively illiquid when compare to standard non-weekend trading (Chaboud et al. 2014). The markets opening hours overlap geographic trading days in Tokyo, Sydney, Frankfurt, London and New York; the most active financial centres. This 24-hour trading day allows the investigation of price formation during the full weekly information cycle.

I source EUR/USD exchange rate data from OLSENDATA (www.olsendata.com). I utilise observations of 5-minute interval exchange rate data to accommodate the creation of non-standard trading windows to investigate price formation during the pre-ECB window in the currency market. Exchange rate observations consists of exchange rate quotes for a period spanning from November 09, 2010 to November 20, 2015 (253 weeks, 1264 trading days), totalling in 364,032 observations. Quote data is available for weekend trading hours (Sunday) however, I choose to omit these observations due to poor levels of liquidity and the prevalence of non-trading intervals. Further, I omit half trading days and major holidays during which trading is considerably less active. Descriptive statistics for the log returns in percentage points for this sample are provided in Table 3.3 below:

Table 3.3
Descriptive statistics for full sample intraday five-minute EUR/USD exchange rate returns (%).

	Mean	St. Dev.	Skewness	Kurtosis	Min	Max	Obs.
EUR/USD 5-minute Returns	-6.312×10^{-5}	0.0361	-0.1757	68.13	-1.918	1.586	364,032

I perform additional analysis on EUR/USD returns around scheduled ECB Governing Council meetings, the associated policy decisions announcement and press conference. The EUR/USD sample is a slightly longer sample which spans a period during which 56 ECB Governing Council meeting policy decisions are announced. The cumulative five-minute log returns are calculated for the 24-hour period from 1300 CET on the day before a scheduled ECB policy decision announcement until 1300 CET on the day of the announcement, i.e. 45 minutes before the scheduled policy decision announcement. By construction cumulative returns calculated during this time period do not include ECB Governing Council decision outcomes, thus allowing the investigation of the rumour impact and the anticipatory effects associated with ECB announcements. I also compute and investigate cumulative log returns on the EUR/USD

from 2300 CET on date $t-2$ to 2300 CET on date $t-1$. This timeframe by design captures any potential anticipatory effect on the trading day prior the ECB announcement window and excludes the morning trading period of the ECB announcement day.

The entire sample spans a period during which the ECB conducts monetary policy measures which could be described as 'tightening' and 'easing'. Such measures include increases, as well as decreases to the benchmark interest rates and quantitative easing. I define a 'tightening cycle' as the period during which the ECB increases interest rates to a peak of 1.75%. This period coincides with the sample period spanning November 09, 2010 to October 20, 2011. I define the 'easing cycle' as the period during which the ECB decreases interest rates from the peak of 1.75% to 0.050%. The 'easing cycle' coincides with the sample period spanning October 21, 2011 to November 20, 2015.

Figure 3.1
European Central Bank benchmark interest rates during the '*Tightening'* and *'Easing'* cycles for entire sample period.

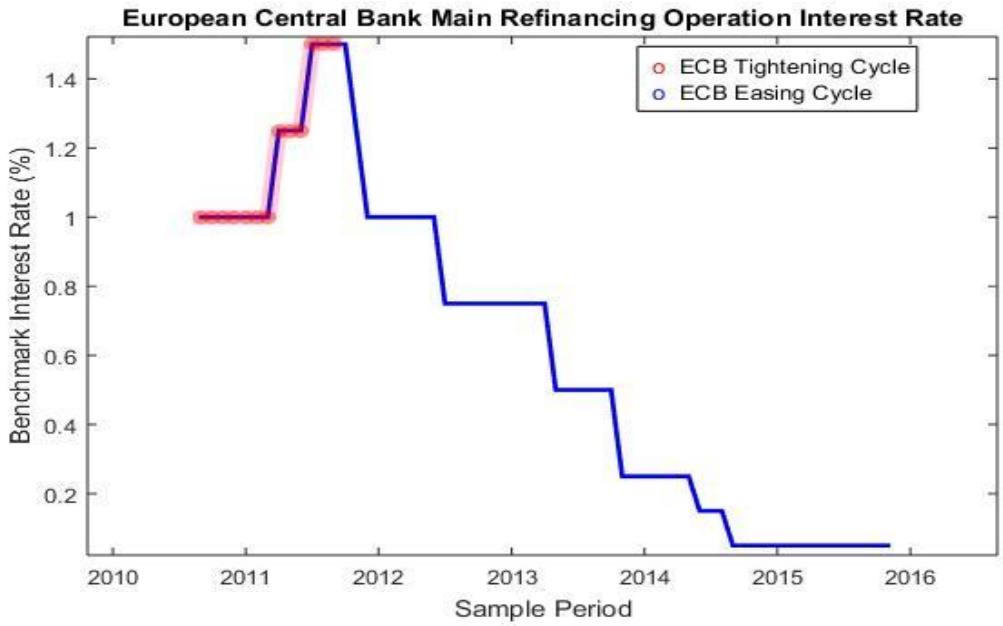


Figure 3.1 charts the ECB's key interest rate for the sample period. The chart indicates the tightening as well as the easing cycles defined for the sample period. It is reasonable to conclude that the anticipatory effect on the EUR/USD exchange rate for pre-ECB announcement windows which take place during tightening cycles would be very different to those observed during 'easing cycles'. For this reason, I split the entire sample into 'tightening' and 'easing' sub-sample for further analysis.

Table 3.4
Descriptive statistics for the cumulative returns (%) on the EUR/USD exchange rate for all computed 24-hour samples.

Sample	Mean	St. Dev.	Skewness	Kurtosis	Min	Max	Obs.
Pre-ECB Announcement Window							
EUR/USD 1300-1300	0.0163	0.4827	0.0618	3.647	-1.150	1.321	56
EUR/USD 2300-2300	0.0177	0.5687	1.043	4.671	-0.8797	2.060	56
EUR/USD 1300-1300 (Tightening)	0.2581	0.6791	-0.4650	2.296	-1.035	1.227	11
EUR/USD 2300-2300 (Tightening)	0.3699	0.7062	-0.3826	1.774	-0.7261	1.199	11
EUR/USD 1300-1300 (Easing)	-0.0678	0.3959	0.7291	5.5783	-1.011	1.218	45
EUR/USD 2300-2300 (Easing)	-0.0684	0.5023	1.612	8.352	-0.8797	2.060	45
Other (Non-Pre-ECB days)							
EUR/USD 1300-1300	-0.0193	0.5756	-0.4101	4.956	-3.631	1.909	1207
EUR/USD 2300-2300	-0.0198	0.5934	-0.1592	4.105	-2.198	2.201	1207
EUR/USD 1300-1300 (Tightening)	-0.0276	0.7106	-0.3319	2.824	-2.267	1.686	227
EUR/USD 2300-2300 (Tightening)	-0.0354	0.7328	-0.2372	2.916	-1.947	1.733	227
EUR/USD 1300-1300 (Easing)	-0.0163	0.5404	-0.4477	5.921	-3.631	1.909	980
EUR/USD 2300-2300 (Easing)	-0.0162	0.5565	-0.0987	4.507	-2.198	2.201	980

Table 3.4 provides descriptive statistics for the pre-ECB windows and for all other non-pre-ECB trading periods. *EUR/USD 1300-1300* is the cumulative log returns on the EUR/USD exchange rate on date $t-1$ to 1300 CET on date t. *EUR/USD 2300-2300* is the cumulative log returns on the EUR/USD exchange rate from 2300 CET on date $t-2$ to 2300 CET on date $t-1$. Samples labelled '*Tightening´* are the cumulative log returns for each respective 24-hour period during the ECB's tightening cycle which spans 11 ECB announcement windows and 227 non-ECB days. Samples labelled '*Easing´* are the cumulative log returns for each respective 24-hour period during the ECB's easing cycle which spans 45 ECB announcement windows and 980 non-ECB days.

3.5.3 European Central Bank

The ECB Governing Council convenes twelve times per year (although in 2015 this schedule was changed to include only eight scheduled meetings per year) as part of their mandated monetary policy operations to review, set or adjust monetary policy for the Euro area. Following this meeting the ECB announces the monetary policy stance at the pre-scheduled time of 1300 CET on a pre-scheduled date. Prior to this scheduled announcement the ECB mandates a *'quiet period'* during which members of the Governing Council are not permitted to comment publicly, on their own opinions or the banks policy stance. The analysis is primarily concerned with this *'quiet'* window, particularly the 24-hour period immediately prior the ECB policy announcement. For this purpose I collect the times and dates of pre-scheduled ECB Governing Council meetings, policy decision announcement and press conference times. I also take note of the key policy stance arrived upon at each meeting, as well as any significant announcements made during the post-meeting press conference. I source this data from the ECB's website (www.ecb.europa.eu) and further details of exact announcement times from Bloomberg. Table 3.5 presents details of ECB Governing Council meetings which are covered by the sample period.

Table 3.5
This table shows dates and outcomes of the European Central Bank's scheduled Governing Council meetings throughout the sample. The second column shows the key interest rate set by the Governing Council. The tightening cycle is defined as that up to October 20, 2011 and the easing sample from October 21, 2011 through November 20, 2015.

Scheduled Date	Benchmark Interest Rate	Monetary Policy Decision (1345 CET)
December 2, 2010	1.00	No Change
January 13, 2011	1.00	No Change
February 3, 2011	1.00	No Change
March 3, 2011	1.00	No Change
April 7, 2011	1.25	Increased 25 basis points
May 5, 2011	1.25	No Change
June 9, 2011	1.25	No Change
July 7, 2011	1.50	Increased 25 basis points
August 4, 2011	1.50	No Change
September 8, 2011	1.50	No Change
October 6, 2011	1.50	No Change
November 3, 2011	1.25	Decreased 25 basis points
December 8, 2011	1.00	Decreased 25 basis points
January 12, 2012	1.00	No Change
February 9, 2012	1.00	No Change
March 8, 2012	1.00	No Change
April 4, 2012	1.00	No Change
May 3, 2012	1.00	No Change

June 6, 2012	1.00	No Change
July 5, 2012	0.75	Decreased 25 basis points
August 2, 2012	0.75	No Change
September 6, 2012	0.75	No Change
October 4, 2012	0.75	No Change
November 8, 2012	0.75	No Change
December 6, 2012	0.75	No Change
January 10, 2013	0.75	No Change
February 7, 2013	0.75	No Change
March 7, 2013	0.75	No Change
April 4, 2013	0.75	No Change
May 2, 2013	0.50	Decreased 25 basis points
June 6, 2013	0.50	No Change
July 4, 2013	0.50	No Change
August 1, 2013	0.50	No Change
September 5, 2013	0.50	No Change
October 2, 2013	0.50	No Change
November 7, 2013	0.25	Decreased 25 basis points
December 5, 2013	0.25	No Change
January 9, 2014	0.25	No Change
February 6, 2014	0.25	No Change
March 6, 2014	0.25	No Change
April 3, 2014	0.25	No Change
May 8, 2014	0.25	No Change
June 5, 2014	0.15	Decreased 10 basis points
July 3, 2014	0.15	No Change
August 7, 2014	0.15	No Change
September 4, 2014	0.05	Decreased 10 basis points
October 2, 2014	0.05	No Change
November 6, 2014	0.05	No Change
December 4, 2014	0.05	No Change
January 22, 2015	0.05	No Change
March 5, 2015	0.05	No Change
April 15, 2015	0.05	No Change
June 3, 2015	0.05	No Change
July 16, 2015	0.05	No Change
September 3, 2015	0.05	No Change
October 22, 2015	0.05	No Change

3.5.4 Rumour Data

It is the primary question of this chapter to determine if the circulation of rumours among investors and market agents can set the tone for the pre-ECB announcement anticipatory market price movement. It is therefore appropriate, that I focus on highly relevant market rumours relating to forthcoming European Central Bank actions or changes in remit. Such highly relevant market rumours are appropriate examples of actionable information discerned by market actors but not yet investigated by economists in relation to pre-event anticipatory price discovery.

I source rumours and their respective time and date of broadcast through Twitter. Rumours of this type are quoted as 'ECB sources' stories. These rumours are reported by 'in the know' financial market commentators via Twitter regularly. ECB sources stories occur throughout the sample but they are particularly prevalent within a one-week window of the ECB's Governing Council meetings. Throughout this one week window the bank mandates that members maintain a 'quiet period', during which they must not communicate any policy opinions and inclination. I can gauge the popularity of the ECB sources story by the number of times the quoted rumour is repeated. It is relatively simple to search Twitter archives for the phrase 'ECB sources'. I select ECB rumour events where the quoted story is repeated by more than 10 financial market commentators. I then perform an advanced search for the full quoted story i.e. "ECB Sources: ECB is working on a discussion paper to execute government bond buying 3 different options", and pinpoint the time of the first broadcast of the quote. For a period spanning November 2010 to November 2015 I observe 236 ECB rumour events. Some 'sources' stories gain so much traction among financial commentators that they are then reported via Bloomberg professional services. A full list of 236 'ECB sources' events are given in the appendix.

Of the 236 observations of ECB rumours events, 33 occur during 31 of the 24-hour pre-ECB announcement window of the 56 pre-announcement windows. For pre-ECB windows during which these 31 rumours are observed the rumour dummy variable in the main regression takes unity value. Table 3.6 gives dates, times, details about these 31 rumour events, as well as noting whether the rumours signify a potential hawkish or a dovish policy decision.

Table 3.6
Rumours pertaining to forthcoming ECB Governing Council policy decisions recorded on Twitter in the 24-hour window prior the scheduled Governing Council policy announcement.

Pre-ECB Period	Time (CET)	Rumour
February 2, 2011	1554	Sources say Axel Weber not to be candidate for ECB president
April 6, 2011	1621	ECB rate hike only start of policy process
May 4, 2011	1317	More ECB rate hikes on the way; discussion on timing
August 3, 2011	1711	ECB ready to buy Italian, Spanish bonds if Berlusconi commits to bringing reforms forward
October 5, 2011	1312	ECB no longer pursuing plans to wean troubled banks off its lending support
November 3, 2011	1104	Greek socialist MPs forging proposal for coalition government headed by former ECB vice-president Papademos
December 8, 2011	1121	ECB sources say ECB sovereign bond buying remains capped at maximum €20bn a week
February 8, 2012	1612	ECB not yet decided on whether to contribute to Greek debt restructuring
May 2, 2012	1452	ECB getting progressively more nervous about Spain fallout. The new LTRO may be coming sooner than expected
June 5, 2012	1738	Source says the ECB is facing pressure to take more non-standard measures but it wants governments to commit to financial integration.
August 1, 2012	1806	According to sources, Greece is expected to finalize €11.5B of cuts in early-August
August 2, 2012	0905	ECB's Draghi faces leadership test over euro pledge
September 5, 2012	1400	ECB "sources" say bond buying will be unlimited but remain sterilized
October 3, 2012	1359	ECB has not closed door to Greek debt maturity extension
November 8, 2012	0940	ECB sources indicated OMT program won't be initiated any time soon
February 6, 2013	1421	Market sources report buying of Italian bonds. The 10-year BTP yield is just hovering above 4.50% level.
March 6, 2013	1750	German press reports ECB considering exiting Troika, sources then say reports are incorrect.
May 01, 2013	1639	Eurosystem sources: conditions for ECB rate cut are there
May 01, 2013	1644	ECB eyeing country-specific approach for SME lending
June 5, 2013	1430	ECB divided on further rate cuts, further rate cut may not deliver desired results
October 01, 2013	1321	ECB SOURCES: ECB likely to base LTRO decision on 2014 stress tests
November 06, 2013	1452	ECB rate change unlikely. Sources Confirm No ECB Rate Cut Tomorrow
January 08, 2014	1531	No major ECB policy changes expected in January
February 05, 2014	1355	Another ECB sources rumour that board split over deflation, unclear if Draghi acts tomorrow
April 02, 2014	1530	Over interpretation by market of QE possibility
June 04, 2014	1849	Sources suggest that ECB Draghi likely to signal cut this week.
September 04, 2014	1146	Sources report ECB Governing Council discussing ABS purchases, worth up to €500 billion, could start this year
October 01, 2014	1917	Greek banks win restructuring plan reprieve in ECB tests
November 05, 2014	1516	Central bankers to challenge Draghi on ECB leadership style
December 03, 2014	1634	ECB sources said to prepare broad based QE package for January meeting
January 21, 2015	1432	ECB exec board's QE proposal calls for roughly €50b in bond buys a month
April 14, 2015	1955	ECB raises Greek bank ELA by €800 million, bringing the ceiling to €74 billion
July 16, 2015	0946	Greece asks ECB for €1.5bn increase in ELA

3.6 Methodology

In this section, I detail the methodological approach adopted for the findings of this chapter. I first outline the basic dummy variable regression model used by Lucca and Moench (2015) in their findings of the pre-FOMC drift. I explain how this model is adapted and developed further to incorporate the effect of rumours on pre-event drift. This last specification is then re-estimated in Maximum Likelihood to account for any clusters of volatility, which are typically present in daily financial series.

I begin by investigating the pre-ECB window for any potential stock market and currency market drift. The intention is to see if the pre-FOMC drift observed by Lucca and Moench (2015) is mirrored in Eurozone's largest markets for the respective pre-ECB window. Figure 3.2 suggests that positive stock market drift should be observable for pre-ECB announcement windows. Further, Figures 3.4 and 3.5 illustrate the potential existence of positive currency market drift during tightening cycles and negative drift for samples covering easing cycles.

To gauge more formally the magnitude of excess returns during the 24-hour anticipatory period prior ECB announcements, I perform the following regression

$$XR_t = \alpha + \beta_1 preECB_t + \varepsilon_t \quad [3.1]$$

where XR_t is the cum-dividend log excess daily return on the DAX over the risk free rate in percent.[15] It is calculated by summing the 5-minute returns on the DAX for a specified trading period. For example, if the trading day is defined as the 24-hour period between 1300 CET on date $t-1$ to date t, the cumulative 5-minute returns during this return window will form a one day return observation for the XR_t vector. The sole explanatory variable is a dummy variable that takes unity value on 56 pre-ECB announcement periods (55 for the DAX dataset) and zero for all other trading periods. That is, the dummy variable takes value 1 for the daily return window immediately prior the scheduled ECB policy announcement (e.g. the trading day defined as 1300 CET at date $t-1$ to 1300 CET at date t). Coefficient β_1 is the average excess return differential on pre-ECB periods versus all other trading periods when the constant is present. The constant α is the unconditional average excess return earned on all periods other than pre-ECB periods.

I define a second regression in order to isolate excess returns earned during the pre-ECB periods where rumours are present, from those periods with no rumour diffusion. The objective being

[15] For the currency market sample XR_t is the log excess returns for the EUR/USD exchange rate in percent for a samples covering both tightening and easing cycles.

to deduce the magnitude of the pre-ECB announcement drift which may be attributable to anticipatory effects resultant from rumour prevalence. I split the sole explanatory variable from equation (3.1) into two separate dummy variables and perform the following regression

$$XR_t = \alpha + \beta_1 Rumour_t + \beta_2 NoRumour_t + \varepsilon_t \quad [3.2]$$

where the dummy variable $Rumour_t$ takes unity value for 31 pre-ECB periods (30 for the DAX dataset) with the presence of rumours about forthcoming ECB policy announcements and zero for all other periods. The dummy variable $NoRumour_t$ takes unity value for 25 pre-ECB periods where no rumours are observed about forthcoming ECB policy announcements and zero for all other periods. The β_1 and β_2 coefficients capture the average excess return differential on pre-ECB periods with rumours and pre-ECB periods without rumours, versus all other trading periods.

I then define a third regression, by supplementing equation (3.2) with lagged dummies for the pre-announcement windows with and without the presence of rumours. The objective being to capture any potential drift that maybe taking place beyond the 24-hour window prior the Governing Council's scheduled meeting. This equation is defined as follows

$$XR_t = \alpha + \beta_1 Rumour_t + \beta_2 NoRumour_t + \beta_3 Rumour_{t-1} + \beta_4 Rumour_{t-2} + \beta_5 NoRumour_{t-1} + \beta_6 NoRumour_{t-2} + \varepsilon_t \quad [3.3]$$

where $Rumour_{t-1}$ and $Rumour_{t-2}$ are dummy variables which take unity value for trading windows at 2 and 3 days, respectively, prior scheduled ECB announcements when rumours are present. $NoRumour_{t-1}$ and $NoRumour_{t-2}$ are dummy variables which take unity value for trading windows at 2 and 3 days, respectively, prior scheduled ECB announcements when rumours are not present.

The residuals from OLS regressions present departures from normality and serial correlation which might impair the statistical properties (asymptotic) of the estimates obtained. The next section details the tests implemented to determine a more appropriate method for coefficient estimation.

Statistical features of the return periods generated by summing 5-minute DAX and EUR/USD log returns demonstrate departures from normality and could potentially suffer from serial correlation and conditional heteroscedasticity. Since the disturbance terms in equations (3.1) and (3.2) may inherit such features, least square estimators might lose consistency and deliver potentially spurious results (see Chien, Lee, and Wang (2002)). Based on these considerations,

I supplement the estimation strategy by using alternative methods such as HAC sandwiches estimators and WLS, which can better cope with ill-conditioned data.

I re-estimate equations (3.1), (3.2) and (3.3) using the following three GARCH specifications:

$$XR_t = \alpha + \beta_1 preECB_t + \varepsilon_t \quad [3.4]$$

$$\sigma_t^2 = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \alpha_2 \sigma_{t-1}^2 \quad [3.5]$$

$$XR_t = \alpha + \beta_1 Rumour_t + \beta_2 NoRumour_t + \varepsilon_t \quad [3.6]$$

$$\sigma_t^2 = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \alpha_2 \sigma_{t-1}^2 \quad [3.7]$$

$$XR_t = \alpha + \beta_1 Rumour_t + \beta_2 NoRumour_t + \beta_3 Rumour_{t-1} + \beta_4 Rumour_{t-2} + \beta_5 NoRumour_{t-1} + \beta_6 NoRumour_{t-2} + \varepsilon_t \quad [3.8]$$

$$\sigma_t^2 = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \alpha_2 \sigma_{t-1}^2 \quad [3.9]$$

The joint estimations of mean and GARCH variance equations, which include dummy variables with structures similar to those defined above, can generate multi-modality in likelihood functions, with the peril of achieving local rather than global maxima (Doornik and Oms (2008)). As the number of dummy variables in the mean equation increases, the issue of multi-modality becomes more severe. To avoid this problem, I conduct two-stage empirical estimations of the above GARCH models. First, I carry out OLS estimation of equation (3.4) and then use the residuals so obtained to estimate equation (3.5). [16] I posit that this approach is more suitable to deliver robust estimators with a negligible impact on the asymptotic efficiency. This is particularly valid given the large sample of daily returns in use. Furthermore, it has been shown that for similar GARCH specifications, the two-step approach is asymptotically equivalent to the joint estimation of the mean and variance equations (Lin, Engle, and Ito (1994)).

[16] The same empirical exercise is carried out for equations (3.6) – (3.7) and (3.8) – (3.9).

3.7 Empirical Findings

Throughout this section, I present the empirical findings of this chapter. First, I document excess return on the DAX index in anticipation of the ECB's scheduled policy decision. I then investigate the nature of the pre-announcement anticipatory effect for tightening and easing monetary policy cycles. The influence of pre-announcement rumours on the anticipatory effect are then provided. Here I present the main findings of this chapter demonstrating that a sizable majority of the pre-announcement anticipatory effect can be attributed to the existence of pre-event rumours. A section documenting similar findings, but for the EUR/USD dataset is then reported. I complete the empirical findings of this chapter by calculating, formally, the profitability of a trading strategy based the findings of this chapter.

3.7.1 The Pre-ECB Announcement Stock Market Drift

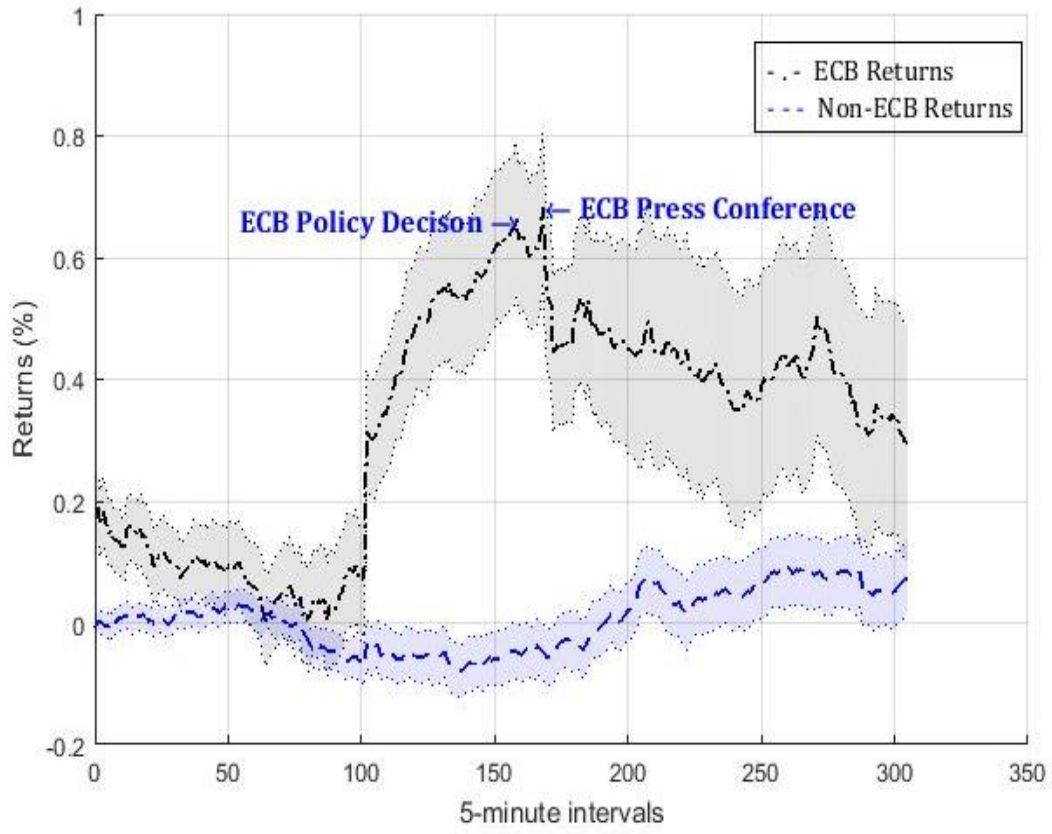
I begin by investigating 3-day return windows around scheduled ECB monetary policy announcement for the DAX index. I compare these to all other day triplets when there are no scheduled ECB scheduled announcements. Figure 3.2 illustrates the comparison between 3-day ECB announcement windows and all other 3-day trading windows. The bold dashed black line represents the average pointwise cumulative 5-minute intraday percentage return on the DAX for all 3-day ECB announcement windows. The announcement window is from the market open of the day prior to schedule ECB monetary policy announcements to the market close on the day following the announcement day. The average pointwise cumulative intraday return is calculated for 55 ECB announcement windows from November 01, 2010 to September 16, 2015. The bold blue dashed line gives the average pointwise cumulative intraday returns, but for all 3-day return windows of the same definition where there are no scheduled ECB policy announcements.

It is apparent from Figure 3.2 that returns on the DAX show significant upward drift in trading hours prior the ECB policy decision. Between the 100^{th} trading interval (market close prior ECB day) and the 102^{nd} trading interval (market open on ECB day), there is a notable jump in cumulative returns. This upward drift in returns continues until the ECB policy decision and it peaks around the time of the scheduled press conference. Just before the ECB policy announcement DAX returns reach levels 40 basis points higher than the market open on the previous day. There is a notable drop during the press conference window, followed by a period of consolidation for the remainder of the day.

On the following day, returns drift negatively from open to close. The pointwise 95% confidence interval for average cumulative returns indicated by the grey shaded area, would

suggest that cumulative pre-ECB returns are positive and significantly different from zero. Moreover, when compare to the cumulative returns on the DAX on all other day triplets and associated 95% confidence interval, the pre-ECB DAX drift appears noteworthy.

Figure 3.2
Cumulative returns on the DAX index. This figure shows the average cumulative returns on the DAX index for 3-day trading windows. The dashed black line is the average cumulative returns on the DAX from 0900 CET 24 hours prior ECB announcement days to 1730 CET 24-hours following the ECB announcement days. The dashed blue line shows average cumulative returns on the DAX on all other 3-day windows that do not include scheduled ECB announcements. The shade black and blue areas are pointwise 95% confidence intervals around the average cumulative returns for corresponding data sets. The sample period is from November 05, 2010 to September 16, 2015. The first blue arrow is set at 1345 CET, when ECB policy decisions are made public. The second blue arrow is set at 1430 CET, when the ECB press conference takes place.



The pre-ECB DAX drift found for the sample appears similar to that found by Lucca and Moench (2015) for the S&P 500 for pre-FOMC windows. The evidence in Figure 3.2 is however notable, given that no pre-ECB drift was observed for their sample which spans a far longer time horizon. It would be plausible though, given the expansion of the ECB's balance sheet and remit in recent years, that a pre-announcement anticipatory effect would be significantly more observable in the shorter and more recent sample. Further, Lucca and Moench (2015) refer to the pre-FOMC anticipatory stock market drift as a 'puzzle'. A puzzle for which they offer a number of potential explanations through fundamental financial economic theory, yet their conclusions acknowledge; that the pre-announcement drift is an economic puzzle. Having found that rumours play a significant role in the price formation

process in chapter 2 of this thesis; I investigate the impact of rumours on the pre-announcement stock market drift. I do this by re-specifying the pre-ECB return window into two independent return windows; those pre-ECB return windows with the presence of a relevant rumour broadcast by in the know market commentators on Twitter and, those pre-ECB return windows where no such rumour is observed. The pre-ECB trading periods where rumours are observed are noted and reported in Table 3.6

The average 5-minute cumulative returns in Figure 3.2 are crude in calculation. Further, the cumulative returns here do not account for dividend payments and do not factor in the possible influence of the risk-free return. I set the dependant variable as the cum-dividend log excess return over the risk-free rate in percentage points on the DAX, and formally investigate the magnitude of the pre-ECB announcement drift by estimating the single dummy variable equation (3.1). To estimate the magnitude of the impact of rumour prevalence on the pre-ECB announcement returns, I estimate equation (3.2). For the purpose of completeness, I expand equation (3.2) to include return windows, which extend beyond just one day prior scheduled ECB announcements. The purpose being to test for a pre-announcement effect persistent beyond one-day prior announcements, in the presence of rumours or otherwise. I formally measure any persistence by estimating equation (3.3).

I estimate all three equations with basic OLS methodology. The result of the OLS coefficient estimates for all three equations are presented in appendix B. Results of standard specification tests, show that OLS estimates may be inefficient or inaccurate due to the presence of an ARCH effect. To control for the latent ARCH effect, I re-estimate using the GARCH(*P,Q*) specifications outlined in equations (3.4) – (3.9). Following further robustness checks, results show that the conditional variance component (*P)* is an over-specification of the model. This term is subsequently dropped from the final model the results of which are presented in Tables 3.7 – 3.11.

Table 3.7 reports coefficient estimates for all three specification. Here, the dependant variable is the cum-dividend log excess daily return over the risk-free rate in percentage points on the DAX calculated as the sum of 5-minute returns 1300 CET on date $t-1$ to 1300 CET on date t. The dependant variable is denoted in the table as XR_t. This is the primary data set of interest given that it captures, by design, a full 24-hour return window closing before any realised ECB monetary policy announcement.

Table 3.7

This table shows the results for the maximum likelihood estimation of equations (3.4) – (3.5), (3.6) – (3.7) and (3.8) – (3.9). The dependant variable is the cum-dividend log excess return (XR_t) on the DAX from 1300 CET on date $t-1$ to 1300 CET on date t. The sample period is from November 05, 2010 to September 16, 2015 (1223 obs.). This sample contains 50 scheduled ECB announcements. In order to account for the effect of tight and loose monetary policies the sample is partitioned into the periods from November 05, 2010 through October 20, 2011 (238 obs.) and from October 21, 2011 through September 2015 (987 obs.) respectively. Each partition contains 11 and 44 ECB announcements respectively. Results for sub-samples accounting for monetary policy stance are presented in the second and third panel. Coefficient estimates and standard errors are presented adjacent to their respective parameters. Q(4) is the Ljung-Box statistic for serial correlation up to lag 4 in residuals. ARCH (4) is the ARCH-LM test for heteroscedasticity in residuals up to lag 4. P-values for specification tests are reported in brackets. ***Significant at 1%, **significant at 5% and *significant at 10%.

*** Significant at 1%, **significant at 5% and *significant at 10%.

	DAX 1300-1300 CET					
	Eq. (3.4) – (3.5)		**Eq. (3.6) – (3.7)**		**Eq. (3.8) – (3.9)**	
	Coefficient	**Std. Err.**	**Coefficient**	**Std. Err.**	**Coefficient**	**Std. Err.**
Constant	0.0343	0.0341	0.0349	0.0341	0.0562	0.0353
Pre-ECB$_t$	***0.483	0.161				
Rumour$_t$			**0.795	0.327	**0.768	0.337
NoRumour$_t$			0.190	0.191	0.180	0.191
Rumour$_{t-1}$					-0.239	0.294
Rumour$_{t-2}$					-0.187	0.208
NoRumour$_{t-1}$					-0.0772	0.273
NoRumour$_{t-2}$					-0.332	0.230
α_0	***1.144	0.0460	***1.140	0.0469	***1.339	0.0454
α_1	***0.353	0.0355	***0.355	0.0356	***3.57	0.0373
R^2	0.005		0.009		0.011	
Q(4)	1.561	0.816	1.624	0.804	1.611	0.807
ARCH(4)	9.988	0.000	9.918	0.000	9.650	0.000
	DAX 1300-1300 CET (Tightening)					
Constant	0.0363	0.0943	0.0354	0.0943	0.0691	0.0990
Pre-ECB$_t$	0.421	0.425				
Rumour$_t$			0.621	1.471	0.572	1.410
NoRumour$_t$			0.288	0.433	0.301	0.431
Rumour$_{t-1}$					0.192	0.669
Rumour$_{t-2}$					0.254	0.815
NoRumour$_{t-1}$					0.435	0.884
NoRumour$_{t-2}$					**-1.220	0.607
α_0	***1.559	0.137	***1.558	0.137	***1.495	0.126
α_1	***0.580	0.116	***0.604	0.119	***0.600	0.119
R^2	0.001		0.003		0.010	
Q(4)	4.324	0.364	4.345	0.361	4.426	0.351
ARCH(4)	3.935	0.001	3.947	0.001	4.041	0.001
	DAX 1300-1300 CET (Easing)					
Constant	0.0260	0.0378	0.0266	0.0376	0.0486	0.0391
Pre-ECB$_t$	***0.506	0.180				
Rumour$_t$			**0.816	0.322	**0.789	0.331
NoRumour$_t$			0.159	0.236	0.151	0.237
Rumour$_{t-1}$					-0.300	0.353
Rumour$_{t-2}$					**-0.384	0.179
NoRumour$_{t-1}$					-0.0936	0.316
NoRumour$_{t-2}$					-0.0835	0.268
α_0	***1.099	0.0541	***1.093	0.0538	***1.088	0.0534
α_1	***0.168	0.0365	***0.171	0.0365	***0.173	0.0377
R^2	0.007		0.010		0.014	
Q(4)	1.262	0.868	1.526	0.822	1.565	0.815
ARCH(4)	6.736	0.000	6.090	0.000	6.049	0.000

Result presented in column 2 of the table show that excess returns earned during 1300 – 1300 CET pre-ECB trading windows are on average 48 basis points higher than those earned on all trading days, with the empirical estimate significant at the 1% level. This would indicate that the DAX exhibits significant positive drift in excess returns during the 24-hours immediately preceding the ECB policy decision announcements. The estimated coefficient on the constant parameter would suggest that on average 1300 – 1300 CET DAX excess returns are not significantly different from zero. This finding is strikingly similar to that found by Lucca and Moench (2015), who find a pre-FOMC drift of 49 basis points for 2pm – 2pm pre-FOMC windows.

I split the sample into two periods; a tightening and an easing period to explore the potential for a heightened anticipatory effect based on a change in the ECB's mandated monetary policy goals. The results for the tightening sample period (November 05, 2010 to October 20, 2011), show no significant average excess returns for 1300 – 1300 CET windows before ECB announcements. In stark contrast, for the easing sample period (October 21, 2011 to September 16, 2015) I find larger, significant average excess returns of over 50 basis points for 1300 – 1300 CET windows before policy decision announcements. These findings would indicate that pre-ECB drift is only observable on the DAX for the sample period during which the ECB's mandate, balance sheet, and monetary policy tools were notably expanded.

In column 3 of the same table, I report results for the coefficient estimates for parameters defined in equations (3.6) – (3.7). The $Rumour_t$ dummy represents the 30 pre-ECB windows where a relevant rumour has been observed on Twitter. The $NoRumour_t$ dummy takes unity value for the remaining pre-ECB windows (25) where no relevant rumours have been detected. Findings show that DAX excess returns, for 1300 – 1300 CET pre-ECB windows where rumours are observed, are statistically significant and orders of magnitude greater that all 1300 – 1300 CET windows and pre-ECB windows without rumours. Results show that excess returns earned on the DAX for pre-ECB windows with rumour are on average almost 80 basis points higher than all other 1300 – 1300 CET windows. I find that excess returns earned on pre-ECB windows without rumours are on average not statistically different from all other non-ECB announcement periods. This result indicates that the pre-ECB anticipatory effect can be rationalised with the simple fundamental financial economic theory that investors trade on informational risk, updating their prior expectation of future large scope information events. This result confirms the initial hypothesis that pre-announcement effect are not due to arbitrary re-allocation prior to a significant public information event. Contrarily, it is a price formation process due to the risk weighted trading decisions made by publicly informed investors. The

puzzle occurs simply due to traders' awareness about market relevant information (such as that available on Twitter) not yet identified by academics.

Column 4 reports results for the coefficient estimates for parameters defined in Equations (3.8) – (3.9). Here I include lagged dummies to test 24-hour trading windows beyond that immediately prior the ECB Governing Council decision.

Table 3.8 reports the coefficient estimates for all equation parameters as above, but where the dependent variable is the cum-dividend excess return on the DAX for partial trading days. The partial trading day is defined as the market close on date $t-1$ to 1300 CET on date t. This partial trading day is calculated by summing the 5-minute returns on the DAX from market close on date $t-1$ to 1300 CET on the following day. The dependant variable is denoted in the table as XR_t. I investigate this particular return window due to the pattern observed for ECB day triplets in Figure 3.2. The cumulative intraday returns earned on the trading day prior ECB, don't appear to exhibit drift from market open to close. The drift appears to result from an overnight jump followed by continuing drift during morning trading hours.

Table 3.8
This table shows the results for the maximum likelihood estimation of equations (3.4) – (3.5), (3.6) – (3.7) and (3.8) – (3.9). The dependant variable is the cum-dividend log excess return (XR_t) on the DAX from the close on date $t-1$ to 1300 CET on date t. The sample period is from November 05, 2010 to September 16, 2015. Coefficient estimates and standard errors are presented adjacent to their respective parameters.
*** Significant at 1%, **significant at 5% and *significant at 10%.

XR_t	DAX Close-1300 CET					
	Eq. (3.4) – (3.5)		Eq. (3.6) – (3.7)		Eq. (3.8) – (3.9)	
	Coefficient	Std. Err.	Coefficient	Std. Err.	Coefficient	Std. Err.
Constant	**0.0588	0.0287	**0.0588	0.0287	**0.0653	0.0297
Pre-ECB$_t$	***0.458	0.168				
Rumour$_t$			**0.554	0.259	**0.548	0.259
NoRumour$_t$			0.348	0.223	0.341	0.223
Rumour$_{t-1}$					-0.00379	0.269
Rumour$_{t-2}$					-0.246	0.173
NoRumour$_{t-1}$					0.00138	0.193
NoRumour$_{t-2}$					-0.0345	0.190
α_0	***0.800	0.0313	***0.800	0.0313	***0.800	0.0317
α_1	***0.227	0.0288	***0.226	0.0287	***0.224	0.0311
R^2	0.010		0.011		0.014	
Q(4)	1.340	0.247	1.263	0.261	1.280	0.258
ARCH(4)	15.205	0.000	15.113	0.000	14.559	0.000

The empirical results in column 2 of the table confirm the initial observation made in Figure 3.2. Despite a trading window of only four hours, 4.5 hours shorter than the 1300 – 1300 CET return window, the pre-ECB drift observed is almost of the same magnitude. Coefficient estimates of the parameters specified in equations (3.4) – (3.5) show that excess returns earned

during Close – 1300 CET pre-ECB trading mornings are significant, and on average almost 46 basis points higher than those earned on all Close – 1300 CET trading windows. This would suggest that a sizable majority of the pre-ECB announcement DAX drift is earned from the close of the previous day to just before the ECB's policy decision announcement.

The results set out in column 3 suggest that only pre-ECB return windows with observed relevant rumours generate significant excess returns over all trading periods. For the close – 1300 CET pre-ECB trading period, cum-dividend excess returns on the DAX are on average 55 basis points higher than that earned on earned on all close – 1300 CET trading return windows. In contrast, average excess returns earned on the DAX during pre-ECB windows of the same description with no rumour observations, are not statistically significant. However, the average excess return of almost 80 basis points earned for rumour driven drift is notably higher for the longer pre-announcement trading window (1300 – 1300 CET), than that earned for the pre-ECB morning trading period (CLOSE-1300 CET). This finding would suggest that trading on the rumour during the afternoon prior ECB days would generate significantly greater excess returns than on ECB mornings.

Table 3.9 reports the coefficient estimates of equations (3.4) – (3.5), (3.6) – (3.7) and (3.8) – (3.9). when the dependent variable is the cum-dividend excess daily return on the DAX for standard open – close return windows. The dependant variable is denoted in the table as XR_t. The *Pre-ECB*, *Rumour* and *NoRumour* dummies take unity value for trading day before the ECB announcement day. The findings reported in Figure 3.2 appears to show that the pre-ECB drift predominantly takes place on the morning and overnight periods before the scheduled ECB announcement. From Figure 3.2 it appears that there is almost no drift for the pre-ECB trading day (Open – Close on date $t - 1$). The parametric results reported in Table 3.9 confirm this.

Table 3.9
This table shows the results for the maximum likelihood estimation of equations (3.4) – (3.5), (3.6) – (3.7) and (3.8) – (3.9). The dependant variable is the cum-dividend log excess return (XR_t) on the DAX from market open to market close. The sample period is from November 05, 2010 to September 16, 2015. The sample is split between tightening and easing cycles and all 3 equations are re-estimated with the results presented below. Coefficient estimates and standard errors are presented adjacent to their respective parameters.
*** Significant at 1%, **significant at 5% and *significant at 10%.

XR_t	DAX Open – Close					
	Eq. (3.4) – (3.5)		Eq. (3.6) – (3.7)		Eq. (3.8) – (3.9)	
	Coefficient	**Std. Err.**	**Coefficient**	**Std. Err.**	**Coefficient**	**Std. Err.**
Constant	**0.0743	0.0357	**0.0741	0.0357	**0.0937	0.0372
Pre-ECB$_t$	-0.0346	0.193				
Rumour$_t$			0.0336	0.347	0.0306	0.339
NoRumour$_t$			0.109	0.231	-0.128	0.233
Rumour$_{t-1}$					-0.290	0.248
Rumour$_{t-2}$					0.0282	0.224
NoRumour$_{t-1}$					-0.00660	0.248
NoRumour$_{t-2}$					**-0.558	0.240
α_0	***1.288	0.0463	***1.290	0.0464	***1.286	0.0466
α_1	***0.253	0.0353	***0.251	0.0351	***0.247	0.0357
R^2	0.001		0.001		0.008	
Q(4)	6.454	0.168	6.603	0.158	6.292	0.178
ARCH(4)	15.696	0.000	15.994	0.000	15.891	0.000

Overall the findings of this section show that trading on the rumour during pre-ECB announcement windows and selling immediately before the schedule ECB monetary policy outcome produce the greatest excess average returns. I discuss the merits of trading strategies designed around ECB announcements in greater detail in section 3.7.3.

3.7.2 The Pre-ECB Announcement Currency Market Rumour Drift

In this section, I perform similar analysis on the EUR/USD currency market to that carried out in the previous section for the DAX index. The approach is pointedly more focus on tightening and easing periods. Currency markets by nature have a markedly different price formation response to hawkish policy decisions than to dovish announcements given the underlying fundamental economic factors at play. The anticipatory effect and associated rumours are expected therefore to have a markedly different result when the sample is split into tight and loose monetary policy periods.

I begin by investigating day triplets around schedule ECB monetary policy announcement for EUR/USD exchange rate returns. I compare these to all other day triplets when there are no scheduled ECB scheduled announcements. Figure 3.3 illustrates the comparison between 3-day return windows when there is a schedule ECB announcement and all other 3-day return windows. The bold dashed black line represents the average pointwise cumulative 5-minute intraday percentage return on the EUR/USD exchange rate for all 3-day ECB announcement windows. The announcement window is from the market open at 0000 CET of the day prior to schedule ECB monetary policy announcements to the market close on the day following the announcement day at 2300 CET. The average pointwise cumulative intraday return is calculated for 56 ECB announcement windows from November 09, 2010 to November 20, 2015. The bold blue dashed line gives the average pointwise cumulative intraday returns, but for 3-day return windows of the same specification where there are no scheduled ECB policy announcements.

Figure 3.3 shows that pointwise cumulative returns on the EUR/USD are largely flat for the trading day prior to ECB announcement days. From the market open at 0000 CET on the day before, cumulative returns increase by 5 basis points during overnight trade before returning to approximately zero. For the remainder of the pre-ECB trading day, overnight and the morning of ECB day up to the ECB policy decision announcement, cumulative returns are approximately zero. Following the policy decision announcement, there is a significant dip in returns of more than 20 basis points until the start of the Governing Council president's press conference. During the press conference returns drift a little higher but the currency trade mostly lower than the pre-ECB period for the remainder of the ECB announcement day. On the following trading day returns on the EUR/USD consolidate during the overnight period and in morning European trade. This is followed by a sharp decline in returns from noon trading into the market close.

The pointwise 95% confidence interval for average cumulative returns indicated by the grey shaded area, suggests that cumulative pre-ECB returns are not significantly different from zero

or that earned on other days. The blue dashed line suggests the same but for all other non-ECB announcement periods.

According to the findings presented in Figure 3.3, the pre-announcement anticipatory effect found for the DAX index does not seem to apply to the EUR USD currency market. There is however, factors of fundamental foreign exchange economics at play. Encompassed in the period for which the EUR/USD sample is observed there are cycles of policy tightening and easing. Further, part way through the sample there is a departure of the ECBs' balance sheet structure from that of the FED, as well as an expansion in the ECB's monetary policy mandate and tools. The implications of this can be observed in Figures 3.4 and 3.5.

Figure 3.3
Cumulative returns on the EUR/USD exchange rate (Full Sample). This figure shows the average cumulative returns on the EUR/USD exchange rate for 3-day trading windows. The dashed black line is the average cumulative returns on the EUR/USD from 0000 CET on the day prior ECB announcement days to 2300 CET on the day following the ECB announcement days. The dashed blue line shows average cumulative returns on the EUR/USD on all other 3-day windows that do not include scheduled ECB announcements. The shade black and blue areas are pointwise 95% confidence intervals around the average cumulative returns for corresponding data sets. The sample period is from November 09, 2010 to November 20, 2015. The red arrow is set at 1345 CET, when ECB policy decisions are made public. The blue arrow is set at 1430 CET, when the ECB press conference takes place.

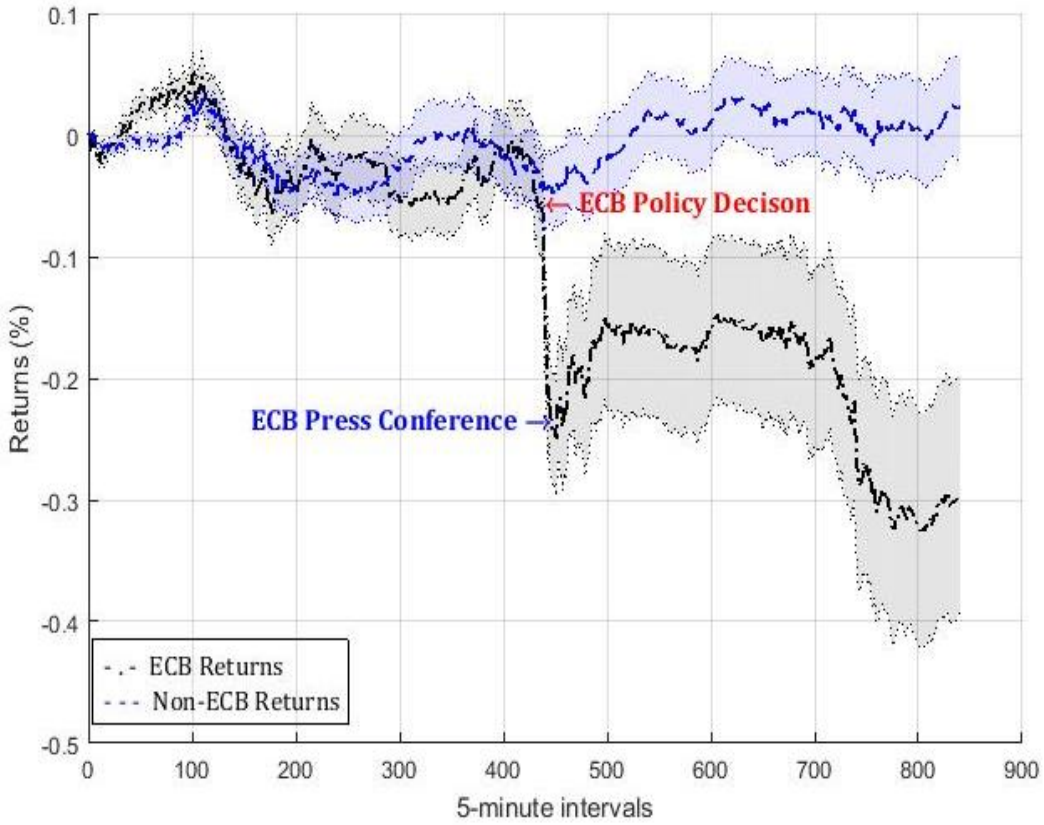
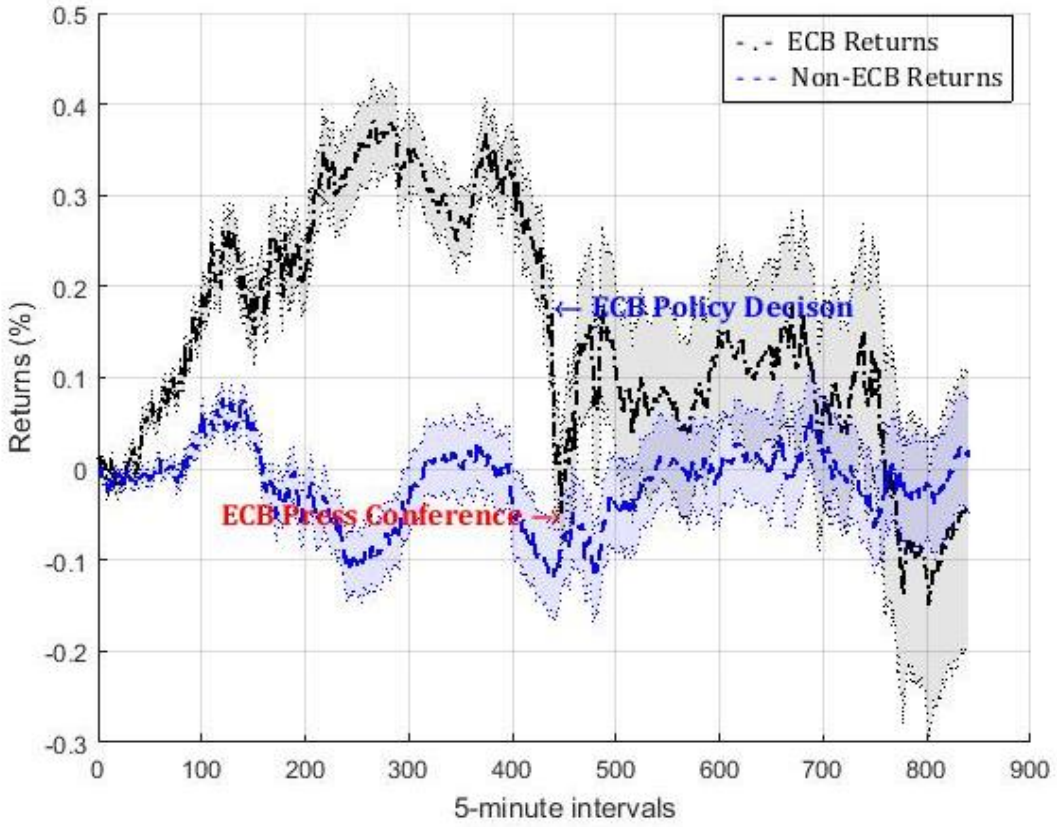


Figure 3.4 illustrates the average cumulative return comparisons for day triplets during the sample period considered to be a tightening cycle. The bold dashed black line represents the

average pointwise cumulative 5-minute intraday percentage return on the EUR/USD exchange rate for the 11, 3-day ECB announcement windows considered to be part of the tightening cycle. The bold blue dashed line gives the average pointwise cumulative intraday returns, but for all 3-day return windows during the policy tightening sample period (November 09, 2010 through October 20, 2011) where there are no scheduled ECB policy announcements.

Figure 3.4
Cumulative returns on the EUR/USD exchange rate (Tightening Sample). This figure shows the average cumulative returns on the EUR/USD exchange rate for 3-day trading windows. The dashed black line is the average cumulative returns on the EUR/USD from 0000 CET on the day prior ECB announcement days to 2300 CET on the day following the ECB announcement days. The dashed blue line shows average cumulative returns on the EUR/USD on all other 3-day windows that do not include scheduled ECB announcements. The shade black and blue areas are pointwise 95% confidence intervals around the average cumulative returns for corresponding data sets. The sample period is from November 09, 2010 through October 20, 2011 encompassing a regime of tightening monetary stance. The blue arrow is set at 1345 CET, when ECB policy decisions are made public. The red arrow is set at 1430 CET, when the ECB press conference takes place.



In contrast to the lack of drift observed in Figure 3.3, it is evident from Figure 3.4 that pre-announcement return drift is observable for the 'tightening' period of the sample. The bold dashed black line shows returns rising sharply from the open of the pre-ECB day (0000 CET) to a peak of almost 40 basis points above zero at the close. Returns on the EUR/USD then consolidate through overnight trade, then dip lower during early morning trade before the schedule ECB announcement. Following the announcement there is a sharp drop in cumulative returns back to zero before the commencement of the ECB press conference. Following the

press conference returns drift higher to about 10 basis points. There is a period of consolidation during overnight trade and in morning trade of the post-ECB trading day, followed by a drop off in the afternoon.

The pointwise 95% confidence interval for average cumulative returns indicated by the grey shaded area suggests that EUR/USD cumulative pre-ECB returns are positive and significantly different from zero during the tightening cycle. The 95% confidence interval indicated by the blue shaded area shows that cumulative returns on the EUR/USD on all other day triplets during the tightening sample period are approximately zero. Comparing the two, the tightening cycle pre-ECB EUR/USD drift appears economically important. I further explore the significance of this positive drift in Table 3.10.

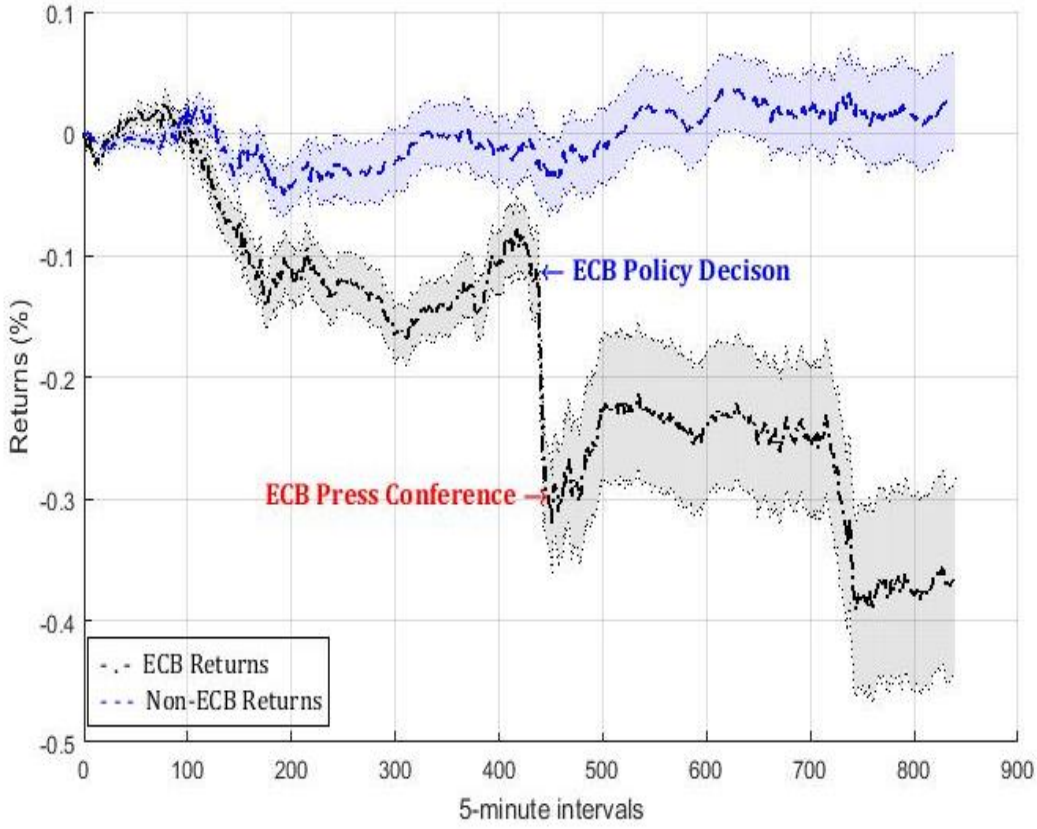
Figure 3.5 illustrates the average cumulative return comparisons for day triplets during the sample period defined as an easing cycle (October 21, 2011 - November 20, 2015). The bold dashed black line represents the average pointwise cumulative 5-minute intraday percentage return on the EUR/USD exchange rate for the 44, 3-day ECB announcement windows during the easing cycle. The bold blue dashed line gives the average pointwise cumulative intraday returns, but for all 3-day return windows where there are no scheduled ECB policy announcements.

In contrast to the lack of drift observed in Figure 3.3 and the positive drift apparent in Figure 3.4, that pre-announcement return drift is visibly negative for pre-ECB return windows in the easing sample period. The bold dashed black line shows cumulative returns dropping from zero on the morning open of European trade at 0830 CET (100^{th} return interval) to a maximum low of approximately -10 basis points in afternoon trade of the pre-ECB day. There is a period of consolidation from this minimum to just before the scheduled ECB policy announcement. Following the announcement there is a new sharp drop in cumulative returns to -30 basis points before the start of the ECB press conference. Following the press conference returns drift higher by about 10 basis points. There is a period of consolidation during overnight trade and in morning trade of the post-ECB trading day, followed by a drop off in the afternoon.

The pointwise 95% confidence interval for average cumulative returns indicated by the grey shaded area suggests that the EUR/USD cumulative pre-ECB returns are negative and significantly different from zero during easing cycles. The 95% confidence interval indicated by the blue shaded area shows that cumulative returns on the EUR/USD on all other day triplets during the easing sample period are approximately zero. Comparing the two, the easing cycle pre-ECB EUR/USD drift appears notable. Such drift however, does not appear to be as large as

that found for the tightening cycle. I explore the significance of this negative drift in Table 3.10.

Figure 3.5
Cumulative returns on the EUR/USD exchange rate (Easing Sample). This figure shows the average cumulative returns on the EUR/USD exchange rate for 3-day trading windows. The dashed black line is the average cumulative returns on the EUR/USD from 0000 CET on the day prior ECB announcement days to 2300 CET on the day following the ECB announcement days. The dashed blue line shows average cumulative returns on the EUR/USD on all other 3-day windows that do not include scheduled ECB announcements. The shade black and blue areas are pointwise 95% confidence intervals around the average cumulative returns for corresponding data sets. The sample period is from October 21, 2011 through November 20, 2015, encompassing a regime of expansionary monetary stance. The blue arrow is set at 1345 CET, when ECB policy decisions are made public. The red arrow is set at 1430 CET, when the ECB press conference takes place.



The figures above report 5-minute cumulative simple returns on the EUR/USD exchange rate using simple statistical properties. I set the dependant variable as the excess daily return on the EUR/USD, that is, the 24-hour return over the mean 24-hour return earned on all trading periods, and formally investigate the magnitude of the pre-ECB announcement drift by estimating the single dummy variable equation (3.1). The daily excess returns are computed by summing the 5-minute returns for a specified 24-hour window. To estimate the magnitude of the impact of rumour prevalence on the pre-ECB announcement returns, I then estimate equation (3.2). I then supplement equation (3.2) by including return windows which extend beyond just one day prior scheduled ECB announcements. The purpose being to test whether the pre-announcement effect persists beyond one day prior announcements. I formally gauge

such persistence by estimating equation (3.3). I perform all 3 regressions for the full sample, as well as the tightening and easing sub samples to unravel any differences in the currency market pre-announcement effects when the monetary policy stance shifts.

All three equations are estimated using OLS methodology. Empirical estimates for all the three equations are set out in tables 3.10 and 3.11. Standard specification tests show that, show that OLS estimates are robust and sufficient for all EUR/USD currency samples.

Table 3.10 summarises coefficient estimates for all three equations where the dependant variable is the excess daily return over the mean sample return in percentage points on the EUR/USD from 1300 CET on date $t-1$ to 1300 CET on date t. The daily excess return is computed by summing the 5-minute returns for a 24-hour window, from 1300 CET on date $t-1$ to 1300 CET on date t. The dependant variable is denoted in the table as XR_t. This is the primary data set of interest given that it captures, by design, a full 24-hour return window closing before any realised ECB monetary policy announcement. The independent parameters, as defined in section 3.6.1, are given in the first column.

Result presented in column 2 of the table show that excess returns earned during 1300 – 1300 CET (full sample period) pre-ECB trading windows, on average, are not significantly different from all other days. The t-statistic being less than 0.5 based on standard errors quoted in the table. This would indicate that the EUR/USD currency exhibits no drift in excess returns during the 24-hours immediately before the ECB policy decision announcement. The estimated coefficient on the constant parameter would suggest that on average the 1300 – 1300 CET EUR/USD excess returns on all other (non-pre-ECB) days are also not significantly different from zero.

I split the currency sample into two periods; a tightening and an easing period to explore the potential for a heightened anticipatory effect based on a change in the ECB's mandated monetary policy goals. The results in column one show that for both the tightening and easing sub samples, there appears to be no significant average excess returns for 1300 – 1300 CET windows before ECB announcements. The magnitude of the coefficient estimates for pre-ECB average excess returns are in line with that shown in Figures 3.4 and 3.5. However, the heightened scrutiny of parametric estimation shows that independent pre-ECB announcement drift cannot be confirmed for the EUR/USD currency market for the full sample period or either sub sample periods.

Table 3.10
This table shows the results for the OLS estimation of equations (3.1), (3.2) and (3.3). The dependant variable is the return (XR_t) on the EUR/USD from 1300 CET on date $t-1$ to 1300 CET on date t. The sample period is from November 09, 2010 to November 20, 2015. The sample is split between tightening and easing cycles and all 3 specifications are re-estimated with the results set out in the mid and lower panel. In order to account for the effect of tight and loose monetary policies the sample is partitioned into the periods from November 09, 2010 through October 20, 2011and from October 21, 2011 through November 20, 2015 respectively, so that each partition contains as many as 11 and 45 ECB announcements respectively. Coefficient estimates and standard errors are presented adjacent to their respective parameters.
*** Significant at 1%, **significant at 5% and *significant at 10%.

XR_t	**EUR/USD 1300 – 1300 CET**					
	Equation (3.1)		**Equation (3.2)**		**Equation (3.3)**	
	Coefficient	**Std. Err.**	**Coefficient**	**Std. Err.**	**Coefficient**	**Std. Err.**
Constant	-0.00169	0.0165	-0.00169	0.0165	0.00822	0.0173
Pre-ECB$_t$	0.0381	0.0781				
Rumour$_t$			-0.0742	0.106	-0.0841	0.106
NoRumour$_t$			0.168	0.113	0.158	0.113
Rumour$_{t-1}$					-0.0165	0.106
Rumour$_{t-2}$					-0.117	0.106
NoRumour$_{t-1}$					-0.119	0.113
NoRumour$_{t-2}$					-0.188	0.113
Obs: 1263	R^2:	0.001	R^2:	0.002	R^2:	0.006
	EUR/USD 1300 – 1300 CET (Tightening)					
Constant	-0.00981	0.0471	-0.00981	0.0468	0.00906	0.0491
Pre-ECB$_t$	0.286	0.219				
Rumour$_t$			**0.640	0.292	**0.621	0.291
NoRumour$_t$			-0.140	0.319	-0.159	0.318
Rumour$_{t-1}$					-0.678	0.291
Rumour$_{t-2}$					0.00465	0.291
NoRumour$_{t-1}$					0.0940	0.318
NoRumour$_{t-2}$					-0.143	0.318
Obs: 238	R^2:	0.007	R^2:	0.021	R^2:	0.045
	EUR/USD 1300 – 1300 CET (Easing)					
Constant	0.000193	0.0171	0.000193	0.0170	0.00803	0.0178
Pre-ECB$_t$	-0.0223	0.0816				
Rumour$_t$			**-0.253	0.110	**-0.260	0.110
NoRumour$_t$			0.241	0.218	0.233	0.217
Rumour$_{t-1}$					0.149	0.110
Rumour$_{t-2}$					-0.147	0.110
NoRumour$_{t-1}$					-0.169	0.217
NoRumour$_{t-2}$					-0.198	0.217
Obs: 1025	R^2:	0.001	R^2:	0.009	R^2:	0.018

In column 3 of the table, I report the empirical for equation 3.2. The *Rumour$_t$* dummy represents the 31 pre-ECB windows where a relevant rumour has been observed on Twitter. The *NoRumour$_t$* dummy takes unity value for the remaining 25 pre-ECB winodws, where no relevant rumours have been detected on Twitter. Empirical estimates for the full sample show that there is no pre-ECB rumour driven drift in EUR/USD excess returns. However, when the sample is split into tightening and easing periods, rumours driven drift is statistically significant.

For the sub-sample period defined as the tightening cycle (November 09, 2010 to October 20, 2011), average excess returns earned on the EUR/USD during the pre-ECB windows with rumour observation (5 in total) are 64 basis points higher than all other days. Further, returns earned on pre-ECB windows with rumour are 64 basis points higher than no-rumour (6 in total) windows. The positive rumour driven drift in the currency market during tightening monetary policy periods is in line with expectation given the underlying economics. It is particularly notable since tightening cycle rumours are mostly indicative or supportive of hawkish expectations.

For the sub-sample period defined as the easing cycle (October 21, 2011 to November 20, 2015), average excess returns earned on the EUR/USD during the pre-ECB windows with rumour observation (26 in total) are over 25 basis points less than all other days. Further, returns earned on pre-ECB windows with rumour are over 25 basis points lower than no-rumour (19 in total) windows. Negative rumour driven drift in the currency market during easing monetary policy periods is in line with the fundamental economics of foreign exchange markets. It is particularly notable since easing cycle rumours are mostly hinting at or encouraging of dovish expectations.

This result adds further support to the initial hypothesis that pre-announcement effects are not due to arbitrary re-allocation prior to a significant public information event. In fact, in the currency market pre-announcement anticipatory effects are almost unobservable when the presence of rumours is not considered. Rumours appear to be noteworthy in the price formation process due to the risk weighted trading decisions made by informed investors. Empirical estimates for the parameters of equation 3.3 are set out in the last column of Table 3.10. Here I include lagged dummies to test 24-hour trading windows beyond that immediately prior the ECB Governing Council decision to include 2 and 3 days return observations prior the announcement.

Table 3.11 reports the coefficient estimates for all three equations as above but where the dependant variable (denoted as XR_t) is the excess daily return over the mean sample return in percentage points on the EUR/USD from 2300 CET on date $t-2$ to 2300 CET on date $t-1$. I investigate this particular return window due to the pattern observed for ECB day triplets in Figures 3.4 and 3.5. The cumulative intraday returns earned on the 24- hour trading day prior ECB announcement days appear to exhibit drift. However, the drift appears to consolidate during overnight and morning trading hours on ECB day up to the announcement time.

Table 3.11
This table shows the results for the OLS estimation of equations (3.1), (3.2) and (3.3). The dependant variable is the excess return (XR_t) on the EUR/USD from 2300 CET on date $t-2$ to 2300 CET on date $t-1$. The sample period is from November 09, 2010 to November 20, 2015. The sample is split between tightening and easing cycles and all 3 specifications are re-estimated with the results set out in the second and bottom panel. In order to account for the effect of tight and loose monetary policies the sample is partitioned into the periods from November 09, 2010 through October 20, 2011and from October 21, 2011 through November 20, 2015 respectively, so that each partition contains as many as 11 and 45 ECB announcements respectively. Coefficient estimates and standard errors are presented adjacent to their respective parameters.
*** Significant at 1%, **significant at 5% and *significant at 10%.

XR_t	**EUR/USD 2300 – 2300 CET**					
	Equation (3.1)		**Equation (3.2)**		**Equation (3.3)**	
	Coefficient	**Std. Err.**	**Coefficient**	**Std. Err.**	**Coefficient**	**Std. Err.**
Constant	0.00685	0.0165	0.00643	0.0165	0.00696	0.0170
Pre-ECB$_t$	-0.0234	0.0796				
Rumour$_t$			-0.0954	0.106	-0.0993	0.107
NoRumour$_t$			0.0719	0.123	0.0714	0.124
Rumour$_{t-1}$					0.0619	0.160
Rumour$_{t-2}$					-0.00985	0.128
NoRumour$_{t-1}$					-0.00342	0.123
NoRumour$_{t-2}$					-0.0780	0.122
Obs: 1263	R^2:	0.001	R^2:	0.001	R^2:	0.003
	EUR/USD 2300 – 2300 CET (Tightening)					
Constant	-0.0173	0.0486	-0.0173	0.0482	-0.00428	0.0509
Pre-ECB$_t$	*0.405	0.226				
Rumour$_t$			***0.855	0.300	***0.842	0.302
NoRumour$_t$			-0.134	0.328	-0.147	0.330
Rumour$_{t-1}$					-0.0450	0.302
Rumour$_{t-2}$					-0.440	0.302
NoRumour$_{t-1}$					0.0684	0.330
NoRumour$_{t-2}$					-0.0765	0.330
Obs: 238	R^2:	0.014	R^2:	0.034	R^2:	0.044
	EUR/USD 2300 – 2300 CET (Easing)					
Constant	0.00765	0.0171	0.00658	0.0170	0.00518	0.0175
Pre-ECB$_t$	-0.0962	0.0892				
Rumour$_t$			**-0.311	0.163	**-0.312	0.161
NoRumour$_t$			0.144	0.125	0.148	0.127
Rumour$_{t-1}$					0.0817	0.178
Rumour$_{t-2}$					0.0480	0.144
NoRumour$_{t-1}$					-0.0238	0.139
NoRumour$_{t-2}$					-0.0676	0.117
Obs: 1025	R^2:	0.001	R^2:	0.010	R^2:	0.011

Empirical results in column 2 confirm the initial observation made in Figure 3.4 and 3.5, i.e. that the pre-announcement drift takes place predominantly in the 24-hour pre-ECB return window. The magnitude on the coefficient estimates for the *pre-ECB* parameter similar to those set out in Table 3.10, but more positive for the tightening sub sample and more negative for the easing sub sample, with the impact of announcements being this time significant at the 10% level for the latter period.

In column three, results reaffirm the hypothesis of rumour driven drift further. Average excess return earned during pre-ECB windows where rumours are observed, during periods of policy tightening, are over 85 basis points higher than on all other days and almost 100 basis points higher than no-rumour pre-ECB windows. The drift here is higher than that observed for the 1300 – 1300 CET window (tightening period), suggesting some level of profit taking during overnight and morning trade immediately prior the scheduled announcement.

For the sub-sample period defined as the easing cycle (October 21, 2011 to November 20, 2015), average excess returns earned on the EUR/USD during the pre-ECB windows with rumour observation are over 31 basis points less than all other days and over 45 basis points less than no-rumour pre-ECB windows. The drift is more negative than that observed for the 1300 – 1300 CET (easing period), suggesting some level of short covering during overnight and morning trade on ECB day.

Overall the findings of this section show that for the currency market, trading on the rumour during pre-ECB announcement windows and covering the trade at the close of the day prior schedule ECB policy announcement, produces the greatest excess average returns. I discuss the merit of such trading strategy in greater detail in the coming section.

3.7.3 Buy the Rumour, Sell Before the Announcement

Empirical results show that pre-announcement abnormal excess returns are statistically significant on both stock and currency markets. In this section I investigate whether investor can reap profits by implementing trading rules designed around the ECB announcements as previously defined. I will then compare the magnitude of such profits with those earned from various other return windows. I will also assess the risk adjusted performance of pre-announcement trading, rumour guided pre-announcement trading and risk adjusted earnings on all other return periods. I conclude that the most efficient trading strategy during the pre-ECB announcement window is to buy the DAX on when rumours of forthcoming central bank policy action are circulating on Twitter and sell out of this position 45 minutes prior the disclosure of the realised policy decision. For the currency market, the most profitable trading rule would be to replicate the above strategy for periods during which the ECB is considered to follow a tight monetary policy stance. And, for times when the bank is considered to be in an accommodative monetary policy cycle, to sell the euro in the pre-ECB window and buy back 45 minutes prior the scheduled announcement.

A simple strategy of buying the DAX index at 1300 CET the day prior to a scheduled ECB monetary policy announcement and selling back at market price 24-hours later on ECB day, will on average earn significant excess returns over all other non-pre-ECB return periods. To contextualise this result, Table 3.12 provides basic statistics and annualised excess returns (in bold) for each defined trading period. It also presents the level of annualised risk adjusted excess return earned on the DAX based on a strategy of buying 1300 CET and selling back at 1300 CET the following day. The annualised Sharpe ratio (highlighted in bold font) is calculated as $SR_{TS} = (R_{TS} - r_f / \sigma_{TS}) \times \sqrt{K}$, where R_{TS} is the average 24-hour return on the trading strategy, r_f is the appropriate risk-free rate for the same period and σ_{TS} is the respective standard deviation. I multiply the simple Sharpe ratio by $\sqrt{K}$ to annualise the Sharpe ration, where *K* is the number of times that particular trading strategy would be executed per year.

Results show that for the full sample period (November 2010 through September 2015), buying the DAX at 1300 CET the day before scheduled ECB announcements and selling it back 45 minutes before the announcement would earn annualised excess returns of 5.708%. This is tantamount to over 64% of annualised returns for the almost five-year sample. It is substantially greater than the 3.192% annualised earnings on all other trading days of the same time window. Further, this annualised return is earned by trading only 12 times in any given year for a 24-hour period versus all other days. A close look at the pre-ECB announcement trading strategy

reveals, as per the results in the previous section that pre-ECB earnings are not arbitrarily earned on all pre-ECB trading windows. Of the aforementioned 5.708% pre-ECB excess returns, almost 90% of this is earned on pre-ECB windows where rumours are observed. This is tantamount to an annualised return of 4.986% on such pre-ECB trading periods. This return is significantly higher than the 0.322% annualised return of pre-ECB windows where no rumours are present. It is worth noting that transaction costs are ignored in the above calculations due to the possible inaccuracy of pinpointing an acceptable rate. However, given the relatively small number of trades required per year to profit from this trade it is fair to state that the impact of transaction cost would pale in comparison to the large profit potential.

Table 3.12

This table provides summary statistics for the excess return over the risk-free rate (XR_t) on the DAX from 1300 CET on date $t-1$ to 1300 CET on date t. The sample period is from November 05, 2010 to September 06, 2015. The sample is split between tightening and easing cycles. Column one defines the summary statistics provided in adjacent cells. Average annualised excess returns (*Annual* XR_t) are computed by summing the excess daily returns for the specified days and dividing by the total number of years. SR_{TS} is the annualised Sharpe ratio of the trading strategy as defined in the text. The return period for which the summary statistics are calculated are defined in the first row. Outliers are defined return observations exceeding the 99% confidence interval.

	DAX 1300 - 1300 CET							
	All Observations				**Excluding Outliers**			
	Pre-ECB	**Rumour**	**No Rumour**	**Other**	**Pre-ECB**	**Rumour**	**No Rumour**	**Other**
Mean	0.502	0.831	0.060	0.013	0.502	0.831	0.060	0.034
St. Dev.	1.184	0.911	1.331	1.341	1.184	0.911	1.331	1.261
Annual XR_t	**5.708**	**4.986**	**0.322**	**3.192**	5.708	4.986	0.322	8.204
SR_{TS}	**1.468**	**2.040**	**0.100**	**0.152**	1.468	2.040	0.100	0.419
Max	3.390	3.355	2.355	7.238	3.390	3.355	2.355	4.702
Min	-2.534	-0.239	-2.569	-6.936	-2.534	-0.239	-2.569	-5.406
Obs.	55	30	25	1169	55	30	25	1163
	DAX 1300 - 1300 CET (Tightening)							
Mean	0.540	1.191	-0.068	0.011	0.540	1.191	-0.068	0.011
St. Dev.	1.601	1.370	1.662	1.880	1.601	1.370	1.662	1.880
Annual XR_t	**6.474**	**6.495**	**-0.442**	**2.650**	6.474	6.495	-0.442	2.650
SR_{TS}	**1.118**	**1.944**	**-0.100**	**0.085**	1.118	1.944	-0.100	0.085
Max	3.491	3.456	2.063	7.339	3.491	3.456	2.063	7.339
Min	-2.117	-0.009	-2.152	-6.349	-2.117	-0.009	-2.152	-6.349
Obs.	11	5	6	227	11	5	6	227
	DAX 1300 - 1300 CET (Easing)							
Mean	0.492	0.752	0.103	0.014	0.492	0.752	0.103	0.021
St. Dev.	1.078	0.836	1.258	1.175	1.078	0.836	1.258	1.154
Annual XR_t	**5.526**	**4.606**	**0.525**	**3.331**	5.526	4.606	0.525	5.108
SR_{TS}	**1.580**	**2.059**	**0.200**	**0.182**	1.580	2.059	0.200	0.285
Max	3.311	3.276	2.330	4.675	3.311	3.276	2.330	4.675
Min	-2.559	-0.265	-2.594	-6.962	-2.559	-0.265	-2.594	-4.773
Obs.	44	25	19	943	44	25	19	942

The Sharpe ratio further reflects the efficiency of the rumour trading strategy in terms of the mean variance relationship. While an annualised Sharpe ratio of 1.468 for a pre-ECB only

strategy is impressive when compared to the 0.152 for all other days, it is substantially lower that the annualised Sharpe ratio of 2.040 for a trading strategy of buying the rumour in the pre-ECB window and selling before the announcements are disclosed. This finding is consistent when the sample is split into sub-samples accounting for the policy stance of the ECB's Governing Council.

A similar trading strategy of buying/selling the EUR/USD index at 2300 CET the two days prior to a scheduled ECB monetary policy announcement and selling/buying back at market price 24-hours later on the night before ECB day, will on average earn significant returns over all other non-pre-ECB return periods. To contextualise this trading strategy, Table 3.13 provides basic statistics and annualised returns (in bold) for each defined trading period. It also presents the level of annualised risk adjusted return earned on the EUR/USD based on the outlined trading strategy. The annualised Sharpe ratio (highlighted in bold font) is calculated as before, however since a short position is taken in the currency during pre-ECB windows in the loose monetary policy regime, the Sharpe ratio reflects in this case the direction of the position.

Results show that for the full sample period there are no notable advantage in taking a position in the EUR/USD market during pre-ECB windows. However, there is a noticeable advantage in implementing a similar strategy to that adopted in the DAX above when the ECB is considered to be in a tightening cycle. Taking a long position in the EUR/USD from 2300 CET two days before ECB day and liquidating 14 hours before the scheduled announcement, yields annualised returns (over the sample mean) of 4.421%. This level of return is remarkably greater in magnitude than those obtained by applying the same rule to all other days with no ECB announcements, which produced average annualised returns of -9.134%. A short position during the pre-ECB window when the Governing Council is judged to be in an easing cycle would produce annualised returns of 0.847% versus 3.666% for being long EUR/USD on all other days. In the presence of rumours the annualised returns increases to 5.356% for the tightening pre-ECB windows, suggesting a long position when rumours are not observed would generate losses. For a short position when rumours are present the annualised return earned is 1.809%.

The Sharpe ratio reflects the efficiency of the rumour trading strategy in the currency market in terms of the mean variance relationship. During the tightening cycle an annualised Sharpe ratio of 1.730 for a pre-ECB only strategy is observed when compared to the -0.746 for all other days. This Sharpe ratio is however, lower that the annualised Sharpe ratio of 4.626 for a trading strategy of buying the rumour in the pre-ECB window and selling before the fact.

The risk adjusted return for a short position in the Euro during easing pre-ECB windows is found to be 0.545. This is notably lower than the 2.345 Sharpe ratio found for a short position in the presence of rumours.

Table 3.13

This table provides summary statistics for the return (R_t) on the EUR/USD from 2300 CET on date $t-2$ to 2300 CET on date $t-1$. The sample period is from November 09, 2010 to November 20, 2015. The sample is split between tightening and easing cycles. Column one defines the summary statistics provided in adjacent cells. The return period for which the summary statistics are calculated are defined in the first row. Average annualised excess returns (*Annual* XR_t) are computed by summing the excess daily returns for the specified days and dividing by the total number of years. SR_{TS} is the annualised Sharpe ratio of the trading strategy as defined in the text. Outliers are calculated as return observations exceeding the 99% confidence interval.

	EUR/USD 2300 – 2300 CET							
	All Observations				**Excluding Outliers**			
	Pre-ECB	**Rumour**	**No Rumour**	**Other**	**Pre-ECB**	**Rumour**	**No Rumour**	**Other**
Mean	0.010	-0.085	0.120	-0.019	-0.028	-0.085	0.042	-0.019
St. Dev.	0.564	0.573	0.544	0.594	0.495	0.573	0.381	0.594
Annual XR_t	**0.107**	**-0.508**	**0.616**	**-4.653**	-0.301	-0.508	0.207	-4.653
SR_{TS}	**0.059**	**-0.366**	**0.491**	**-0.507**	-0.193	-0.366	0.245	-0.507
Max	2.060	1.217	2.060	2.201	1.199	1.217	0.809	2.201
Min	-0.880	-0.880	-0.726	-2.198	-0.880	-0.880	-0.726	-2.198
Obs.	56	31	25	1207	55	31	24	1207
	EUR/USD 2300 – 2300 CET (Tightening)							
Mean	0.368	0.818	-0.171	-0.037	0.368	0.818	-0.171	-0.037
St. Dev.	0.706	0.433	0.587	0.733	0.706	0.433	0.587	0.733
Annual XR_t	**4.421**	**5.356**	**-0.935**	**-9.134**	4.421	5.356	-0.935	-9.134
SR_{TS}	**1.730**	**4.626**	**-0.653**	**-0.746**	1.730	4.626	-0.653	-0.746
Max	1.197	1.197	0.678	1.731	1.197	1.197	0.678	1.731
Min	-0.728	0.039	-0.728	-1.949	-0.728	0.039	-0.728	-1.949
Obs.	11	5	6	227	11	5	6	227
	EUR/USD 2300 – 2300 CET (Easing)							
Mean	-0.078	-0.311	0.189	-0.015	-0.126	-0.311	0.095	-0.015
St. Dev.	0.494	0.325	0.524	0.557	0.375	0.325	0.310	0.557
Annual XR_t [17]	**0.847**	**1.809**	**-0.962**	**3.666**	1.346	1.809	0.462	3.666
SR_{TS}	**0.545**	**2.345**	**-0.806**	**0.429**	1.166	2.345	0.689	0.429
Max	2.061	0.264	2.061	2.202	0.809	0.264	0.809	2.202
Min	-0.880	-0.879	-0.546	-2.197	-0.880	-0.879	-0.546	-2.197
Obs.	45	26	19	981	44	24	18	981

Evidence that the pre-ECB announcement drift is rumour conditional is clearly apparent from the results set out in both section 3.7.1 and 3.7.2. In this section, I demonstrate further that such conditional drift is not realised ex-post, but must have been apparent to traders at the time. In addition, the basic calculations presented above show that a simple strategy of buying the rumour and selling it before the announcement would earn significantly higher annual returns than holding the stock market for all other days. Moreover, the risk-adjusted returns by

[17] The figures in bold here are calculated for a short position taken in the EUR/USD for the specified return windows during the easing sample defined in the text.

implementing such strategy presents orders of magnitude greater than holding the market all other days in both currencies and stocks.

3.8 Conclusion

The chapter begins by applying the central hypothesis of this thesis to the pre-announcement price formation puzzle. The pre-announcement window of scheduled central bank policy releases is identified as a pre-information window worthy of testing. Such pre-event windows had been shown to exhibit puzzling price formation processes by Lucca and Moench (2015). The assertion in this chapter is that a Bayesian updating process of traders' *prior* expectations is taking place in the pre-announcement window prior to large scope macroeconomic news events. Such updating is posited to be as a result of new information, perhaps public, which has been detected by market agents but not by academics. The information is therefore, not private but also not public in the regulatory sense. That is, it is not published and/or archived by mandated outlets such as Bloomberg or Reuters. Should the content of such information change the weighted average expectation of market agents, about the scale, probability or timing about the forthcoming large scope central bank announcement, then pre-announcement price formation process should be observable.

This chapter documents large excess returns on the DAX stock exchange during 24-hour trading windows prior to 55 scheduled ECB policy announcements. These pre-announcement excess returns are earned during policy tightening, as well as policy easing periods. The average earning on the DAX during the pre-ECB window is almost 50 basis points. Buying the index 24 hours prior the announcement and selling immediately before the announcement is found to produce a far greater return than simply holding the index for a full year. Further, the risk weighted efficiency of such a strategy is also found to be far greater far greater.

The finding of this particular pre-announcement price formation process is novel. A similar price formation process is observed by Lucca and Moench (2015) for the pre-FOMC window but not for other central banks. Lucca and Moench (2015) conclude that such a price formation puzzle is puzzling. This thesis asserts that the price formation process is not a puzzle and simply an intact price discovery process.

A survey of Twitter.com reveals 236 information events, rumours pertaining to forthcoming ECB policy broadcast by market agents and commentators. Of these 236 rumours, 30 are observed during the 24-hour pre-ECB announcement window. The observation of such information events presents the opportunity to test the central hypothesis of this thesis further. The pre-announcement windows with and without rumour are tested for the latent price formation process.

Results show that during 25 pre-ECB announcement windows absent of rumour observation, no significant excess returns can be earned on the DAX. Whereas, during the 30 pre-ECB windows with rumour observations, 80 basis point can be earned on average. To quantify the economic significance of the rumour driven pre-ECB price discovery process; the excess returns on the DAX in the 24-hour pre-ECB window are tantamount to almost 60% of the annualised total excess returns on the DAX for the full sample period. The annualised Sharpe ratio of trading the ECB rumour and selling prior the announcement is 2.04. This is compared to 1.47 for simply buying the 24-hour pre-announcement period and 0.15 for holding the DAX for all other days of the year.

This chapter sets out to solve a price formation puzzle and identify the puzzle as an intact price discovery process with a dataset of public market relevant information in the form of market rumours. The pre-central bank announcement price formation process is shown to be one of price discovery. Findings in this chapter show that information delivered as rumour has significant value to market agents through observable and sizable risk adjusted excess earnings. The information is clearly identified by such market agents but previously undetected by academics.

Appendix B

Appendix B1
Rumours pertaining to potential ECB policy decisions broadcast on Twitter by 'in the know' financial market commentators

Date	Time	Rumour
17/11/2010	6.59 pm	According to sources, the ECB has bought Portuguese and Greek gov't bonds today to curb fallout to the ongoing Ireland issues.
26/11/2010	5.41 am	Without revealing sources FT Deutschland says € zone nations and ECB are urging Portugal to get bailout funds
8/12/2010	5.54 am	Currency reserves create temptation for intervention; says new sources of international liquidity needed for systemic crises
13/12/2010	5.59 pm	ECB considering request for more (potentially double) capital, says Reuters citing Eurozone central bank sources.
20/12/2010	1.50 pm	ECB wants liquidity included in new stress
07/01/2011	11.02 am	Market sources say ECB was seen buying Portuguese bonds this morning.
18/01/2011	11.22 am	ECB EXPECTS MORE BANKS TO FAIL 2011 TESTS THAN IN 2010 BECAUSE OF THE LIQUIDITY CRITERION
28/01/2011	3.18 pm	ECB Mulling Higher Rate On Loans To 'Addicted' Banks
02/02/2011	3.54 pm	SOURCES SAY AXEL WEBER NOT TO BE CANDIDATE FOR ECB PRESIDENT
9/02/2011	10.48 am	BUNDESBANK'S AXEL WEBER WILL NOT BE CANDIDATE TO REPLACE TRICHET AS ECB PRESIDENT
6/4/2011	4.21 pm	ECB rate hike only start of policy process
19/04/2011	6.25 am	ECB FOCUS-Greek restructuring could slow pace of rate hikes
28/04/2011	8.10 pm	Government sources say Angela Merkel has approved Italy's Mario Draghi as the next ECB president
4/05/2011	1.17 pm	MORE ECB RATE HIKES ON THE WAY; DISCUSSION ON TIMING
19/05/2011	6.18 pm	Eurozone eyes new deal for Greece; ECB issues threat: The sources told of the new strategy on Thursday
2/06/2011	12.15 pm	EU/IMF/ECB inspectors plan to issue joint statement on Greece
23/06/2011	1.28 pm	GREECE'S PAPANDREOU, ECB'S TRICHET, MERKEL, SARKOZY AND VAN ROMPUY TO MEET AHEAD OF EU LEADERS' SUMMIT
24/06/2011	9.47 am	Italian ECB board member Bini-Smaghi gave EU president Van Rompuy assurances that he will step down according to EU sources
21/07/2011	10.49 am	German gov't sources on Reuters saying ECB would accept selective default
28/07/2011	9.08 am	New sources of inflationary pressure could emerge
3/8/2011	5.11 pm	ECB READY TO BUY ITALIAN, SPANISH BONDS IF BERLUSCONI COMMITS TO BRING FORWARD SPECIFIC REFORMS
5/08/2011	9.486 am	Four ECB Governing Council members voted against re-activating bond buying - Eurozone central bank sources
6/8/2011	2.55 pm	ECB split over whether to buy Italy bonds
6/8/2011	6.08pm	ECB to discuss crisis action on Sunday
8/8/2011	10.01 am	Market sources so far say ECB has bought around E700mln combined bonds in both Italy & Spain so far this morning
9/8/2011	3.13 pm	Market sources say ECB is back in the market again buying Italy bonds
9/9/2011	1.54 pm	ECB chief economist Stark is about to retire according to sources // after German market close
11/9/2011	10.42 pm	French banks braced for credit-rating downgrade
12/9/2011	2.29 pm	ECB announces bond purchases for the last week in a few minutes.: The expectations according to sources is 10 B
4/10/11	8.52 am	Market sources say ECB is in the market buying 10-year Italian bonds via SMP

5/10/11	1.12 pm	ECB no longer pursuing plans to wean troubled banks off its lending support according to sources
13/10/2011	10.58 am	French for making EFSF into a bank; ECB and Germany are against
20/10/2011	8.27 am	IMF AT ODDS WITH EU/ECB ON SUSTAINABILITY OF GREEK DEBT, WANTS CLEARER PICTURE BEFORE RELEASING NEXT AID TRANCHE
25/10/2011	12.22 pm	EU SOURCES SAY "NON-STANDARD MEASURES" REFERS TO ECB BUYING DISTRESSED COUNTRIES' BONDS IN SECONDARY MARKET
27/10/2011	8.56 pm	Market sources say ECB is in buying Italian bonds via Securities Market Program (SMP)
1/11/2012	10.25 am	ECB IN DEBT REPURCHASE OPS TARGETING ITALY AND SPAIN
3/11/2011	11.04 am	GREEK SOCIALIST MPS FORGING PROPOSAL FOR COALITION GOVT HEADED BY FORMER ECB VICE-PRESIDENT PAPADEMOS
7/11/2011	8.46 am	Market sources say ECB is buying Italy 10-year BTPs via Securities Market Program -- Italy 10-year spread
7/11/2011	8.51 am	Market sources also reported that ECB was seen buying Spain 10-year via SMP
10/11/2011	5.34 pm	#ECB Seen Buying Covered Bonds In Secondary Market
14/11/2011	11.42 am	ITALY: Market sources say ECB is in buying Italy via its Securities Market Program (SMP)
17/11/2011	2.11 pm	Discussions have taken place on possible ECB lending to IMF for on lending to EZ states
17/11/2011	2.47 pm	Talk of #ECB lending to #IMF may be revived, but ECB funding IMF EU bailouts shot down by Germany
22/11/2011	2.46 am	Market talk that the ECB is targeting short and medium term Italian paper according to sources
23/11/2011	2.22 pm	Rumours about an increase of eligible collateral to ECB for Italian banks in few days
24/11/2011	12.01 pm	ECB examining possibility of extending term over which it offers bank liquidity
25/11/2011	9.53 am	Market sources now acknowledging ECB is in buying short-dated Italian bonds via SMP
25/11/2011	1.38 pm	Market sources report that the ECB is buying Irish bonds via its Securities Market Program (SMP)
27/11/2011	12.52 pm	MF to offer Italy a 600 billion euro bailout via ECB funding
8/12/2011	11.21 am	ECB sources say ECB sovereign bond buying remains capped at maximum E20bn a week
15/12/2011	11.55 am	ECB's Draghi says stable sources of funding are reducing for banking system
20/12/2011	8.03 pm	Italian banks aim to use state-guaranteed bonds as collateral for ECB 3yr loans to be launched tomorrow according to sources
21/12/2011	2.51 pm	Italian banks tapped at least 49bln of ECB loans
22/12/2011	5.33 pm	Spanish banks will use ECB cash to cover maturing debt in 2012 according to sources
3/1/2012	3.43 pm	Market sources say the ECB is also buying Portuguese bonds as well now via its Securities Market Program
4/1/2012	11.00 am	Market sources report ECB is in the market buying Spain 10-year bond via Securities Market Program (SMP)
4/1/2012	11.00 am	Sources note that ECB buying Italian and Spanish bonds
6/1/2012	11.03 am	EU CRISIS BREAKING: ECB's Draghi 'ready to go full-tilt at QE
9/1/2012	10.37 am	ECB funding to Italian banks at EUR 209.995bln in December (Prev. EUR 153.203bln)
16/1/2012	8.36am	Market sources say ECB is buying Spain 5-year Bono issue this morning via its Securities Market Program (SMP)
16/01/2012	9.35 am	Market talk of ECB buying Italian paper via SMP
19/01/2012	9.45 am	ECB discussing possibility of engaging in US style quantitative easing according to anonymous sources cited
27/01/2012	8.42 am	ITALY: Market sources report ECB is buying Italian bonds via its

		Securities Market Program (SMP)
30/01/2012	2.05pm	PORTUGAL: Market sources say ECB is buying Portuguese bonds via its Securities Market Program (SMP)
7/02/2012	8.57 pm	ECB willing to exchange Greek bonds with EFSF; won't take losses on exchange
8/02/2012	4.12 pm	ECB NOT YET DECIDED ON WHETHER TO CONTRIBUTE TO GREEK DEBT RESTRUCTURING - EURO ZONE SOURCES
13/02/2012	6.35 pm	ECB, National Central Banks Would Agree To Bond Repayment Below Face Value
14/02/2012	4.34 pm	Greece Headed For A Default Say Central Bank Sources
16/02/2012	5.27 pm	ECB to swap Greek bonds to avoid forced losses
17/02/2012	1.18 pm	ECB CONSIDERING ALLOWING GREEK BONDS HELD BY EURO ZONE CENTRAL BANKS IN INVESTMENT PORTFOLIOS TO BE SUBJECTED TO PSI WRITEDOWNS
17/02/2012	2.16 pm	Sources saying that ECB/Greek bond exchange has taken place
20/02/2012	10.12 am	Greek Fin Min sources: Questions remain over whether ECB's Greek bond portfolio profits should be transferred to Greece
9/03/2012	10.50 am	Deutsche Bank (DB) tapped the ECB's lending program last week for €5B-10B
16/03/2012	2.39 pm	ECB to boost liquidity for Greek banks
26/03/2012	6.00 pm	Spain eyes female #ESM nominee as grip on #ECB seat slips
2/05/2012	2.52 pm	ECB getting progressively more nervous about Spain fallout. the NEW LTRO may be coming up sooner than expected
16/05/2012	7.58 pm	According to sources, the ECB is increasingly refusing requests for liquidity from Greek banks
16/05/2012	4.05 pm	ECB STOPS MONETARY POLICY OPERATIONS TO SOME GREEK BANKS AS RECAPITALISATION NOT IN PLACE
18/05/2012	10.45 am	Official sources report that the EU and ECB are working on a Greek exit as part of a contingency plan.
1/06/2012	2.44 pm	hearing from banking sources ECB buying Spanish bonds
5/06/2012	5.38 pm	Source says the ECB is facing pressure to take more non-standard measures but it wants governments to commit to financial integration.
21/06/2012	1.02 pm	Ecb Discussing Medium Term Plans To Make Own Assessment Of Sovereign Bonds Rather Than Use Rating Agencies
21/06/2012	1.23 pm	ECB mulls scrapping rating rules for government bonds
26/06/2016	3.00 pm	EU and ECB mission to begin work on bailout in Cyprus early next week
28/06/2012	3.13 pm	Two EU sources say decision about Eurogroup President, ESM and ECB Jobs will be taken tomorrow at Eurozone summit
2/07/2012	1.11 pm	EU Summit may smooth path for #ECB Interest Rate Cut
18/07/2012	1.59 pm	ECB pushes to overhaul Euribor rate setting: sources ECB pushes to overhaul Euribor rate setting
27/07/2012	4.40 pm	Greece Likely To Seek ECB Debt Forgiveness Before New Funds
27/07/2012	6.35 pm	ECB's Draghi proposal said to include bond buys, rate cut or new LTRO
1/08/2012	1.18 am	Germany and the ECB Want More Cuts in Spain Before Lowering Yields
1/08/2012	11.17 am	ECB's watchdog could get power to order bank closures
1/08/2012	6.06 pm	According to sources, Greece is expected to finalize €11.5B of cuts in early-August
2/08/2012	9.05 am	ECB's Draghi faces leadership test over euro pledge
23/08/2012	8.52 am	ecb may set bond buys yield target but keep it secret and flexible
23/08/2012	3.47 pm	PREFERRED OPTION IS EFSF BUYING SPANISH BONDS ON PRIMARY MARKET, ECB BUYING ON SECONDARY MARKET
28/08/2012	10.57 am	ECB considering plan to allow banks to borrow against €1 trillion of asset-backed securities, according to sources

4/09/2012	11.14 am	ECB "sources" now leaking data to Dutch paper: Weidman Isolated in Resistance Against Draghi Plan
5/09/2012	2.00 pm	ECB "sources" say bond buying will be unlimited but remain sterilized
5/09/2012	2.04 pm	Draghi set to unveil MOT for Spain and Italy - unlimited, sterilised bond buying
5/09/2012	3.55 pm	ECB READY TO DROP PREFERRED CREDITOR STATUS ON GOVT BONDS IT BUYS UNDER NEW PROGRAMME
5/09/2012	3.56 pm	ECB WILL NOT ANNOUNCE SPECIFIC INTEREST RATE OR YIELD TARGETS FOR BOND MARKET INTERVENTION ON THURSDAY
14/09/2012	7.53 pm	ECB, IMF IN TALKS OVER €300B RESCUE PLAN-
14/09/2012	9.52 am	Eurogroup and #Ecb sources deny talks for a Ecb-Imf plan to help #Spain with 300 billions
03/10/2012	1.59 pm	ECB has not closed door to Greek debt maturity extension
05/10/2012	10.31 am	Ecb Would Buy "Heavily" In Bond Markets For 1-2 Months Under Omt Programme, Then Stop For Assessment Period
08/10/2012	3.45 pm	ECB to wind down covered bond purchase programme
19/10/2012	9.54 am	$EUR/USD EU Leaders Splinter On ECB Supervisory Role: Sources: Leaders of European Union star
05/11/2012	8.31 pm	ECB Could Return To Greece Up To EUR11 Billion, But Legal Issues Loom
08/11/2012	9.40 am	ECB sources indicated OMT program won't be initiated any time soon
16/11/2012	10.23 am	Eu Leaders To Decide At Summit Next Week On Nomination Of Yves Mersch To Ecb Executive Board
07/12/2012	12.51 pm	MAJORITY OF #ECB GOVERNING COUNCIL SAID TO SUPPORT RATE CUT
17/12/2012	10.46 am	ECB will supervise banks representing 80pc of European banking sector assets
15/01/2013	3.42 pm	European #banks to repay ~€80-300B of #ECB #LTRO loans in 2013
26/01/2013	3.27 pm	ECB rejects Irish bid on promissory note
30/01/2013	7.25 am	According to Elpais, Spanish #banks will repay EUR 44bn in the 3y #LTRO today, citing EU and ECB sources
5/02/2013	4.10 pm	EUR still not strong enough to prompt action out of the ECB
5/02/2013	2.21 pm	ECB FLOWS: Market sources report buying of Italian bonds. The 10-year BTP yield is just hovering above 4.50% level.
7/02/2013	12.18 pm	ECB and Ireland reach deal on cutting Irish cost of servicing debt for winding up Anglo Irish Bank according to sources
7/02/2013	12.59 pm	Irish sources deny reports of Government deal with ECB
6/03/2013	5.50 pm	German press reports ECB considering exiting Troika, sources then say reports are incorrect.
18/03/2013	1.21 pm	ECB said to oppose taxing Cypriot savings accounts under 100,000 euros
19/03/2013	8.37 pm	ECB Officials Working on Capital-Control Plans
20/03/2013	3.23 pm	ECB likely to delay a decision on whether to continue to supply #Cyprus banks with emergency funds
16/04/2013	12.02 pm	Spain to stick to plan to use deposit fund for risky debt losses despite ECB's negative opinion
22/04/2013	9.10 am	sources told MNI that Morgan Stanley has changed its ECB rate forecast calling 25bps cut by June
24/04/2013	11.27 am	ECB poised to cut rates to help recession-hit euro zone Reuters
01/05/2013	4.39 pm	EUROSYSTEM SOURCES: CONDITIONS FOR ECB RATE CUT ARE THERE
01/05/2013	4.44 pm	ECB EYEING COUNTRY-SPECIFIC APPROACH FOR SME LENDING
5/06/2013	2.30 pm	ECB divided on further rate cuts, further rate cut may not deliver desired results
28/06/2013	9.30 am	ECB mulling government bond-buying programme that would extend all 17 Euro countries

8/07/2013	10. 00 am	ECB considers consultancies for asset quality review
11/07/2013	2.08 pm	ECB PREPPING DETAILS OF CNY800BN SWAP LINE WITH PBOC
27/08/2013	1.54 pm	Easing Shot Down - High Level Committee's View: Ext vulnerability & adverse implications for Finance sector
1/10/2013	1.21 pm	ECB SOURCES: ECB likely to base LTRO decision on 2014 stress tests
22/10/2013	3.13 pm	ECB TO ASK EURO ZONE BANKS TO HOLD 8 PCT CORE TIER ONE CAPITAL RATIO IN ASSET QUALITY REVIEW
25/10/2013	12.21 pm	'HESITANCY' AT ECB OVER NEGATIVE RATE CONSEQUENCES, BUT NEGATIVE RATE MOVE STILL POSSIBLE
6/11/2013	2.52 pm	ECB rate change unlikely
6/11/2013	3.07 pm	Sources" Confirm No ECB Rate Cut Tomorrow, Euro Soars Pushing Dow Jones To New Record High
20/11/2013	3.21 pm	EUR heading lower, #ECB sources say ECB said to consider negative deposit rate of 0.1% if stimulus needed
26/11/2013	2.45 pm	ECB sources say no consensus now for action in December
08/01/2014	3.31 pm	No major ECB policy changes expected in January
05/02/2014	1.55 pm	Another ECB sources rumour that board split over deflation, unclear if Draghi acts tomorrow
26/02/2014	9.11 am	NO CONSENSUS WITHIN GC NOW FOR MARCH POLICY MOVE
10/03/2014	10.32 am	ECB Set To Give Euro Zone Banks Details Of Asset Quality Test Approach On Dealing With Bad Loans
18/03/2014	10.42 am	Sources close to negotiations of #Greece authorities with #troika: An agreement has been reached
19/03/2014	10.45 am	Spanish banks face fresh property reviews for ECB check-up
01/04/2014	10.34 am	BOE, ECB, BOJ and Fed to announce synchronised bi-annual monetary policy meetings
2/04/2014	3.30 pm	'OVER-INTERPRETATION' BY MARKET OF QE POSSIBILITY
24/04/2014	11.42 am	ECB sources are saying there is no consensus on need for May policy action
13/05/2014	11.12 am	Bundesbank sources say BUBA willing to accept significant stimulus at next ECB mtg
14/05/2014	8.33 am	ECB sources on the wires saying ECB is preparing a package of measures, including cuts to all three rates
14/05/2014	9.21 am	ECB SOURCES SAY "QE STILL SOME WAY OFF
14/05/2014	9.22 am	ECB Rate Cut Would be complemented With Either targeted LTRO or ABS Purchase Plan
14/05/2014	6.16 opm	Yields, sterling fall on ECB outlook; U.S. stocks dip: Euro zone sources said the ECB plans a package
20/05/2014	11.05 am	ECB said to be looking at six-week meeting schedule in order to help write minutes + take monetary policy decisions.
22/05/2014	7.05 pm	ECB supervisors to ease stress tests for Belgium's Dexia
02/06/2014	4.55 pm	ECB to lead revamp of global FX codes of conduct
04/06/2014	6.49 pm	sources suggest that ECB Draghi is likely to signal cut this week, won't necessarily be the last
16/06/2014	3.33 pm	$EUR/USD pokes higher on @ecb sources indicating that no new easing measures are likely in coming months
26/06/2014	2.40 pm	ECB may not have reached lower bound on key rate
09/07/2014	7.54 pm	ECB aims to give banks 48 hours to sign off comprehensive assessment results before publication in October
27/08/2014	3.15 pm	New ECB Action Next Week Unlikely, But Outcome Much Depends On August Inflation Data
29/08/2014	11.35 am	No ECB consensus on QE next week
04/09/2014	11.46 am	Sources report ECB Governing Council discussing ABS purchases, worth up to €500 billion, could start this year
07/09/2014	11.44 am	latest ECB measures could amount up to €800bn
01/10/2014	7.17 pm	Greek banks win restructuring plan reprieve in ECB tests
13/10/2014	11.56 am	Commerzbank set to pass ECB bank stress test

21/10/2014	10.30 am	ECB BUYING SPAIN SHORT-DATED COVERED BONDS
21/10/2014	10.31 am	ECB considering buying corporate bonds - sources familiar with situation say #forex #EUR/USD
21/10/2014	11.04 am	ECB Is Buying French Covered Bonds, Maturities Up To 5-Years
24/10/2014	2.34 pm	According to credible sources, ECB set to "fail" 25 banks
27/10/2014	12.36 pm	ECB SOURCES CITE BARRIERS TO QE, NEED TO LET OLD MEASURES WORK this is neg risk no QE coming from ECB
27/10/2014	2.55 pm	ECB stimulus may lack desired scale, QE an option
03/11/2014	10.26 am	ECB NOT SET TO CHANGE TLTRO TERMS AT NOV POLICY MEETING
05/11/2014	3.16 pm	Central bankers to challenge Draghi on ECB leadership style
06/11/2014	10.59 am	ECB governors didn't confront Draghi at council dinner
14/11/2014	3.41 pm	ECB Said To Allow 24hrs To Make Smaller ABS Purchases
26/11/2014	12.50 pm	Q1 TIME FRAME FOR QE DECISION LARGELY AGREED
04/12/2014	4.35 pm	German ECB policymakers opposed new balance sheet language
03/12/2014	4.34 pm	ECB sources said to prepare broad based QE package for January meeting
19/12/2014	10.13 am	ECB officials consider making weaker Eurozone countries bear larger risk burden in any quantitative easing plan
01/01/2015	6.42 am	ECB is working on a discussion paper to execute government bond buying over 3 different option
09/01/2015	9.54 am	Eur500bn suggested as potential QE programme by ECB sources
09/01/2015	11.51 am	ECB CONSIDERS DUAL QE APPROACH INVOLVES ECB BUYING GOVT BONDS WITH EURO ZONE RISK-SHARING AND NATIONAL CENBANKS BUYING AT OWN RISK
16/01/2015	5.07 pm	QE will not include Greek bonds due to ratings, ECB says
19/01/2015	2.48 pm	BUNDESBANK STILL STRIVING TO PUT LIMITS ON ECB QUANTITATIVE EASING
21/01/2015	2.32 pm	ECB EXEC BOARD'S QE PROPOSAL CALLS FOR ROUGHLY EUR50B IN BOND BUYS A MONTH
29/01/2015	6.41 pm	ECB will not comment on MNI sources story that Greece refuses to enter new Troika programme
03/02/2015	2.22 pm	ECB won't accept bond swap and wants full repayment
04/02/2015	7.59 pm	Greece may run out of cash as early as March
10/02/2015	12.06 pm	ECB TO ACCEPT GREEK BOND AS COLLATERAL IF DEAL REACHED
10/02/2015	12.10 pm	EU Commission to propose 6 month extension for Greece
12/02/2015	11.58 am	ECB POLICYMAKERS HELD THURSDAY TELECONFERENCE ON OPTIONS FOR EMERGENCY FUNDING FOR GREEK BANKS
12/02/2015	5.45 pm	ECB lifts amount of emergency lending available to Greek banks
18/02/2015	4.44 pm	ECB divided over extra emergency funds for Greek banks
18/02/2015	8.17 pm	Greece Asked ECB for Extra 5 Bln Euros in ELA Funding-Sources
19/02/2015	7.25 am	ECB wants Greece to introduce capital controls
19/02/2015	8.20 pm	ECB may push Greek banks to shed state debt if talks fail
01/03/2015	9.30 pm	ECB may begin QE purchases on 9 March
02/03/2015	2.44 pm	ECB Staff Projections Could Signal End Of QE In Sept 2016
09/03/2015	8.30 am	Market sources report that ECB has started QE programme
18/03/2015	9.32 pm	ECB granted Greece less emergency liquidity than requested
19/03/2015	9.30 pm	Sources say ECB Governing Council has approved an additional EUR 400mln for Greek banks as emergency liquidity
24/03/2015	2.22 pm	Greece hoping to get EUR1.9bn in ECB profits on Greek bonds; EUR1.2bn bank rescue funds if EG approves reform list
25/03/2015	2.02 pm	Sources indicate that the ECB are to increase the limit of the ELA funding for Greek banks to EUR 71bln
01/04/2015	7.24 pm	ECB raises emergency funding cap for Greek banks by €700m
09/04/2015	1.45 pm	ECB Raises Greek ELA By EUR1.2 Bln
14/04/2015	7.55 pm	ECB raises Greek bank ELA by €800 million, bringing the ceiling to €74 billion
17/04/2015	7.17 pm	ECB examines possibility of Greek IOU currency in case of default

21/04/2015	8.46 am	ECB Proposal Sees Haircut Of 90% In Disorderly Default
28/04/2015	7.32 am	Deutsche's radical revamp foiled by ECB stress test
06/05/2015	3.36 pm	ECB officials are considering tighter liquidity rules for Greek banks
19/05/2015	5.25 am	ECB would not lower ELA if Greece misses its IMF payment
20/05/2015	7.04 pm	ECB will raise Greek bank emergency cash by 200 million euros
27/05/2015	10.04 am	Sources suggest Greek ELA ceiling will be unchanged at EUR 80.2bln by ECB
10/06/2015	3.57 pm	ECB to raise Greece's ELA ceiling to €83Bn from €80.7Bn
19/06/2015	12.56 pm	ECB said to raise emergency funding cap for Greek banks
25/06/2015	11.46 am	ECB limits funding lifeline for Athens amid Bundesbank protest
28/06/2015	9.25am	ECB to pull the plug on Greek banks later today
28/06/2015	11.17 am	ECB CONSIDERING INCREASING HAIRCUT ON SECURITY OFFERED BY GREEK BANKS FOR ELA, WHILE KEEPING ELA AVAILABLE
28/06/2015	11.45 am	ECB considers tightening emergency funding for Greek banks
28/06/2015	1.21 pm	Greece to consider closing banks on Monday, says finance minister
03/07/2015	9.46 am	ECB considers tightening emergency funding for Greek banks
05/07/2015	9.08 pm	ECB Seen Maintaining Emergency Liquidity Assistance For Greek Banks At Current Restricted Level When Governing Council Talks On Mon
13/07/2015	9.55 am	ECB'S Governing Council to hold ELA for Greek banks steady today
16/07/2015	9.46 am	Greece asks ECB for €1.5bn increase in ELA
16/07/2015	11.16 am	AUSTRIAN FINANCE MINISTER SCHELLING SAYS HEARD FROM ECB SOURCES THAT ELA FOR GREECE WILL BE EXTENDED
22/07/2015	2.41 pm	ECB SAID TO RAISE #GREEK ELA CEILING BY EU900M
28/07/2015	2.44 pm	ECB has approved modified plan for reopening #Greece's stock market
05/08/2015	12.57 pm	ECB keeps Greek #ELA unchanged for the next 2 weeks
09/09/2015	11.48 am	ECB Has Modestly Raised Capital Requirements For Italian Banks After SREP Review
29/10/2015	2.20 pm	CB HEALTH CHECK OF GREECE'S FOUR BIG BANKS TO SHOW TOTAL CAPITAL SHORTFALL OF ABOUT 14 BLN EUROS
09/11/2015	1.10 pm	Arguing for more deposit rate cut in December than the markets are expecting some on the ECB
10/11/2015	1.48 am	ECB May Struggle With QE vs Rate Cut
10/11/2015	6.36 pm	ECB divided over supervisor's tough stance on banks
11/11/2015	3.47 pm	ECB EXAMINES POSSIBLE EXTENSION OF QE PURCHASES TO MUNICIPAL BONDS (EUROPEAN CITIES AND REGIONS)

Appendix B2

This table shows the results for the OLS estimation of equations (3.1), (3.2) and (3.3). The dependant variable is the cum-dividend log excess return (XR_t) on the DAX from 1300 CET on date $t-1$ to 1300 CET on date t. The sample period is from November 05, 2010 to September 16, 2015. The sample is split between tightening and easing cycles and all 3 specifications are re-estimated with the results set out in the second and bottom panel. In order to account for the effect of tight and loose monetary policies the sample is partitioned into the periods from November 05, 2010 through October 20, 2011 and from October 21, 2011 through September, 2015 respectively. Each partition contains 11 and 44 ECB announcements respectively. Coefficient estimates and standard errors are presented adjacent to their respective parameters. Specification test results for each regression are provided in the bottom four rows of each panel.

*** Significant at 1%, **significant at 5% and *significant at 10%.

	DAX 1300-1300 CET					
XR_t	**Equation (3.1)**		**Equation (3.2)**		**Equation (3.3)**	
***Observations:* 1224**	**Coefficient**	**Std. Err.**	**Coefficient**	**Std. Err.**	**Coefficient**	**Std. Err.**
Constant	0.013	0.039	0.013	0.039	0.033	0.041
Pre-ECB$_t$	***0.488	0.184				
Rumour$_t$			***0.853	0.251	***0.834	0.251
NoRumour$_t$			0.082	0.264	0.062	0.264
Rumour$_{t-1}$					-0.027	0.251
Rumour$_{t-2}$					-0.321	0.251
NoRumour$_{t-1}$					-0.140	0.264
NoRumour$_{t-2}$					-0.342	0.264
F Statistic	7.03		5.82		2.51	
ARCH LM:	χ^2 = 120.12	Yes	χ^2 = 118.67	Yes	χ^2 = 121.83	Yes
White's test:	χ^2 = 0.53	No	χ^2 = 1.62	No	χ^2 = 0.59	No
Breusch-Godfrey:	χ^2 = 0.15	No	χ^2 = 0.10	No	χ^2 = 0.10	No
***Observations:* 238**	**DAX 1300-1300 CET (Tightening)**					
Constant	-0.047	0.120	-0.047	0.120	-0.029	0.126
Pre-ECB$_t$	0.485	0.577				
Rumour$_t$			1.172	0.845	1.154	0.847
NoRumour$_t$			-0.086	0.773	-0.104	0.775
Rumour$_{t-1}$					0.785	0.847
Rumour$_{t-2}$					-0.010	0.847
NoRumour$_{t-1}$					-0.132	0.775
NoRumour$_{t-2}$					-1.246	0.775
F Statistic	0.71		0.97		0.91	
ARCH LM:	χ^2 = 36.71	Yes	χ^2 = 36.66	Yes	χ^2 = 36.15	Yes
White's test:	χ^2 = 0.30	No	χ^2 = 0.56	No	χ^2 = 0.94	No
Breusch-Godfrey:	χ^2 = 0.03	No	χ^2 = 0.07	No	χ^2 = 0.09	No
***Observations:* 987**	**DAX 1300-1300 CET (Easing)**					
Constant	0.029	0.038	0.029	0.038	0.049	0.040
Pre-ECB$_t$	***0.488	0.178				
Rumour$_t$			***0.783	0.239	***0.764	0.239
NoRumour$_t$			0.134	0.261	0.115	0.261
Rumour$_{t-1}$					-0.200	0.239
Rumour$_{t-2}$					-0.389	0.239
NoRumour$_{t-1}$					-0.139	0.261
NoRumour$_{t-2}$					-0.069	0.261
F Statistic	7.49		5.48		2.41	
ARCH LM:	χ^2 = 14.67	Yes	χ^2 = 14.71	Yes	χ^2 = 16.71	Yes
White's test:	χ^2 = 0.24	No	χ^2 = 1.61	No	χ^2 = 1.28	No
Breusch-Godfrey:	χ^2 = 0.23	No	χ^2 = 0.20	No	χ^2 = 0.25	No

Appendix B3

This table shows the results for the OLS estimation of equations (3.1), (3.2) and (3.3). of equations of equations (3.1), (3.2) and (3.3). The dependant variable is the cum-dividend log excess return (XR_t) on the DAX from the close on date $t-1$ to 1300 CET on date t. The sample period is from November 05, 2010 to September 16, 2015. Coefficient estimates and standard errors are presented adjacent to their respective parameters. Specification test results for each regression are provided in the bottom four rows.

*** Significant at 1%, **significant at 5% and *significant at 10%.

	DAX Close-1300 CET					
XR_t	**Equation (3.1)**		**Equation (3.2)**		**Equation (3.3)**	
***Observations:* 1224**	**Coefficient**	**Std. Err.**	**Coefficient**	**Std. Err.**	**Coefficient**	**Std. Err.**
Constant	0.034	0.030	0.034	0.030	0.041	0.031
Pre-ECB$_t$	***0.517	0.140				
Rumour$_t$			***0.633	0.191	***0.626	0.192
NoRumour$_t$			0.387	0.202	0.380	0.202
Rumour$_{t-1}$					0.163	0.192
Rumour$_{t-2}$					-0.378	0.192
NoRumour$_{t-1}$					-0.064	0.202
NoRumour$_{t-2}$					0.001	0.202
F Statistic	13.53		7.16		3.19	
ARCH LM:	χ^2 = 52.07	Yes	χ^2 = 51.95	Yes	χ^2 = 51.94	Yes
White's test:	χ^2 = 2.69	No	χ^2 = 2.87	No	χ^2 = 9.22	No
Breusch-Godfrey:	χ^2 = 2.15	No	χ^2 = 2.01	No	χ^2 = 2.19	No

Appendix B4

This table shows the results for the OLS estimation of equations (3.1), (3.2) and (3.3). of equations of equations (3.1), (3.2) and (3.3). The dependant variable is the cum-dividend log excess return (XR_t) on the DAX from market open to market close. The sample period is from November 05, 2010 to September 16, 2015. Coefficient estimates and standard errors are presented adjacent to their respective parameters. Specification test results for each regression are provided in the bottom four rows.

*** Significant at 1%, **significant at 5% and *significant at 10%.

	DAX Open – Close					
XR_t	**Equation (3.1)**		**Equation (3.2)**		**Equation (3.3)**	
***Observations:* 1224**	**Coefficient**	**Std. Err.**	**Coefficient**	**Std. Err.**	**Coefficient**	**Std. Err.**
Constant	0.033	0.038	0.033	0.038	0.064	0.040
Pre-ECB$_t$	0.052	0.180				
Rumour$_t$			0.318	0.245	0.287	0.245
NoRumour$_t$			-0.245	0.259	-0.276	0.258
Rumour$_{t-1}$					*-0.473	0.245
Rumour$_{t-2}$					-0.051	0.245
NoRumour$_{t-1}$					-0.122	0.258
NoRumour$_{t-2}$					***-0.672	0.258
F Statistic	0.08		1.32		2.17	
ARCH LM:	χ^2 = 43.93	Yes	χ^2 = 40.87	Yes	χ^2 = 40.09	Yes
White's test:	χ^2 = 0.19	No	χ^2 = 0.64	No	χ^2 = 1.37	No
Breusch-Godfrey:	χ^2 = 0.45	No	χ^2 = 0.45	No	χ^2 = 0.43	No

Chapter 4. The ECB Conditional Friday Effect

4.1 Introduction

This chapter explores the EUR/USD price formation process that takes place in the immediate aftermath of the ECB announcements over the period spanning from January 2011 to November 2015. Empirical results show that the EUR/USD exchange rate response to ECB scheduled policy announcements is consistent with the standard economic theory formalised through the Efficient Market Hypothesis (see Fama (1970)). The Euro currency experiences large and negative returns in the immediate (5-minute) period following the Central Bank Monetary Policy announcements, which is deemed to be mostly accommodative throughout the sample return period. This finding is unsurprising, given that it is simply the anticipated financial market response to new and relevant public information.

The main finding of this study, however, is in stark contrast to the predictions of standard asset pricing theories. I document large and significantly negative returns on the EUR/USD exchange rate on the day following scheduled ECB policy decision announcements. However, such pricing anomaly only occurs on the Friday trading days that follow scheduled ECB announcements taking place on Thursdays. When the day of the week following an ECB announcement falls on a Thursday then no pricing anomaly can be observed. I define this ECB Friday pricing anomaly as the *'ECB conditional Friday effect'*. In section 4.6 of this chapter I explore several possible explanations for the ECB Friday effect, however, fail to find a definitive explanation in line with that found in standard economic and financial economic theory. I pose that the ECB conditional Friday effect is a day-of-the-week (DoW) effect previously undetected due, mainly, to the conditionality of the pricing anomaly to the aforementioned ECB announcement schedules.

The empirical analysis is based on a 5-minute series for the EUR/USD exchange rates. I make use of standard linear regressions with dummy variables to isolate the ECB conditional Fridays from all other unconditional days of the week including non-ECB Fridays. Empirical results show that average returns earned on the EUR/USD on 50 Fridays following scheduled ECB announcements, are over 18 basis points lower than all other unconditional days of the week. The same analysis is then replicated when the sample is split into two sub-samples accounting for the tight and subsequently loose ECB's policy stance, finding that the ECB Friday effect is negative and significant for both tightening and easing cycles. The ECB conditional negative Friday drift is larger in magnitude, at over 18 basis points, when overnight trading hours are excluded and the trading day is defined to start at the European opening bell. The magnitude of

this negative return effect in the EUR/USD market, when annualised, amounts to over 185 basis points. This is orders of magnitude lower than the annualised 48 basis point positive return observed for all other days exclusive of ECB Fridays.

Throughout the full sample, 5 scheduled ECB announcements are observed on Wednesdays. When tested, findings show that an ECB conditional Thursday effect does not exist. Average returns on such Thursdays are approximately zero and not statistically significant different from all other unconditional days of the week. The day of the week is therefore a crucial factor in this conditional return effect.

Overall, these findings document the presence of a price formation anomaly, which is conditional on a prevailing scheduled ECB policy decision announcement and on the trading day following the announcement falling on a Friday. Several explanations are explored for this conditional price formation process.

The initial intuition is that such a uniform post-ECB negative drift must be a result of relevant and new public information arrival. However, findings in this chapter show that scheduled public information events observed on days following scheduled ECB announcements, are heterogeneous in macroeconomic data type and report both Euro negative and positive information. The intuitive reasoning based on standard asset pricing theory is concluded to be ineffective in explaining the ECB conditional Friday price formation process. The lack of relevant, new information arrival would indicate that this is a price reaction to 'stale' news or an anticipation of overnight news.

An alternative explanation of the ECB conditional Friday effect is based on the market microstructure literature. Such literature finds that Friday afternoons in multiple markets experience higher levels order flows, volume and short selling (see among others, Breedon and Ralando (2013)). Large-scale profit taking and closing of positions may be expected following high impact ECB policy announcements. The magnitude of the average negative return on the EUR/USD following scheduled announcements is over 20 basis points. Therefore, this argument is also dismissed given that post-ECB scheduled announcement immediate market reaction is likely to be short positions in the EUR/USD, the covering of which would result in an opposite directional Friday price effect than that observed in the empirical results.

The most plausible reason for the ECB conditional Friday effect is a risk-averse liquidation of long positions in the Euro prior to Friday market close. The intuition being that traders - cautious of a potentially 'news rich' weekend relating to an already dovish ECB during a predominantly accommodative policy cycle - would not be willing to remain long in the

currency over the weekend following ECB announcements. Further, ECB governing council (GC) members, who are mandated to a quiet period prior to scheduled announcements, tend to make frequent comments and clarifications to the world press during the days following ECB meetings. Following predominantly dovish ECB announcements, traders may justifiably attach a higher probability to such comments resulting in a negative impact on post-weekend market open. Therefore, a conclusion can be drawn that traders, long the currency on post ECB Fridays, are likely to make a risk-weighted decision to cut their positions whereas traders short the currency, are likely to make the risk-weighted decision to remain short. This conclusion comes with a caveat; that the strength of this argument is very much linked to the intuition underpinning rational risk-weighted investor/trader behaviour. Thus, the ECB conditional Friday effect is, in part, still a pricing puzzle worthy of further investigation.

The remainder of this chapter is structured as follows; the coming section discusses the unconditional and conditional DoW effect literature. Section 4.3 presents the data and Section 4.4 the methodology in use. Section 4.5 comments on the main empirical findings. Section 4.6 outlines the explanations for the existence of the ECB conditional Friday effect and Section 4.7 concludes.

4.2 Day-of-the-Week Effects

Calendar effects are widely considered to be market pricing anomalies, and therefore violations of standard asset pricing theories (Philpot and Peterson (2011)). The January (see Rozeff and Kinney (1976)), Weekend, Monday (see Cross (1973) and French (1980)) and Turn-of-the-month effects (Ariel (1987)) are examples of systematic return patterns around a particular month-of-the-year, DoW and day-of-the-month, respectively. The literature studying calendar affects has been predominantly concerned with equity markets; however, treasury (Gibbon and Hess (1981)), futures (Junkus (1986)) and foreign exchange markets (Levine (1988) and Bush and Stephens (2016)) have also been investigated and found to exhibit seasonal return patters.

The literature studying the existence of calendar effects, focuses predominantly on DoW effects, although time-of-day-effects (see among others Breedon and Ralando (2013), Baillie and Bollerslev (1991) and Ranaldo (2009)) are also more prevalent with greater availability of intra-day data. The Monday effect is perhaps the most investigate financial market asset pricing ‘anomaly’. Equity markets, in developed economies, are found to generate consistent negative returns on Mondays (Siegel (1998)). The pre-weekend Friday effect is characterised, in contrast with the Monday effect with the observation of positive equity market returns (Pettengill (2003)). The weekend effect is less consistent for currency markets. Yamori and Kurihara

(2003) find returns to the USD versus several major currencies to be high on Mondays and Wednesdays but low on Tuesdays and Fridays. This result is however, not consistent over their full sample period. For the EUR/USD market, the market of primary interest to this chapter, the only observable DoW effect has been found on Mondays. Bush and Stephens (2016) find negative Monday effects of around 16 and 19 basis points for two short sub-samples spanning January 1999 through May 2000 and November 2004 through November 2005. At the time of writing, an unconditional Friday effect has not been documented in the literature for the EUR/USD market.

Such unconditional calendar effects have been characterised as evidence against the EMH, specifically in its weakest form. Unconditional calendar effects, by definition, are excess security returns that are observed in the absence of information events. Moreover, their regularity of occurrence suggests that these foreseeable patterns are not exploited by informed traders and the pricing anomalies are not corrected.

More recently, the uniformity of the weekend effect has been challenged with studies showing that for sub-samples covering longer time horizons for equity market data the Monday and Friday effects disappear or even reverse direction (Galai et al. (2008)) depending on the macroeconomic business cycle. Similarly, Bush and Stephens (2016) have shown that the DoW effects for currency markets are strongly dependent on macroeconomic cycles, and therefore challenged the idea that such calendar effect are unconditional.

Scholars have criticized the literature on the DoW effects for a number of different aspects spanning from the methodological approach (Connoly (1989)) to the issue of data mining (Sullivan et al. (2001)). The former critique is predominantly targeted at those assuming normality in asset price returns for adopted methods of estimation. This methodological misnomer has been accounted for in this chapter as outline in section 5. The use of maximum likelihood ARCH estimation, where appropriate, accounts for departures from normality in the specific series under analysis. The findings and methodological approach of this chapter certainly do not fall into this category of critique given that the ECB conditional Friday effect exists throughout the entire data sample used.

Some studies seeking to explain the existence of systematic DoW patters have suggested that such patterns have been mischaracterised as unconditional price discovery. Such explanations are based on market microstructure factors, information flows and order flows. Fama (1991) noted that the magnitude of the Monday effect deferential versus other days of the week is less than the magnitude of the typical bid-ask spread. Significant reductions in the average bid-ask

spread in recent years are referenced as the reason for the diminishing observation of the Monday effect in respective data samples (Galai et al. (2008)). Gregoriou et al. (2004) show that the weekend effect disappear once the bid-ask spread is used as a proxy for transaction costs. Bell and Levin (1998) and Draper and Paudyal (2002) find that controlling for institutional settlement procedures effectively eliminates the weekend effect.

Explanations based on information flows, include Dyl and Maberly (1988) who suggest that the negative Monday return effect is simply due to both Micro and Macro information arrival. Micro information flows in the form of earnings and dividend announcements are found to have no conclusive impact on the weekend effect (Peterson (1990)). However, when Micro information flows are expanded to control for all firm specific events, DeFusco et al. (1993) find that the weekend effect becomes unobservable. Steely (2001) finds that the Monday effect disappears, for equity markets, when macroeconomic data announcements are controlled for by categorisating outcomes as negative and positive shocks.

The weekday patterns observed in order flows has been linked by some studies to the systematic DoW return pattern. Miller (1988), Seigel (1998), Chen and Singal (2003) argue that investors with heterogeneous investment horizons exhibit similar patterns in order flows. They argue that liquidation of positions is more likely on days either side of closed weekend markets. They refer to heightened order flows on Mondays and Fridays as evidence of this explanation. The impact of order flows on the ECB conditional Friday effect is addressed in section 4.6.

4.3 Data description

The Euro-US dollar (EUR/USD) foreign exchange market is the largest in the world by number of transactions per day. The EUR/USD exchange rate data is sourced from OLSENDATA (www.olsendata.com). I collect observations of 5-minute interval exchange rate data to accommodate the creation of non-standard trading windows to investigate price formation during the post-ECB window in the currency market. 5-minute interval observations are used since there are fewer instances of non-trading intervals than higher frequency observations. Exchange rate observations consists of exchange rate quotes for a period spanning from January 03, 2011 to November 20, 2015 (238 weeks, 1194 trading days), totalling in 343,872 observations.[18]

In order to more formally analyse the post-ECB announcement trading window, I calculate cumulative returns on the EUR/USD for different trading periods following scheduled ECB announcements. More specifically, I am interested in post-ECB days which fall on Fridays since preliminary analysis shows that the conditional post-ECB trade only takes place when the ECB scheduled announcement takes place on a Thursday. For the entire sample, there are 55 Scheduled GC policy decision announcements. Five of these announcements take place on Wednesdays whereas the remaining 50 occur on Thursdays.

For completeness, I calculate cumulative returns on the EUR/USD for a number of different return windows. The aim is to comprehensively analyse the 'Post-ECB Friday effect' as a conditional DoW effect as well as a conditional time of day effect. For this purpose, cumulative five-minute log returns (in percentage points) are calculated for the 24-hour period from 2300 CET on the day of a scheduled ECB policy decision announcement until 2300 CET on the day after the announcement. I also compute and investigate return windows on the EUR/USD from the 0800 CET (European open) and 1200 CET (European Lunch) on the day following scheduled announcements to the close of the same day. By construction, cumulative returns calculated during over these windows do not include the trading period immediately following the ECB GC decision outcome.

[18] Pre-market (Sunday) trading is available through some exchanges, however trading is relatively illiquid when compare to standard non-weekend trading (Chaboud et al. (2014)). Due to poor levels of liquidity and the prevalence of non-trading intervals, these observations are omitted. This is standard practice in the literature, which utilise data of this type. Half trading days and major holidays during which trading is considerably less active, are also omitted.

Table 4.1

Descriptive statistics for cumulative returns (%) on EUR/USD exchange rate for three return windows are calculated as follows. The 2300-2300 cumulative return window is calculated as the sum of 5-minute returns on the EUR/USD exchange rate from 2300 CET at the market open though 2255 CET the following day at market close. The 0800-2300 cumulative return window is calculated as the sum of 5-minute returns on the EUR/USD exchange rate from 0800 CET at the European market open though to 2255 CET on the same day at market close. The 1200-2300 cumulative return window is calculated as the sum of 5-minute returns on the EUR/USD exchange rate from 1200 CET at the European market Lunch though to 2255 CET on the same day at market close. Post-ECB Fridays are the post-ECB return windows that fall on a Friday following ECB scheduled announcements on Thursdays. All other Fridays are all respective Friday return windows, which do not follow ECB scheduled announcements. All other Days represent all respective return windows on all non-Friday trading periods.

Sample	**Mean**	**St. Dev.**	**Min.**	**Max.**	**Obs.**
post-ECB Fridays					
EUR/USD 2300-2300	-0.190	0.746	-1.738	1.671	50
EUR/USD 0800-2300	-0.199	0.701	-1.749	1.564	50
EUR/USD 1200-2300	-0.161	0.534	-1.428	0.900	50
EUR/USD 2300-2300 (Tightening)	-0.283	1.107	-1.738	1.400	10
EUR/USD 0800-2300 (Tightening)	-0.364	0.984	-1.749	1.361	10
EUR/USD 1200-2300 (Tightening)	-0.230	0.705	-1.428	0.900	10
EUR/USD 2300-2300 (Easing)	-0.166	0.637	-1.703	1.671	40
EUR/USD 0800-2300 (Easing)	-0.156	0.616	-1.572	1.564	40
EUR/USD 1200-2300 (Easing)	-0.143	0.490	-1.137	0.814	40
All other Fridays					
EUR/USD 2300-2300	0.019	0.561	-1.532	1.771	191
EUR/USD 0800-2300	0.013	0.502	-1.315	1.393	191
EUR/USD 1200-2300	0.025	0.456	-1.619	1.163	191
EUR/USD 2300-2300 (Tightening)	0.037	0.740	-1.532	1.202	31
EUR/USD 0800-2300 (Tightening)	0.022	0.640	-1.159	1.041	31
EUR/USD 1200-2300 (Tightening)	0.078	0.594	-1.215	1.024	31
EUR/USD 2300-2300 (Easing)	0.016	0.522	-1.375	1.771	160
EUR/USD 0800-2300 (Easing)	0.011	0.473	-1.315	1.393	160
EUR/USD 1200-2300 (Easing)	0.015	0.426	-1.619	1.163	160
All other Days					
EUR/USD 2300-2300	0.003	0.578	-2.153	2.299	955
EUR/USD 0800-2300	-0.011	0.526	-2.275	2.185	955
EUR/USD 1200-2300	0.001	0.436	-1.932	1.912	955
EUR/USD 2300-2300 (Tightening)	0.054	0.700	-1.957	1.793	167
EUR/USD 0800-2300 (Tightening)	0.030	0.641	-2.275	2.045	167
EUR/USD 1200-2300 (Tightening)	0.016	0.544	-1.932	1.763	167
EUR/USD 2300-2300 (Easing)	-0.008	0.549	-2.153	2.299	788
EUR/USD 0800-2300 (Easing)	-0.020	0.498	-2.072	2.185	788
EUR/USD 1200-2300 (Easing)	-0.002	0.410	-1.836	1.912	788

The entire sample spans a period during which the ECB has implemented monetary policy measures, which could be described as 'tightening' and 'easing'. The 'tightening cycle' corresponds to the period January 03, 2011 to October 20, 2011 during which the ECB increases interest rates to a peak of 1.75%. The 'easing cycle' corresponds to the period October 21, 2011 to November 20, 2015 during which the ECB decreases interest rates from the peak of 1.75% to 0.050%. It is reasonable to assume that average post-announcement returns are affected by the policy stance of the GC during their scheduled press conference. The currency market response to such very divergent tones would be expected to be very different. For this reason, throughout the analysis in this chapter, the sample is split into 'tightening' and 'easing' sub-samples.

I then carry out a more formal analysis by looking at the mean, median and standard deviations of three previously defined windows for the post-ECB Friday announcements, as well as for the same returns windows on all other days and all other Fridays. Such statistics are reported in Table 4.1 for the full sample, as well as for the samples labelled '*Tightening' and 'Easing'. The former consists of* the cumulative log returns for each respective return window considered to be during the ECB's tightening cycle which spans 10 post-ECB Fridays and 31 non-ECB Fridays, whereas the latter is the cumulative log returns for the same return windows during the ECB's easing cycle which spans 40 post- ECB Fridays and 160 non-ECB Fridays. The post-ECB return window in the EUR/USD currency market appears to show an interesting price formation process on the day following scheduled announcements. This price formation is particularly prominent for post-ECB Fridays. To investigate the post-ECB window further, I collect the times and dates of scheduled ECB GC meetings, policy decision announcement and press conference times.

The ECB GC convenes twelve times per year as part of their mandated monetary policy operations to review set or adjust monetary policy for the Euro area[19]. Following these meetings, the ECB announces its monetary policy stance at the pre-scheduled time of 1300 CET on a pre-scheduled date. Such announcements mostly take place on a Thursday (50 out of 55) with only a few (5 out of 55) scheduled on Wednesdays.[20] Contrary to the quiet period observed by the GC members during the pre-announcement window, the post-announcement window is characterised by commentary and press briefings. GC members frequently speak to the world

[19] Since 2015, scheduled GC policy meetings have been reduced to eight meetings per year.
[20] This is usually due to the close proximity of a public holiday, which interrupts the scheduled meeting.

press and market agents about the policy stance of the bank and provide reasons for any changes in policy.[21]

The day of the week on which the scheduled announcement falls is of vital importance. Any significant policy decisions are also noted, which may have been taken. The dates of meeting and policy decisions are sourced from the ECB's website (www.ecb.europa.eu) and further details of exact announcement times are gathered from Bloomberg. The above features of the GC meetings are set out in Appendix C1.

[21] It is also common for members of the governing council to voice any divergence in their personal opinion on the bank's policy decisions.

4.4 Methodology

I base the empirical analysis on a standard dummy variable regression model to detect any potential day of the week effect for the EUR/USD market. The model is then adapted to suit the investigation of a potential 'ECB conditional Friday effect'. This last specification is then re-estimated in Maximum Likelihood to account for any clusters of volatility, which are typically present in daily financial series.

Calendar Effect Model

I begin by investigating for the entire sample the presence of any potential unconditional DoW effect in the daily EUR/USD series under scrutiny. I do so by means of the following equation:

$$R_t = \sum_{i=1}^{5} \beta_i \, DoW_{i,t} + \varepsilon_t \qquad [4.1]$$

where R_t is the cumulative daily return on the EUR/USD in percentage points, and *t* spans from 1 to 1194. Such cumulative returns are calculated by summing the 5-minute returns for a specified trading period. For example, if the trading day is defined as the 24-hour period between 2300 CET on date $t-1$ to date t, the cumulative 5-minute returns during such return window will form a one day return observation. The explanatory variables are dummy variables that take unity when the return interval falls on a specific day, and zero otherwise.[22] The coefficients β_i capture the average return differential for each DoW versus all other days. The disturbance term, ε_t, is assumed to be the normally distributed with mean zero and variance σ^2. Equation (4.1) is the baseline model that I employ to investigate the 'ECB conditional Friday effect'.

This model is the standard approach taken in financial economics literature to test for calendar effects in multiple asset classes and across international market (see, e.g., Zhang et al. (2017) and Yamori and Kurihara (2004)).

I then gauge the magnitude of the ECB conditional Friday drift in returns by splitting the Fri_t dummy variable into two separate dummy variables as follows:

[22] For instance, the $DoW_{1,t}$ dummy variable takes value 1 if t is a Monday and zero when t falls on any other day.

$$R_t = \sum_{i=1}^{4} \beta_i DoW_{i,t} + \beta_{ECB}(Fri|ECB)_t + \beta_{NO}(Fri|NoECB)_t + \varepsilon_t \quad [4.2]$$

The dummy variable $(Fri|ECB)_t$ takes unity value for when date t is the Friday following scheduled monetary policy announcements and zero otherwise, whereas the dummy $(Fri|NoECB)_t$ is equal to one when date t is any Friday that does not follow ECB announcement days and zero otherwise. The coefficients β_{ECB} and β_{NO} capture the estimated average return on ECB Fridays and Non-ECB Fridays above all other days, respectively. Equation (4.2) therefore controls for all other unconditional days of the week returns while the Fridays which follow scheduled ECB announcements are isolated.

Statistical features of the return periods generated by summing 5-minute EUR/USD log returns demonstrate departures from normality and could potentially suffer from serial correlation and conditional heteroscedasticity. Since the disturbance terms in equations (4.1) and (4.2) may inherit such features, least square estimators might lose consistency and deliver potentially spurious results (see Chien, Lee, and Wang (2002)). Based on these considerations, I supplement the estimation strategy by using alternative methods such as HAC sandwiches estimators, WLS and bootstrapping which can better cope with ill-conditioned data.

I then re-estimate equations (4.1) and (4.2) using the following two GARCH specifications:

$$R_t = \sum_{i=1}^{5} \beta_i DoW_{i,t} + \varepsilon_t \quad [4.3]$$

$$\sigma_t^2 = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \alpha_2 \sigma_{t-1}^2 \quad [4.4]$$

$$R_t = \sum_{i=1}^{4} \beta_i DoW_{i,t} + \beta_{ECB}(Fri|ECB)_t + \beta_{NO}(Fri|NoECB)_t + \varepsilon_t \quad [4.5]$$

$$\sigma_t^2 = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \alpha_2 \sigma_{t-1}^2 + \alpha_{ECB}(Fri|ECB)_t \quad [4.6]$$

The joint estimations of mean and GARCH variance equations, which include dummy variables with structures similar to those defined above, can generate multi-modality in likelihood functions, with the peril of achieving local rather than global maxima (Doornik and Oms (2008)). As the number of dummy variables in the mean equation increases, the issue of multi-

modality becomes more severe. To avoid this problem, I conduct two-stage empirical estimations of the above GARCH models. First, I carry out OLS estimation of equation (4.3) and then use the residuals so obtained to estimate equation (4.4). [23] I posit that this approach is more suitable to deliver robust estimators with a negligible impact on the asymptotic efficiency. This is particularly valid given the large sample of daily returns in use. Furthermore, it has been shown that for similar GARCH specifications, the two-step approach is asymptotically equivalent to the joint estimation of the mean and variance equations (Lin, Engle, and Ito (1994)).

[23] The same empirical exercise is carried out for equations (4.5) – (4.6).

4.5 Empirical Findings

In this section, I set out the empirical estimates for the specifications reported in the previous section. I then re-assess the economic significance of the post-ECB announcements by looking at the risk/return delivered by trading rules designed around the same announcements.

4.5.1 The post-ECB Trading Window

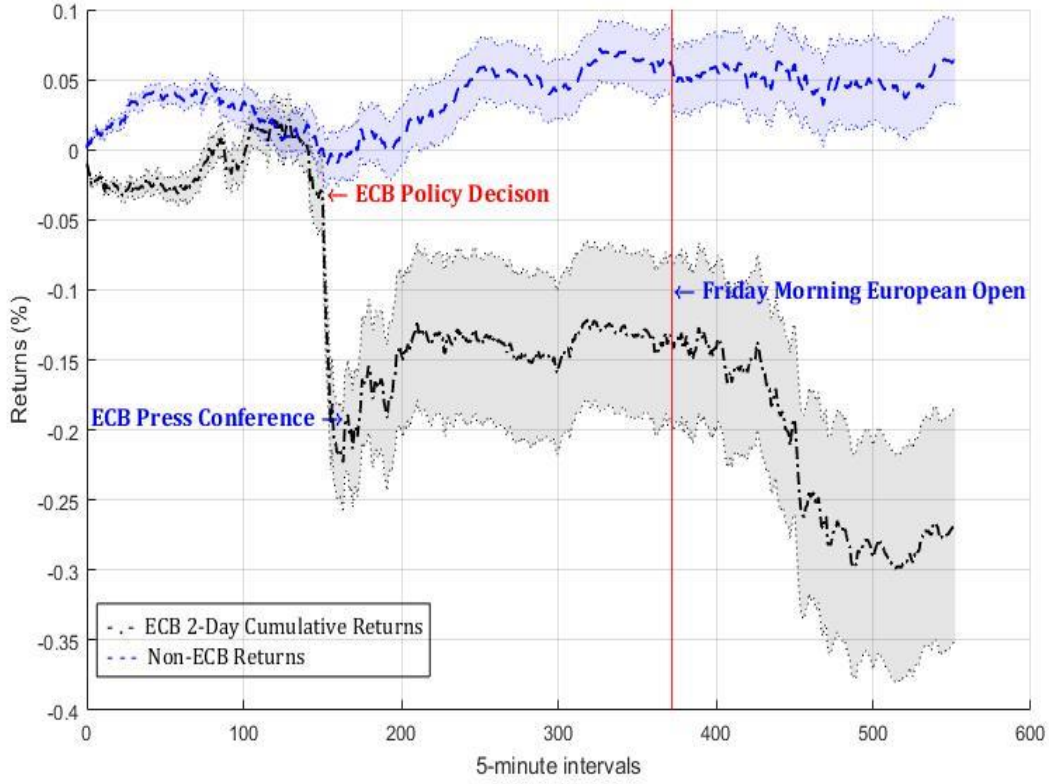
I begin by looking at the price formation process in the EUR/USD foreign exchange market on Thursday scheduled ECB policy announcements and Fridays, which follow. This price formation process is contrasted with all other Thursday/Friday day-couplets where there are no scheduled ECB policy decisions. Figure 4.1 illustrates this comparison between ECB Thursdays and Fridays and all other Thursday/Friday 2-day return windows. The bold dashed black line represents the average pointwise cumulative 5-minute intraday percentage return on the EUR/USD for all 2-day ECB announcement windows. The announcement window is taken from the market open of the day of schedule ECB monetary policy announcements to the market close on the day following the announcement day. The average pointwise cumulative intraday return is calculated for 50 ECB announcement windows, where the policy announcement is made on a Thursday, from January 03, 2011 to September 16, 2015. The bold blue dashed line gives the average pointwise cumulative intraday returns, but for all 2-day Thursday/Friday return windows of the same definition where there are no scheduled ECB policy announcements.

As predicted by standard economic theory there is an immediate price reaction to the arrival of new public information in the form of the ECB's policy announcement. From approximately zero in the pre-announcement morning, average cumulative returns fall to a low of -20 basis points almost immediately following the ECB's policy announcement. The price formation process taking place at the 152nd return interval on ECB Thursdays (1345 CET) is broadly in line with expectations given that, the central bank was in a period of policy easing for the majority of the sample period. Further, the announcement of all policy easing measures and new accommodative policy tool such as bond buying programmes were made at the regular scheduled announcement window.

Following the policy decision announcement, there appears to be a period of profit taking during the ECB's press conference at the 163rd return interval (1430 CET) and through to

European market close. Cumulative returns on the EUR/USD are mostly flat during overnight trade on the post-ECB Friday and into European market open on Friday mornings.

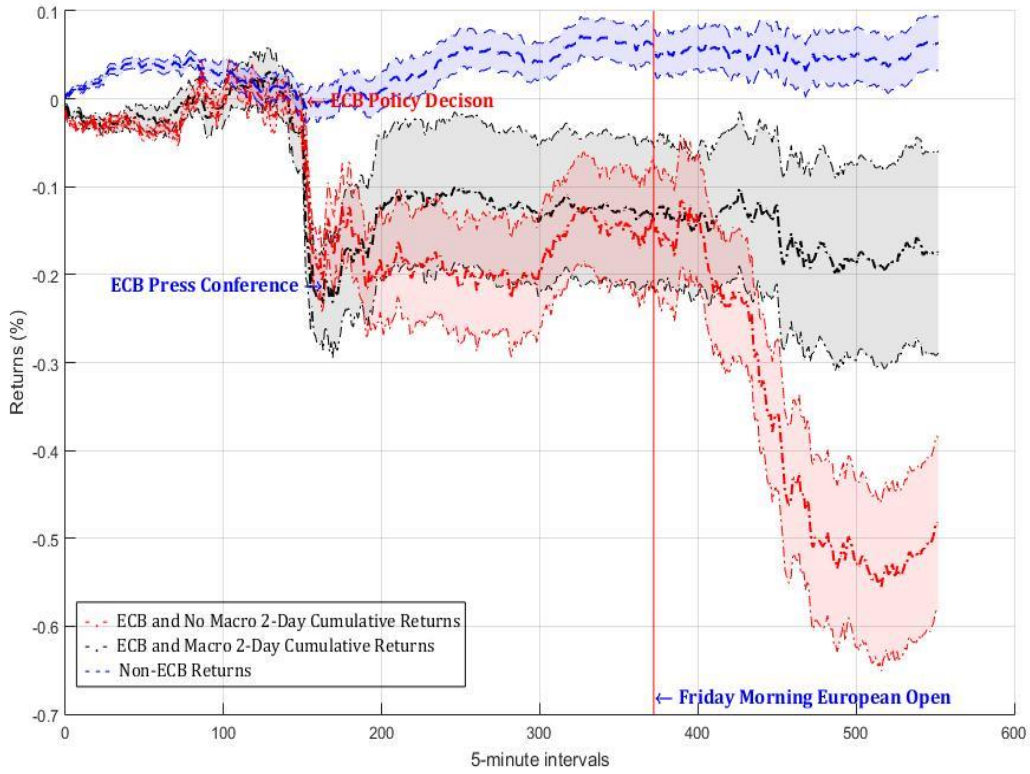
Figure 4.1
5-minute cumulative returns on the EUR/USD exchange rate over 2 days trading window. This figure shows the average cumulative returns on the EUR/USD exchange rate for 2-day trading windows. The dashed black line is the average cumulative returns from 0000 CET on the day of the ECB announcement (Thursday) to 2300 CET on the day following the ECB announcement day (Friday). The dashed blue line shows average cumulative returns on all other Thursday/Friday couplets that do not include scheduled ECB announcements. The shade black and blue areas are pointwise 95% confidence intervals around the average cumulative returns. The sample period is from January 03, 2011 to November 20, 2015. The red arrow is set at 1345 CET, when ECB policy decisions are made public. The blue arrow is set at 1430 CET, when the ECB press conference takes place. The vertical red line represents the start of European Friday trading hours.



Up to this stage of the trading period, the post-ECB price formation process is in line with fundamental economic theory. However, at the 426th return interval, corresponding to the European Lunch time (1200 CET) there is a noticeable drop in cumulative EUR/USD returns. This drop-off can be characterised as a drift since it takes place consistently over 70, five-minute, return intervals (almost 6 hours). This post-ECB Friday afternoon drift is tantamount to approximately -15 basis points and appears to commence in the absence of any scheduled macroeconomic data points. The pointwise 95% confidence interval for average cumulative returns indicated by the grey shaded area, would suggest that cumulative post-ECB returns are negative and significantly different from zero. Moreover, when compared to the cumulative

returns on the EUR/USD on all other day couplets and associated 95% confidence interval, which are roughly zero to +5 basis points, the post-ECB drop off appears to be significant.

Figure 4.2
Accounting for Macroeconomic Announcements. This figure shows the average cumulative returns on the EUR/USD exchange rate for 2-day trading windows. The dashed red line is the average cumulative returns on the EUR/USD from 0000 CET ECB Thursdays to 2300 CET on ECB Fridays during which there are no observations of macroeconomic announcements. The dashed black line is the average cumulative returns on the EUR/USD from 0000 CET on ECB Thursdays to 2300 CET on ECB Fridays during which macroeconomic announcements are observed. The dashed blue line shows average cumulative returns on the EUR/USD on all other Thursday/Friday couplets that do not include scheduled ECB announcements. The shade black and blue areas are pointwise 95% confidence intervals around the average cumulative returns for corresponding data sets. The sample period is from January 03, 2011 to November 20, 2015. The red arrow is set at 1345 CET, when ECB policy decisions are made public. The blue arrow is set at 1430 CET, when the ECB press conference takes place. The vertical red line represents the start of European Friday trading hours.



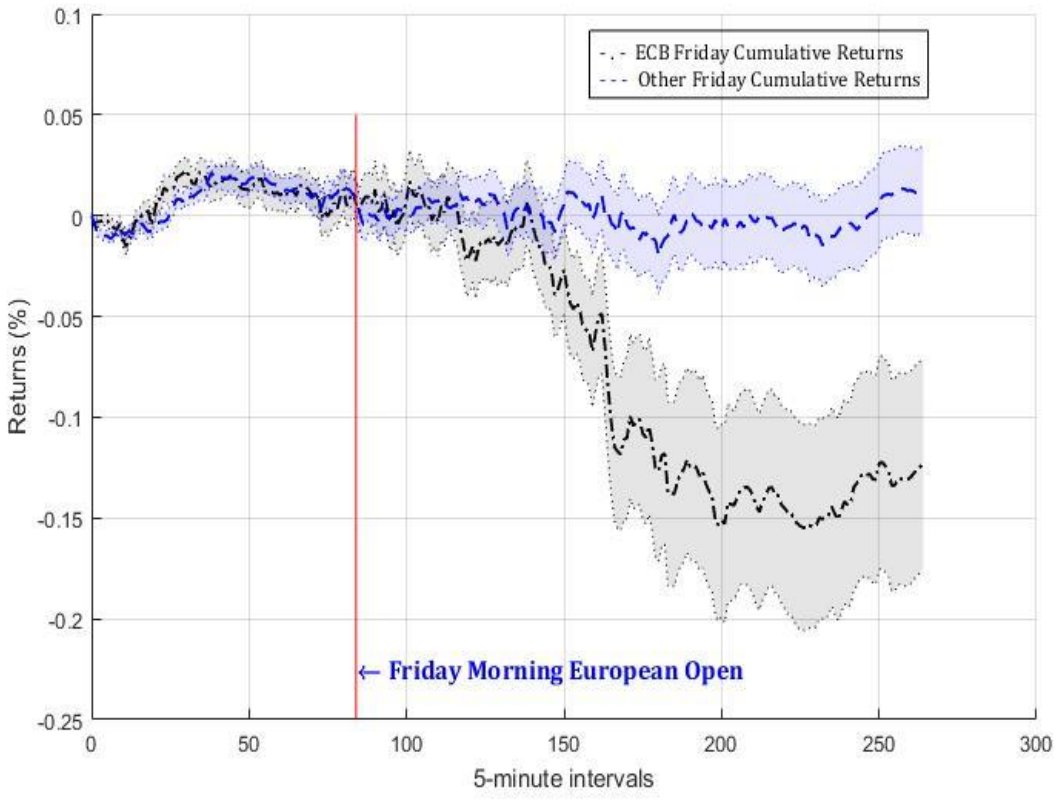
It is worth noting that there are scheduled macroeconomic data announcements on some post-ECB Fridays at 1430 CET (175th return interval), however, the outcomes of such data announcements are heterogeneous in expected EUR/USD market impact (see Appendix C2). To assess further the potential impact of macroeconomic news on the conditional ECB Friday drift, I split the post-ECB return window to those, which feature macroeconomic announcements (20) (such as the U.S Employment Report, U.S Inflation Report, Eurozone Inflation Report, etc.) and post-ECB trading periods during absent of major macroeconomic announcements (30). The result of this exercise presented in Figure 4.2, show that the drift is

very large and negative drift during post-ECB Fridays absent of major macroeconomic announcements. This negative drift appears to be in excess of 30 basis points.

In contrast, ECB Fridays appear to exhibit no significant drift when macroeconomic news is detected. Based on this result I rule out the possibility that the ECB conditional Friday drift is due to news arrival.

To differentiate between the policy announcement conditional price formation process and the Friday afternoon drift, the post-ECB Fridays is isolated and contrasted with all other Fridays. Figure 4.3 provides an illustrative comparison between EUR/USD average cumulative returns on Fridays following scheduled ECB announcements and all other Fridays.

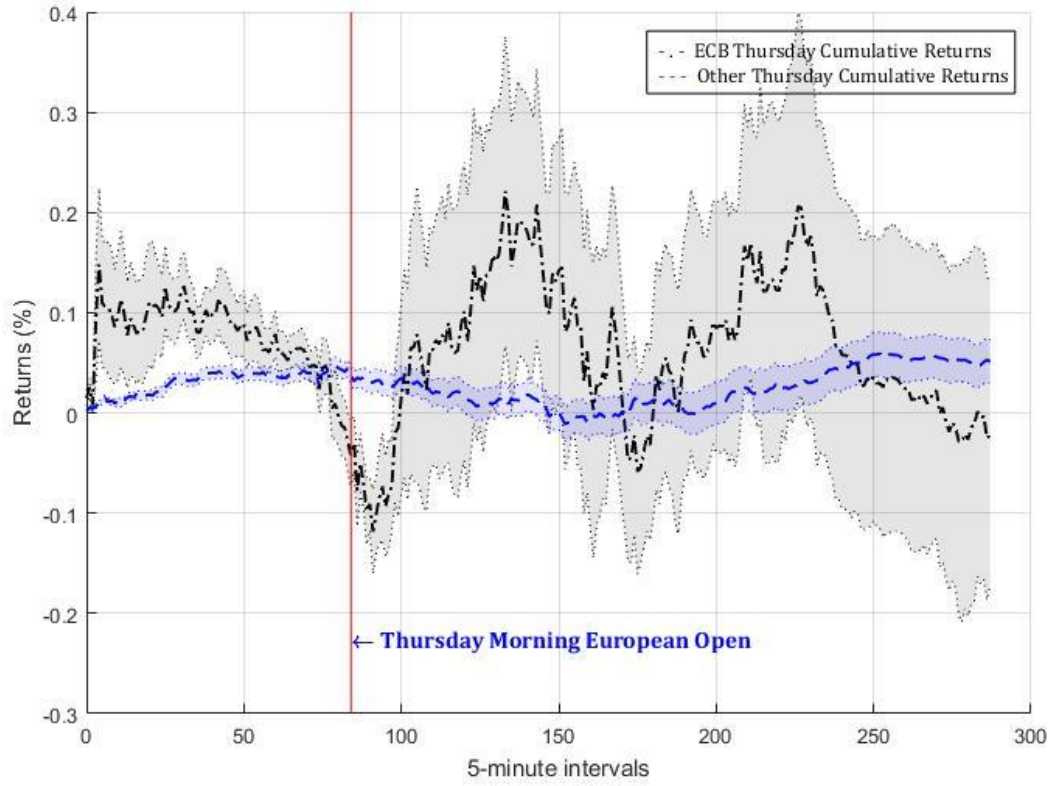
Figure 4.3
Friday returns on the EUR/USD exchange rate. This figure shows the average cumulative returns on the EUR/USD exchange rate for Friday trading windows. The dashed black line is the average cumulative returns on the EUR/USD from 0000 CET on the Friday after ECB announcement days to 2300 CET at market close. The dashed blue line shows average cumulative returns on the EUR/USD on all other Fridays that do not follow scheduled ECB announcements. The shade black and blue areas are pointwise 95% confidence intervals around the corresponding average cumulative returns. The sample period is from January 03, 2011 to November 20, 2015. The vertical red line represents the start of European Friday trading hours.



It is clear from the figure that cumulative returns on the EUR/USD on Fridays following ECB announcements (illustrated with dashed black line) are approximately in line with all other Fridays, at zero. There is however, a notable decoupling at 1230 CET (return interval 138),

where cumulative returns begin to drift on ECB Fridays. This drift continues throughout the afternoon until approximately 1640 CET (the 200th return interval), and is tantamount to -15 basis points at European market close. Isolating Friday trading periods in this way shows that there is a significant conditional Friday effect observable. This effect is worthy of further investigation given the economic implication of an observable consistent price formation process, which is unexplained by standard economic theory.

Figure 4.4
Thursday returns on the EUR/USD exchange rate. This figure shows the average cumulative returns on the EUR/USD exchange rate for Thursday trading windows. The dashed black line is the average cumulative returns on the EUR/USD from 0000 CET on the Thursday after ECB announcement days to 2300 CET at market close. The dashed blue line shows average cumulative returns on the EUR/USD on all other Thursdays that do not follow scheduled ECB announcements. The shade black and blue areas are pointwise 95% confidence intervals around the average cumulative returns for corresponding data sets. The sample period is from January 03, 2011 to November 20, 2015. The vertical red line represents the start of European Thursday trading hours.



The apparent pricing anomaly detailed above only takes place on Friday trading days, which follow scheduled ECB announcements taking place on Thursdays. When the day of the week following an ECB announcement falls on a Thursday (rather than a Friday) no pricing anomaly can be observed. This can be seen from the results presented in Figure 4.4. The dashed bold black line represents the average cumulative returns on the EUR/USD for Thursdays, which follow Wednesday, scheduled ECB policy announcements. In total, there are 5 such Thursday trading periods in the sample. It is clear from the figure that average cumulative returns on ECB

conditional Thursdays do not follow the same pattern as that observed for ECB Fridays. There is an afternoon negative drift in cumulative returns, however, as indicated by the 95% confidence intervals (shaded blue and grey areas) this drift cannot be shown to be statistically different from zero or different from the average cumulative returns observed on all other non-ECB Thursdays (indicated by the bold dashed blue line).

It is fair to surmise, from the evidence presented in the Figures above, that the day-after ECB conditional drift is a Friday pricing anomaly and does not occur when scheduled ECB announcements take place on Wednesdays.

4.5.2 The Conditional Friday Effect

To more formally investigate the existence, and gauge the magnitude of an ECB conditional Friday effect, in this section I present the results of the methodology outline in section 4.5.

The empirical estimates of equations (4.1) to (4.6) set out in Table 4.2 confirm the existence of the ECB conditional Friday effect.

I start the empirical analysis by evaluating results for the full sample, inclusive of periods of monetary easing and tightening. I find that there are no observable unconditional DoW effect in the EUR/USD foreign exchange market when the trading day is defined as the 24-hour period between 2300 – 2300 CET, 0800 – 2300 CET and 1200 – 2300 CET. In fact, all estimated coefficients of equation (4.1) are not statistically significant at standard significance levels. It is also worth noting at this stage, that the GARCH term is omitted from equation (4.4) and (4.6). Specification tests carried out show that the addition of a GARCH term over specifies the model and makes coefficient estimates less efficient.[24]

Empirical estimation of equation (4.2) and (4.5) – (4.6) reported in Table 4.2 confirm the existence of a highly significant ECB conditional Friday effect, where the returns earned on the EUR/USD currency are orders of magnitude lower that that earned on all other days tested. Average returns on the EUR/USD on Fridays following scheduled ECB policy decision announcements are over 18 basis points lower than all other unconditional days in sample for 24-hour trading day. The magnitude of the negative ECB Friday drift is approximately the same when the trading day is defined as spanning European trading hours (0800 – 2300 CET). I investigate this particular return window due to the apparent zero average return on the EUR/USD during overnight trading hours as observed in Figure 4.3. In fact, the decoupling of the average return pattern observed for ECB Fridays from all other Fridays appears to be more pronounced only after the European opening bell (0800 CET).

Moreover, looking closer at findings presented in Figure 4.3 it appears that the negative drift is more pronounced and predominantly takes place in the afternoon. When the trading day is defined as such, the magnitude of the EUR/USD negative drift on ECB Friday afternoons is on average 15 basis points. Comparing the magnitude of the negative drift for all three definitions of the trading day, empirical results show that the majority of the ECB Friday effect takes place during afternoon trading hours.

[24] This is determined by the Akaike Information Criterion

Table 4.2

This table shows the results for OLS estimates of equation (4.1) and (4.2) and maximum likelihood estimates of equations (4.3) – (4.4) and (4.5) – (4.6). The dependant variable is the cumulative return (R_t) on the EUR/USD from 2300 CET on date $t-1$ to 2300 CET on the date t (first panel), from 0800 CET on date t to 2300 CET on the same date (second panel) and from 1200 CET on date t to 2300 CET on the same date (third panel). The sample period is from January 01, 2011 to November 20, 2015 (1194 Observations). This sample contains 50 scheduled ECB announcements. Coefficient estimates for the mean equation are provided in the top panel and for the variance equation, in the bottom panel. Standard errors are given in brackets. Bootstrapped Bias-Corrected confidence intervals at 5% level in squared brackets (DiCiccio and Efron (1996)).Q(4) is the Ljung-Box statistic for serial correlation up to lag 4 in residuals. ARCH (4) is the ARCH-LM test for heteroscedasticity in residuals up to lag 4. P-values for specification tests are reported in brackets. ***Significant at 1%, **significant at 5% and *significant at 10%.

	EUR/USD 2300-2300 CET				**EUR/USD 0800-2300 CET**				**EUR/USD 1200-2300 CET**			
	Eq. (1)	**Eq.(3)-(4)**	**Eq. (2)**	**Eq.(5)-(6)**	**Eq. (1)**	**Eq.(3)-(4)**	**Eq. (2)**	**Eq.(5)-(6)**	**Eq. (1)**	**Eq.(3)-(4)**	**Eq. (2)**	**Eq.(5)-(6)**
	OLS	**ML**	**OLS**	**ML**	**OLS**	**ML**	**OLS**	**ML**	**OLS**	**ML**	**OLS**	**ML**
β_1	0.017	0.028	0.017	0.030	0.005	0.009	0.005	0.011	0.021	0.026	0.021	0.027
	(0.038)	(0.041)	(0.038)	(0.040)	(0.034)	(0.040)	(0.034)	(0.039)	(0.029)	(0.035)	(0.029)	(0.035)
			[-0.056,0.090]				[-0.062,0.072]				[-0.035,0.077]	
β_2	0.024	0.028	0.024	0.028	0.021	0.012	0.021	0.013	0.026	0.022	0.026	0.022
	(0.038)	(0.041)	(0.038)	(0.041)	(0.034)	(0.038)	(0.034)	(0.038)	(0.029)	(0.034)	(0.029)	(0.033)
			[-0.050,0.098]				[-0.046,0.088]				[-0.030,0.083]	
β_3	-0.041	-0.040	-0.041	-0.040	-0.048	-0.046	-0.048	-0.046	-0.041	-0.040	-0.041	-0.041
	(0.038)	(0.033)	(0.038)	(0.033)	(0.034)	(0.030)	(0.034)	(0.030)	(0.029)	(0.026)	(0.029)	(0.026)
			[-0.114,0.033]				[-0.115,0.019]				[-0.097,0.015]	
β_4	0.011	0.015	0.011	0.015	-0.023	-0.028	-0.023	-0.027	-0.002	-0.003	-0.002	-0.004
	(0.038)	(0.032)	(0.038)	(0.032)	(0.034)	(0.029)	(0.034)	(0.029)	(0.029)	(0.025)	(0.029)	(0.025)
			[-0.063,0.085]				[-0.090,0.044]				[-0.058,0.055]	
β_5	-0.023	-0.012			-0.030	-0.025			-0.012	-0.009		
	(0.038)	(0.036)			(0.034)	(0.033)			(0.029)	(0.027)		
β_{ECB}			**-0.190*** **	**-0.183*** **			**-0.199*** **	**-0.181*** **			**-0.161** **	**-0.150** **
			(0.084)	**(0.092)**			**(0.077)**	**(0.068)**			**(0.064)**	**(0.062)**
			[-0.357,-0.026]				**[-0.350,-0.048]**				**[-0.287,-0.035]**	
β_{NO}			0.019	0.019			0.013	0.008			0.025	0.022
			(0.042)	(0.035)			(0.038)	(0.038)			(0.032)	(0.030)
			[-0.063,0.102]				[-0.062,0.088]				[-0.038,0.088]	
α_0		0.281***		0.277***		0.239***		0.239***		0.180***		0.180***
		(0.018)		(0.018)		(0.001)		(0.001)		(0.006)		(0.006)
α_1		0.180***		0.171***		0.150***		0.145***		0.087***		0.084***
		(0.060)		(0.060)		(0.034)		(0.034)		(0.028)		(0.028)
α_{ECB}				0.170				0.115				0.044
				(0.161)				(0.078)				(0.069)
R^2	0.002	0.001	0.006	0.005	0.002	0.002	0.007	0.007	0.003	0.003	0.009	0.009
$Q(4)$	4.848	3.063	5.198	3.234	5.117	3.162	5.285	3.160	7.438	6.373	7.900	6.594
	(0.303)	(0.547)	(0.268)	(0.519)	(0.276)	(0.531)	(0.259)	(0.531)	(0.114)	(0.173)	(0.095)	(0.159)
$ARCH(4)$	13.943	0.094	27.359	0.123	31.123	0.005	29.560	0.021	6.659	0.040	5.227	0.077
	(0.000)	(0.760)	(0.000)	(0.726)	(0.000)	(0.944)	(0.000)	(0.885)	(0.010)	(0.842)	(0.022)	(0.782)

Note: The distribution and sample statistics of the bootstrapped betas and respective standard errors are asymptotically coverage to values achieved through OLS estimation. The results of this exercise are presented in appendix C3.

I believe that this particular finding differentiates the ECB Friday effect from simply the 'pricing in' of information reported in the Thursday announcement. Assuming at least semi-strong form efficiency in the EUR/USD market, the information content of the ECB announcement should be priced prior to the European opening hours or at least European lunch, given the 24-hour nature of the EUR/USD market.

All quoted results are significant at the 1% percent level, of a higher magnitude when estimated using least square methodology and confirmed to be robust with bootstrapped bias-corrected confidence intervals. The findings reported here therefore suggest, that the ECB conditional Friday effect is both statistically and economically relevant.

Table 4.3 reports findings for when the sample is split to only include the policy tightening period from January 01, 2011 through October 20, 2011. When the ECB's policy tightening period is isolated, the magnitude of the average return differential on ECB Fridays remains large and negative, yet not statistically significant.

It is somewhat surprising to find such large negative returns in the aftermath of ECB announcements during a policy tightening cycle. However, given the statistical properties of these results it is difficult to arrive at any conclusive explanations.

Table 4.4 reports findings for when the sample is split to only include the policy easing period from October 20, 2011 through November 20, 2015. For the sub-period characterized by loosened monetary policy stance the ECB Friday announcements produce a slightly less negative but significant negative drift over all other Fridays. Here the average excess return differential is almost 17 basis points less than all other easing sub-sample days. This result is notable and somewhat surprising given that the full sample ECB Friday drift is larger in absolute terms.

When the trading day is re-defined as the 15-hour European trading day, between 0800 CET – 2300 CET, the EUR-USD drifts lower on average, by almost 16 basis points versus all other unconditional days of the week in the easing period sample. The larger, more negative ECB Friday drift found for the tightening sub-sample is consistent with that found for the 24-hour trading days. I observe similar levels of negative drift when the trading day is confined to after Lunch market hours.

Table 4.3

Results for the OLS estimates of equation (4.1) and (4.2) and Maximum Likelihood estimates of equations (4.3) – (4.4) and (4.5) – (4.6). The dependant variable is the cumulative return (R_t) on the EUR/USD from 2300 CET on date $t-1$ to 2300 CET on the date t (first panel), from 0800 CET on date t to 2300 CET (second panel) and from 1200 CET on date t to 2300 CET on the same date (third panel). In order to account for the effect of tightening monetary policy the sample is partitioned into the period from January 01, 2011 through October 20, 2011, so that this sample contains 10 scheduled ECB announcements. Coefficient estimates for the mean equation are provided in the top panel and for the variance equation, in the bottom panel. Standard errors are given in brackets. Bootstrapped Bias-Corrected confidence intervals at 5% level in squared brackets (DiCiccio and Efron (1996)).*Q(4)* is the Ljung-Box statistic for serial correlation up to lag 4 in residuals. ARCH (4) is the ARCH-LM test for heteroscedasticity in residuals up to lag 4. P-values for specification tests are reported in brackets. ***Significant at 1%, **significant at 5% and *significant at 10%.

	EUR/USD 2300-2300 CET (Tightening)				**EUR/USD 0800-2300 CET (Tightening)**				**EUR/USD 1200-2300 CET (Tightening)**			
	Eq. (1)	**Eq.(3)-(4)**	**Eq. (2)**	**Eq.(5)-(6)**	**Eq. (1)**	**Eq.(3)-(4)**	**Eq. (2)**	**Eq.(5)-(6)**	**Eq. (1)**	**Eq.(3)-(4)**	**Eq. (2)**	**Eq.(5)-(6)**
	OLS	**ML**	**OLS**	**ML**	**OLS**	**ML**	**OLS**	**ML**	**OLS**	**ML**	**OLS**	**ML**
β_1	-0.006	0.031	-0.006	0.034	0.033	0.055	0.033	0.060	0.018	0.035	0.018	0.039
	(0.114)	(0.130)	(0.114)	(0.129)	(0.104)	(0.114)	(0.103)	(0.112)	(0.088)	(0.112)	(0.088)	(0.112)
			[-0.227,0.214]				[-0.168,0.231]				[-0.151,0.188]	
β_2	**0.232	0.235	**0.232	0.235	0.191	0.155	0.191	0.159	0.154	0.123	0.154	0.125
	(0.112)	(0.153)	(0.112)	(0.153)	(0.102)	(0.174)	(0.102)	(0.173)	(0.087)	(0.108)	(0.087)	(0.108)
			[0.015,0.450]				[-0.005,0.390]				[-0.013,0.322]	
β_3	0.025	0.010	0.025	0.010	-0.019	-0.041	-0.019	-0.041	-0.117	-0.126	-0.117	-0.126
	(0.112)	(0.094)	(0.112)	(0.094)	(0.102)	(0.081)	(0.102)	(0.081)	(0.087)	(0.083)	(0.087)	(0.082)
			[-0.193,0.242]				[-0.217,0.178]				[-0.284,0.051]	
β_4	-0.038	-0.022)	-0.038	-0.028)	-0.085	-0.089	-0.085	-0.093	0.009	0.005	0.009	-0.001
	(0.112)	(0.102)	(0.112)	(0.102)	(0.102)	(0.093)	(0.102)	(0.092)	(0.087)	(0.070)	(0.087)	(0.070)
			[-0.255,0.180]				[-0.283,0.112]				[-0.160,0.176]	
β_5	-0.021	0.021			-0.047	-0.018			0.025	0.061		
	(0.112)	(0.098)			(0.102)	(0.093)			(0.087)	(0.078)		
β_{ECB}			**-0.283**	**-0.253**			**-0.364***	***-0.341***			**-0.230**	**-0.183**
			(0.230)	**(0.190)**			**(0.209)**	**(0.204)**			**(0.177)**	**(0.194)**
			[-0.744,0.177]				**[-0.776,0.060]**				**[-0.585,0.124]**	
β_{NO}			0.061	0.078			0.052	0.055			0.105	0.121
			(0.129)	(0.116)			(0.117)	(0.107)			(0.099)	(0.085)
			[-0.189.0.311]				[-0.175,0.280]				[-0.088,0.300]	
α_0		0.436***		0.440***		0.353***		0.354***		0.273***		0.272***
		(0.057)		(0.056)		(0.040)		(0.040)		(0.026)		(0.026)
α_1		0.159		0.141		0.173*		0.156*		0.112		0.105
		(0.104)		(0.102)		(0.096)		(0.092)		(0.079)		(0.081)
α_{ECB}				0.453				0.170				0.017
				(0.679)				(0.444)				(0.256)
R^2	0.019	0.017	0.027	0.026	0.021	0.020	0.036	0.035	0.024	0.022	0.037	0.035
$Q(4)$	3.084	1.612	3.606	1.815	2.480	1.473	3.186	1.572	2.789	2.214	3.831	2.875
	(0.544)	(0.807)	(0.462)	(0.770)	(0.648)	(0.831)	(0.527)	(0.814)	(0.594)	(0.697)	(0.429)	(0.579)
$ARCH(4)$	5.531	0.032	5.705	0.008	9.515	0.160	9.461	0.052	3.530	0.080	2.377	0.017
	(0.020)	(0.859)	(0.018)	(0.928)	(0.002)	(0.689)	(0.002)	(0.821)	(0.062)	(0.778)	(0.125)	(0.896)

Note: The distribution and sample statistics of the bootstrapped betas and respective standard errors are asymptotically coverage to values achieved through OLS estimation. The results of this exercise are presented in appendix C3.

This finding suggests that potentially, the policy stance adopted by the ECB does not impact the directional return for the ECB Friday effect. The sign of the ECB Friday effect is consistently negative and not dependent on the ECB monetary policy stances. However, the significance and magnitude are dependent on ECB monetary policy stances.

Emperical estimation of equations (4.4) and (4.6) show that there are no significant increases to volatility for any DoW or ECB conditional Fridays. This result is consistent for the full sample, sub-sample periods and all three definitions of the trading day.

Table 4.4

Results for the OLS estimates of equation (4.1) and (4.2) and Maximum Likelihood estimates of equations (4.3) – (4.4) and (4.5) – (4.6). The dependant variable is the cumulative return (R_t) on the EUR/USD from 2300 CET on date $t-1$ to 2300 CET on the date t (first panel), from 0800 CET on date t to 2300 CET (second panel) and from 1200 CET on date t to 2300 CET on the same date (third panel). In order to account for the effect of 'easing' monetary policy the sample is partitioned into the period from October 21, 2011 through November 20, 2015, so that this sample contains 40 scheduled ECB announcements. Coefficient estimates for the mean equation are provided in the top panel and for the variance equation, in the bottom panel. Standard errors are given in brackets. Bootstrapped Bias-Corrected confidence intervals at 5% level in squared brackets (DiCiccio and Efron (1996)).Q(4) is the Ljung-Box statistic for serial correlation up to lag 4 in residuals. ARCH (4) is the ARCH-LM test for heteroscedasticity in residuals up to lag 4. P-values for specification tests are reported in brackets. ***Significant at 1%, **significant at 5% and *significant at 10%.

	EUR/USD 2300-2300 CET (Easing)				**EUR/USD 0800-2300 CET (Easing)**				**EUR/USD 1200-2300 CET(Easing)**			
	Eq. (1)	**Eq.(3)-(4)**	**Eq. (2)**	**Eq.(5)-(6)**	**Eq. (1)**	**Eq.(3)-(4)**	**Eq. (2)**	**Eq.(5)-(6)**	**Eq. (1)**	**Eq.(3)-(4)**	**Eq. (2)**	**Eq.(5)-(6)**
	OLS	**ML**	**OLS**	**ML**	**OLS**	**ML**	**OLS**	**ML**	**OLS**	**ML**	**OLS**	**ML**
β_1	0.021	0.025	0.021	0.026	-0.001	-0.001	-0.001	0.000	0.021	0.022	0.021	0.022
	(0.039)	(0.042)	(0.039)	(0.042)	(0.036)	(0.042)	(0.036)	(0.041)	(0.030)	(0.035)	(0.030)	(0.035)
			[-0.055,0.098]				[-0.071,0.069]				[-0.37,0.079]	
β_2	-0.021	-0.011	-0.021	-0.011	-0.015	-0.011	-0.015	-0.011	-0.001	0.001	-0.001	0.000
	(0.039)	(0.041)	(0.039)	(0.041)	(0.036)	(0.037)	(0.036)	(0.037)	(0.030)	(0.036)	(0.030)	(0.036)
			[-0.097,0.056]				[-0.085,0.054]				[-0.059,0.057]	
β_3	-0.055	-0.053	-0.055	-0.053	-0.054	-0.048	-0.054	-0.048	-0.025	-0.024	-0.025	-0.024
	(0.039)	(0.036)	(0.039)	(0.035)	(0.036)	(0.033)	(0.036)	(0.033)	(0.030)	(0.027)	(0.030)	(0.027)
			[-0.132,0.021]				[-0.124,0.015]				[-0.083,0.033]	
β_4	0.021	0.023	0.021	-0.023	-0.010	-0.014	-0.010	-0.013	-0.004	-0.004	-0.004	-0.004
	(0.039)	(0.033)	(0.039)	(0.033)	(0.036)	(0.030)	(0.036)	(0.030)	(0.030)	(0.026)	(0.030)	(0.026)
			[-0.055,0.098]				[-0.079,0.060]				[-0.062,0.054]	
β_5	-0.024	-0.022			-0.026	-0.029			-0.020	-0.022		
	(0.039)	(0.039)			(0.036)	(0.035)			(0.030)	(0.028)		
β_{ECB}			**-0.166***	**-0.170****			**-0.156***	**-0.158****			**-0.143****	**-0.143****
			(0.089)	**(0.079)**			**(0.081)**	**(0.069)**			**(0.067)**	**(0.060)**
			[-0.340,0.011]				**[-0.315,0.004]**				**[-0.276,-0.010]**	
β_{NO}			0.011	0.010			0.005	0.001			0.009	0.006
			(0.043)	(0.044)			(0.040)	(0.041)			(0.033)	(0.032)
			[-0.074,0.096]				[-0.073,0.082]				[-0.055,0.074]	
α_0		0.264***		0.260***		0.220***		0.220***		0.167***		0.168***
		(0.010)		(0.010)		(0.009)		(0.009)		(0.006)		(0.006)
α_1		0.119***		0.118***		0.115***		0.112***		0.029		0.025
		(0.038)		(0.037)		(0.035)		(0.035)		(0.031)		(0.030)
α_{ECB}				0.102				0.117				0.060
				(0.078)				(0.072)				(0.069)
R^2	0.003	0.003	0.006	0.006	0.001	0.001	0.005	0.005	0.002	0.002	0.006	0.006
$Q(4)$	5.230	4.265	5.238	4.329	4.822	4.492	4.798	4.498	5.225	5.218	5.067	5.051
	(0.265)	(0.371)	(0.264)	(0.363)	(0.306)	(0.343)	(0.309)	(0.343)	(0.265)	(0.266)	(0.280)	(0.282)
$ARCH(4)$	13.916	0.143	13.679	0.170	8.967	0.158	8.640	0.172	0.267	0.032	0.160	0.031
	(0.000)	(0.705)	(0.000)	(0.681)	(0.003)	(0.692)	(0.003)	(0.679)	(0.605)	(0.859)	(0.690)	(0.860)

Note: The distribution and sample statistics of the bootstrapped betas and respective standard errors are asymptotically coverage to values achieved through OLS estimation. The results of this exercise are presented in appendix C3.

Empirical findings in this section demonstrate the existence of a highly significant and negative return effect on Friday trading days conditional on a prevailing Thursday scheduled ECB policy decision announcement. This conditional Friday effect is orders of magnitude more negative than any average return observed on all other unconditional days-of-the-week under scrutiny. This conditional day-of-the-week effect is consistent for multiple definitions of the trading day, including full 24-hour trading days, European and US combined opening hours and European afternoons. Further, there is no evidence of any unconditional day-of-the-week effect for EUR/USD currency market.

4.5.3 Trading the Conditional Friday Effect

The empirical findings presented in the previous section show that the Euro consistently depreciates against the U.S Dollar on Fridays following the ECB's regular monetary policy announcement. Such negative returns are observable and thus have been apparent to traders/investors for, at least the duration of the sample under scrutiny.

Thus, it could be possible in principle to reap significant profits with a simple trading strategy of selling the Euro against the U.S Dollar on the Friday following the ECB's policy announcement and closing out the position prior market close. This section evaluates such a trading strategy and compares it with equivalent short positions taken on all non-ECB Fridays and all other days.

Table 4.5 presents evaluation of the profits earned (in percentage points) from this simple trading rule. The trading day examined is define as a full 24 hour period between 2300 CET on date *t-1* to 2300 CET on date *t*, a 15-hour trading window from 0800 CET to 2300 CET on date *t* and a 11-hour trading window from 1200 CET to 2300 CET on date *t*.

The figures reported are the annualised percentage profit and relative Sharpe ratio. Average annualised profits (*Annual P*) are computed by summing the daily profits for the specified days and dividing by the total number of years. The annualised Sharpe ratio (SR_{TS}) is calculated as $SR_{TS} = (R_{TS} - r_f/\sigma_{TS}) \times \sqrt{K}$, where R_{TS} is the average 24, 15, or 11-hour return on the trading strategy, r_f is the appropriate risk-free rate for the same period and σ_{TS} is the respective standard deviation. The Sharpe ratio is multiplied by $\sqrt{K}$ to annualise the result, where K is the number of times that particular trading strategy would be executed per year.

I first focus on the profitability of the trading rule for a 24-hour holding period, the results for which are presented in the first panel of the table. Consistent with parametric results the mean percentage profit on taking short position in the EUR/USD on ECB Fridays is positive and relatively large. Conversely, the mean percentage profits for the same trading rule is negative and relatively small for all other days and non-ECB Fridays.

The average annual profit and Sharpe ratio are highlighted in bold and show that trading on this basic rule for 10 days per year would generate average annualised returns of approximately 185 basis points for the entire sample duration. Conversely shorting the EUR on all other Fridays would generate an average annualised loss.

Table 4.5

This table provides statistical assessment of the profitability (in percentage points) of a trading rule defined as selling the EUR/USD and reversing the trade at the end of the defined trading day. Trading days are specified as from 2300 CET on date $t-1$ to 2300 CET on date t, (first panel), from 0800 CET on date t to 2300 CET on the same date (second panel) and from 1200 CET on date t to 2300 CET on the same date (third panel). The sample period is from January 01, 2011 to November 20, 2015. In order to account for the effect of tight and loose monetary policies the sample is partitioned into the periods from January 01, 2011 through October 20, 2011 and from October 21, 2011 through November 20, 2015 respectively, so that each partition contains 10 and 40 ECB announcements respectively. Average annualised profits (*Annual P*) are computed by summing the daily profits for the specified days and dividing by the total number of years. SR_{TS} is the annualised Sharpe ratio of the trading strategy. The profit period for which the summary statistics are calculated are defined in the headings of the upper, mid and bottom panels.

	EUR/USD 2300-2300 CET			**EUR/USD 0800-2300 CET**			**EUR/USD 1200-2300 CET**		
	ECB Fridays	**Other Fridays**	**All other Days**	**ECB Fridays**	**Other Fridays**	**All other Days**	**ECB Fridays**	**Other Fridays**	**All other Days**
Mean	0.190	-0.019	-0.003	0.199	-0.013	0.011	0.161	-0.025	-0.001
St. Dev.	0.746	0.561	0.578	0.701	0.502	0.526	0.534	0.456	0.436
Annual P	**1.857**	**-0.737**	**-0.477**	**1.944**	**-0.500**	**2.203**	**1.573**	**-0.974**	**-0.201**
SR_{TS}	**1.769**	**-0.468**	**-0.132**	**1.970**	**-0.355**	**0.667**	**2.091**	**-0.760**	**-0.073**
Obs.	50	191	955	50	191	955	50	191	955
	EUR/USD 2300-2300 CET (Tightening)			**EUR/USD 0800-2300 CET (Tightening)**			**EUR/USD 1200-2300 CET (Tightening)**		
Mean	0.283	-0.037	-0.054	0.364	-0.022	-0.030	0.230	-0.078	-0.016
St. Dev.	1.107	0.740	0.700	0.984	0.639	0.641	0.705	0.594	0.544
Annual P	**3.141**	**-1.278**	**-9.973**	**4.045**	**-0.745**	**-5.604**	**2.557**	**-2.694**	**-2.948**
SR_{TS}	**0.808**	**-0.279**	**-0.992**	**1.170**	**-0.189**	**-0.609**	**1.032**	**-0.733**	**-0.377**
Obs.	10	31	167	10	31	167	10	31	167
	EUR/USD 2300-2300 CET (Easing)			**EUR/USD 0800-2300 CET (Easing)**			**EUR/USD 1200-2300 CET (Easing)**		
Mean	0.166	-0.016	0.008	0.156	-0.011	0.020	0.143	-0.015	0.002
St. Dev.	0.637	0.522	0.549	0.616	0.473	0.498	0.490	0.426	0.410
Annual P	**1.570**	**-0.616**	**1.648**	**1.474**	**-0.444**	**3.951**	**1.352**	**-0.588**	**0.415**
SR_{TS}	**1.608**	**-0.375**	**0.430**	**1.560**	**-0.299**	**1.136**	**1.801**	**-0.439**	**0.145**
Obs.	40	160	788	40	160	788	40	160	788

Note: The annualised Sharpe ratio (SR_{TS}) is calculated as $SR_{TS} = (R_{TS} - r_f/\sigma_{TS}) \times \sqrt{K}$, where R_{TS} is the average 24, 15, or 11-hour return on the trading strategy, r_f is the appropriate risk-free rate for the same period and σ_{TS} is the respective standard deviation. I multiply the Sharpe ratio by $\sqrt{K}$ to annualise the result, where K is the number of times that particular trading strategy would be executed per year.

This is also true for shorting the currency on all other days throughout the sample. Further, the annualised Sharpe ratio of the trading rule is over 1.76, which shows that on a risk adjusted basis, the trading rule far outperforms shorting the EUR or holding the USD on all other days/all other Fridays. In fact, the risk-adjusted performance of this trading rule is far greater than holding the DAX index over the same period (Annualised Sharpe ratio of 0.152).

When the sample is split to account for the ECB's policy stance the profitability of the trading rule increases on an annualised basis for the tightening cycle, at over 314 basis points, but is slightly lower at over 157 basis points during the easing period. This shows that the results are somehow independent from the monetary regimes, since standard economic theory would suggest instead that annual profits should be smaller under tightening regimes.

The risk-adjusted performance of the trading rule is lower during the tightening cycle due to higher levels of volatility, with a Sharpe ratio of over 0.8. During the easing cycle, the Sharpe ratio is similar to that calculated for the full sample. The strategy outperforms shorting the EUR on all other days during the easing cycle on a risk adjusted basis and produces similar annualised profits, but with only 40 trades versus 788. During the tightening cycle the trading rule is only marginally outperformed on a risk adjusted basis by holding the USD on all other days (Sharpe ration of 0.99), however this would involve trading for 167 days versus only 10 days shorting the EUR.

The second and third panel set out the same statistics for two alternative trading windows. Panel 2, is the 'European Trading day which is calculated from 0800 CET – 2300 CET. The latter panel refers to the trading day 1200 CET – 2300 CET and therefore to the profitability of the trading strategy tailored around afternoon only (U.S market hours) trading hours. It is worth noting that transaction costs are ignored in the above calculations due to the possible inaccuracy of pinpointing an acceptable rate. However, given the relatively small number of trades required per year to profit from this trade it is fair to state that the impact of transaction cost would pale in comparison to the large profit potential.

Results show that the trading rule would be most successful when implemented from the European open (0800 CET) to market close on ECB Fridays. The annualised average percentage profit would be in excess of 194 basis points. This is higher than the profit, which could be achieved for a full 24-hour window and for those found by implementing the strategy on afternoons only. The risk-adjusted performance of the strategy is also higher when implemented for a European trading day on ECB Fridays versus a 24-hour window due to lower

levels of volatility. However, the risk-adjusted performance of the trading rule is greater still when implemented during afternoon trading windows due to even lower levels of volatility.

4.6 Explanations for the ECB conditional Friday Effect

The ECB conditional Friday effect appears to be an asset-pricing anomaly when standard financial economic theory is applied. In this section, a number of possible explanations are explored to find a conceivable economic reason behind this conditional return effect. The final discussion (3.3) outlines the one favoured by the authors as the most intuitive.

4.6.1 Public Information Announcements

The initial intuition is that such a uniform post-ECB negative drift must be a result of similarly relevant and new, public information arrival. However, scheduled public information events observed on days following scheduled ECB announcements are heterogeneous in terms of macroeconomic data type and report both Euro negative and positive information. This heterogeneity in public information type and outcome, along with the absence of large outliers in the data, initially indicates that the post-ECB drift cannot be explained with new scheduled public information flows. Further, it is noteworthy that the post-ECB Friday selloff in the EUR/USD appears to take place after, but not dependant on the announcement of major U.S macroeconomic data (see Figure 4.3). This may suggest that the drift is not due to the information content delivered by the schedule macro news, but rather by the lack of market direction altering data. Overall, the anomalous price formation process found, appears to be conditional on the prevailing ECB announcement and specific to Friday afternoons. It is not, however, a direct result of new scheduled public information arrival.

4.6.2 Friday Afternoon Order Flows

A second possible explanation for the ECB conditional Friday effect is provided by the market microstructure literature. Market volume and order flows are found to be many times higher for numerous asset classes across multiple international markets during Friday afternoon/evening trading hours (see, among others, Breedon and Ralando (2013)). The practical explanation for this observation is the liquidation of short-term positions executed by day traders as well as the closing of order books for market makers. It would be reasonable to argue that such liquidations and closing of positions is more uniform following a large-scale market information event such as the prevailing ECB announcement. However, the positions held following largely dovish ECB announcement event are likely to be short positions, the profit taking from which is likely to cause a short covering spike in the EUR/USD exchange rate rather than the large negative drift observed in the data under scrutiny. Nonetheless, the structural requirements of large

brokerage houses and their resultant order flows following a large scale market event may be an influential factor in the post-ECB Friday price formation process.

4.6.3 Risk Weighted Weekend Liquidation

The most intuitively persuasive reason for the ECB conditional Friday effect is simply a risk-weighted liquidation of long positions in the Euro prior to Friday market close. The intuition being that traders, cautious of weekend news relating to an already dovish ECB during a predominantly loose monetary policy cycle, would not be willing to stay long the currency over the weekend following ECB announcements. This argument appears to be the most robust given that ECB conditional Friday negative drift is not observed when the ECB announcement falls on a Wednesday. This is compounded by the fact that GC members, in contrast to the pre-announcement silence, often give interviews and comments to market agents and the world press following ECB announcements (Faturn and Hutchinson (2002)). Such interviews are rarely in decent of the ECB's policy stance. Should the *prior* updating process on aggregate, result in a significant enough change to the weighted average valuation that market agents place on the EUR/USD, then a price formation process should be observable. It would be fair to suggest that in a predominantly dovish policy period the overall weighted average valuation of the market should be negatively skewed. Therefore, a lack of market altering information content during the scheduled U.S data points may form part of the updating process of traders' *prior* expectation.

Further, the market structural influences on Fridays differ from other days of the week in the currency market. New information emerging from GC members during weekend press interactions are likely to weigh on the average valuation of the market based on the arguments made above, however only incorporate into price at market open Sunday evening. The result being a 'gap lower' in the market, potentially circumventing stops place by those holding long positions. The potential loss from such a structural event could be large for market agents; as a result the structural risk should be priced.

A further institutional factor may be compounding the risk weighted post-ECB Friday liquidation. Large institutions such as pension funds react slower to large scale/scope public information events. Decisions such as currency hedging and reallocation face pre-mandated scrutiny, which can be a relatively slow process. These institutions may be expected to execute such decisions days following the ECB's dovish policy and forward guidance announcements. The anticipation of large EUR negative order flows potentially leading the market, at Monday

open could form part of the expectation updating process for Friday afternoon traders. Thus, plausibly forming part of the risk adjusted liquidation.

However, the strength of this argument is very much linked to the intuition underpinning rational risk-adjusted investor/trader behaviour. Thus, the ECB conditional Friday effect is in part a pricing puzzle worthy of further investigation.

4.7 Conclusion

This chapter identifies a day-of-the-week effect conditional on a prevailing European Central bank policy announcement. There is a large, significant and persistently observable negative drift in the EUR/USD exchange rate on Fridays, which follow scheduled policy meetings, from January 01, 2011 through November 20, 2015. This conditional DoW effect has not been identified by previous studies in the literature.

Empirical results show that following scheduled ECB policy announcements, specifically 24-hours following the announcement the EUR/USD exchange rate drifts lower. This drift is statistically significant, but only on Fridays following scheduled ECB policy announcements, whereas the same drift becomes not statistically significant when the day following the ECB announcement is a Thursday. The negative Friday afternoon drift is not observable for all other Fridays or any other day. This price formation process is therefore named the *'ECB conditional Friday effect'*.

DoW average returns on the EUR/USD during Friday trading hours following ECB announcements are over 17 basis points lower than all other days for a 5-year sample period. Moreover, when compared to all other Fridays in sample, average returns are over 19 basis points lower. When the 5-year sample is split to account for the ECB's policy stance, findings show that the ECB conditional Friday effect is significant only during policy easing periods. It is worthy of note however, that during tightening periods a negative drift is observable but not statistically significant.

The economic significance of these results is apparent when the profit potential of trading rules tailored around the "ECB Fridays effect". A simple trading strategy of selling the EUR/USD on 10 Fridays per year and buying back at market close, following ECB announcements, during policy easing periods, is calculated to yield annualised returns of over 135 basis points. The annualised Sharpe ratio, a measure of the risk-weighted profitability on such a trading strategy, is 1.8. This is notably greater than the 0.14 annualised Sharpe ratio for remaining short the currency during all other days of the easing period.

I explore a number of explanations based on economic theory for this novel price formation process. The most plausible economic argument for such price formation mechanism draws on the idea of Bayesian *prior* expectation updating. Market agents, aware of the ECB's accommodative policy stance, update their expectations of potential weekend information flows from GC members. The price formation process resulting from the *prior* updating process appears to be independent of any macroeconomic information arrival. This updating process

can be defined as the ‘pricing in’ of weekend information risk, taking place only on Fridays due the structural properties of the market.

Appendix C

Appendix C1

Dates and outcomes of the ECB's scheduled GC meetings for the period January 13, 2011 - November 20, 2015. The second column indicates on which day of the week the scheduled announcement took place. The third column shows the key interest rate set by the GC. The tightening cycle is defined as that up to October 20, 2011 and the easing sample from October 21, 2011 through November 20, 2015.

Scheduled Date	Day of the Week	Benchmark Interest Rate	Monetary Policy Decision
January 13, 2011	Thursday	1.00	No Change
February 3, 2011	Thursday	1.00	No Change
March 3, 2011	Thursday	1.00	No Change
April 7, 2011	Thursday	1.25	Increased 25 basis points
May 5, 2011	Thursday	1.25	No Change
June 9, 2011	Thursday	1.25	No Change
July 7, 2011	Thursday	1.50	Increased 25 basis points
August 4, 2011	Thursday	1.50	No Change
September 8, 2011	Thursday	1.50	No Change
October 6, 2011	Thursday	1.50	No Change
November 3, 2011	Thursday	1.25	Decreased 25 basis points
December 8, 2011	Thursday	1.00	Decreased 25 basis points
January 12, 2012	Thursday	1.00	No Change
February 9, 2012	Thursday	1.00	No Change
March 8, 2012	Thursday	1.00	No Change
April 4, 2012	Wednesday	1.00	No Change
May 3, 2012	Thursday	1.00	No Change
June 6, 2012	Wednesday	1.00	No Change
July 5, 2012	Thursday	0.75	Decreased 25 basis points
August 2, 2012	Thursday	0.75	No Change
September 6, 2012	Thursday	0.75	No Change
October 4, 2012	Thursday	0.75	No Change
November 8, 2012	Thursday	0.75	No Change
December 6, 2012	Thursday	0.75	No Change
January 10, 2013	Thursday	0.75	No Change
February 7, 2013	Thursday	0.75	No Change
March 7, 2013	Thursday	0.75	No Change
April 4, 2013	Thursday	0.75	No Change
May 2, 2013	Thursday	0.50	Decreased 25 basis points
June 6, 2013	Thursday	0.50	No Change
July 4, 2013	Thursday	0.50	No Change
August 1, 2013	Thursday	0.50	No Change
September 5, 2013	Thursday	0.50	No Change
October 2, 2013	Wednesday	0.50	No Change
November 7, 2013	Thursday	0.25	Decreased 25 basis points
December 5, 2013	Thursday	0.25	No Change
January 9, 2014	Thursday	0.25	No Change
February 6, 2014	Thursday	0.25	No Change
March 6, 2014	Thursday	0.25	No Change
April 3, 2014	Thursday	0.25	No Change
May 8, 2014	Thursday	0.25	No Change
June 5, 2014	Thursday	0.15	Decreased 10 basis points
July 3, 2014	Thursday	0.15	No Change
August 7, 2014	Thursday	0.15	No Change
September 4, 2014	Thursday	0.05	Decreased 10 basis points
October 2, 2014	Thursday	0.05	No Change
November 6, 2014	Thursday	0.05	No Change
December 4, 2014	Thursday	0.05	No Change
January 22, 2015	Thursday	0.05	No Change
March 5, 2015	Thursday	0.05	No Change
April 15, 2015	Wednesday	0.05	No Change
June 3, 2015	Wednesday	0.05	No Change
July 16, 2015	Thursday	0.05	No Change
September 3, 2015	Thursday	0.05	No Change
October 22, 2015	Thursday	0.05	No Change

Appendix C2

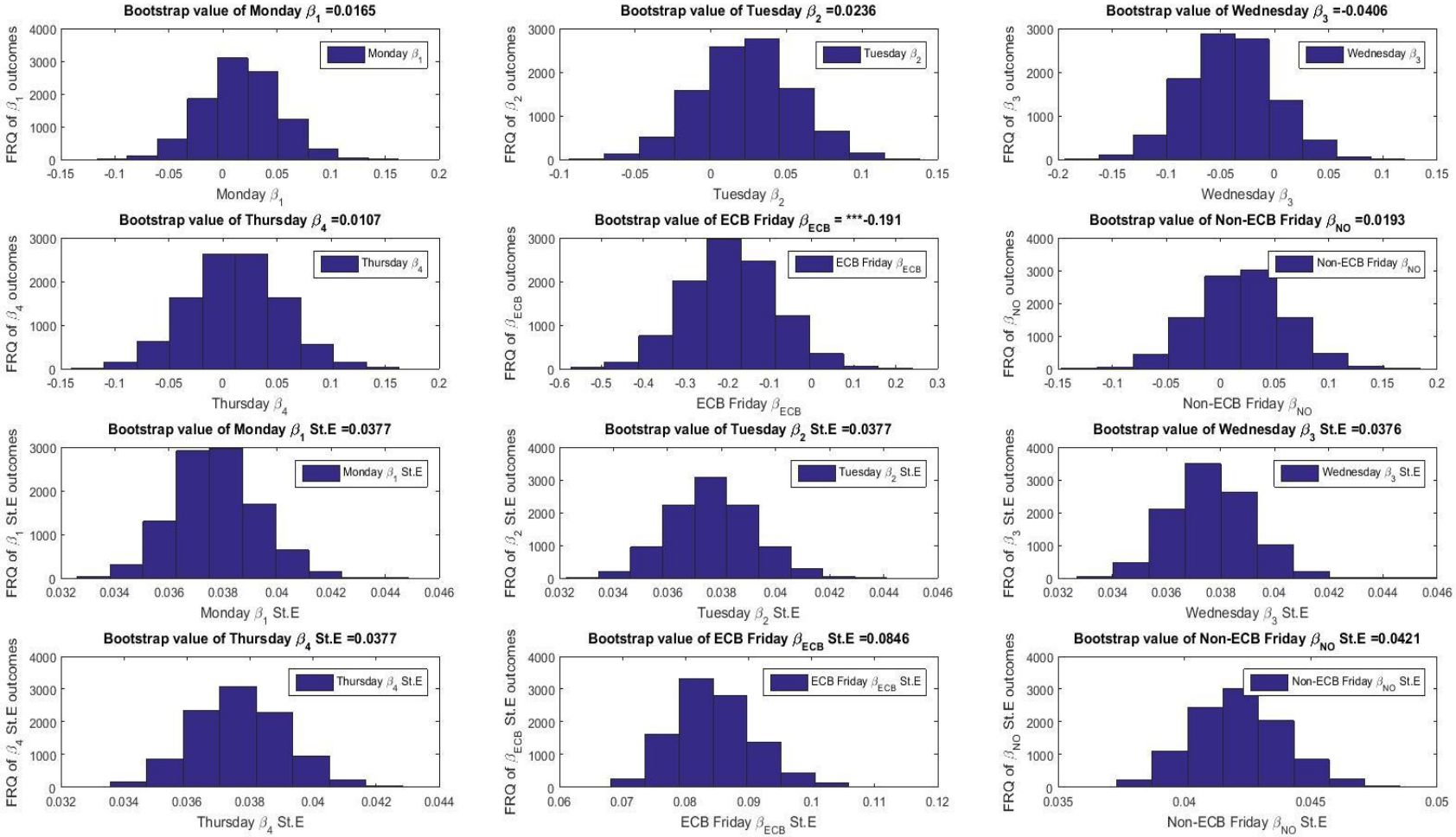
The table below reports details of scheduled major macroeconomic data announcements, which occur during relevant post-ECB trading windows. Reported outcome and details of analyst forecasts are obtained from Bloomberg.

Date	Outcome	Median Forecast	Maximum Forecast	Minimum Forecast	Above/Below
ECB Friday with U.S Employment Report					
03/12/2010	103	150	240	98	-47
04/02/2011	192	196	297	100	-4
04/03/2011	216	190	295	150	26
06/05/2011	54	165	250	65	-111
08/07/2011	117	85	150	0	32
05/08/2011	0	68	160	-20	-68
07/10/2011	80	95	150	50	-15
04/11/2011	120	125	175	75	-5
09/03/2012	120	205	250	175	-85
04/05/2012	69	150	195	75	-81
06/07/2012	163	100	165	50	63
03/08/2012	96	130	185	70	-34
07/09/2012	114	115	165	60	-1
05/10/2012	171	125	154	30	46
07/12/2012	155	152	305	80	3
08/03/2013	88	190	366	100	-102
05/04/2013	165	140	238	100	25
03/05/2013	175	163	290	80	12
07/06/2013	195	166	220	77	29
05/07/2013	162	185	225	23	-23
02/08/2013	169	180	220	79	-11
06/09/2013	148	180	256	100	-32
08/11/2013	203	185	230	115	18
06/12/2013	74	197	250	100	-123
10/01/2014	113	180	270	105	-67
07/02/2014	175	149	220	100	26
07/03/2014	192	200	275	150	-8
04/04/2014	288	218	292	155	70
06/06/2014	288	215	290	145	73
05/09/2014	248	215	265	155	33
03/10/2014	214	235	314	140	-21
07/11/2014	321	230	306	140	91
05/12/2014	252	240	305	160	12
06/03/2015	126	245	300	179	-119
04/09/2015	142	200	256	75	-58
ECB Friday U.S Inflation Report					
14/01/2011	0.4	0.3	0.5	0.2	0.1
17/07/2015	0.1	0.2	0.3	-0.1	-0.1
ECB Friday U.S Retail Sales					
14/01/2011	0.3	0.5	1.1	-0.5	-0.2
ECB Fridays Euro-Zone Inflation Report					
14/01/2011	2.4	2.3	2.5	2.2	0.1
ECB Friday Euro-Zone GDP					
10/01/2014	0.9	0.9	1	0.8	0
05/09/2014	0.8	0.8	0.8	0.8	0
05/12/2014	0.9	0.9	0.9	0.9	0
06/03/2015	1	1	1.4	1	0

Appendix C3

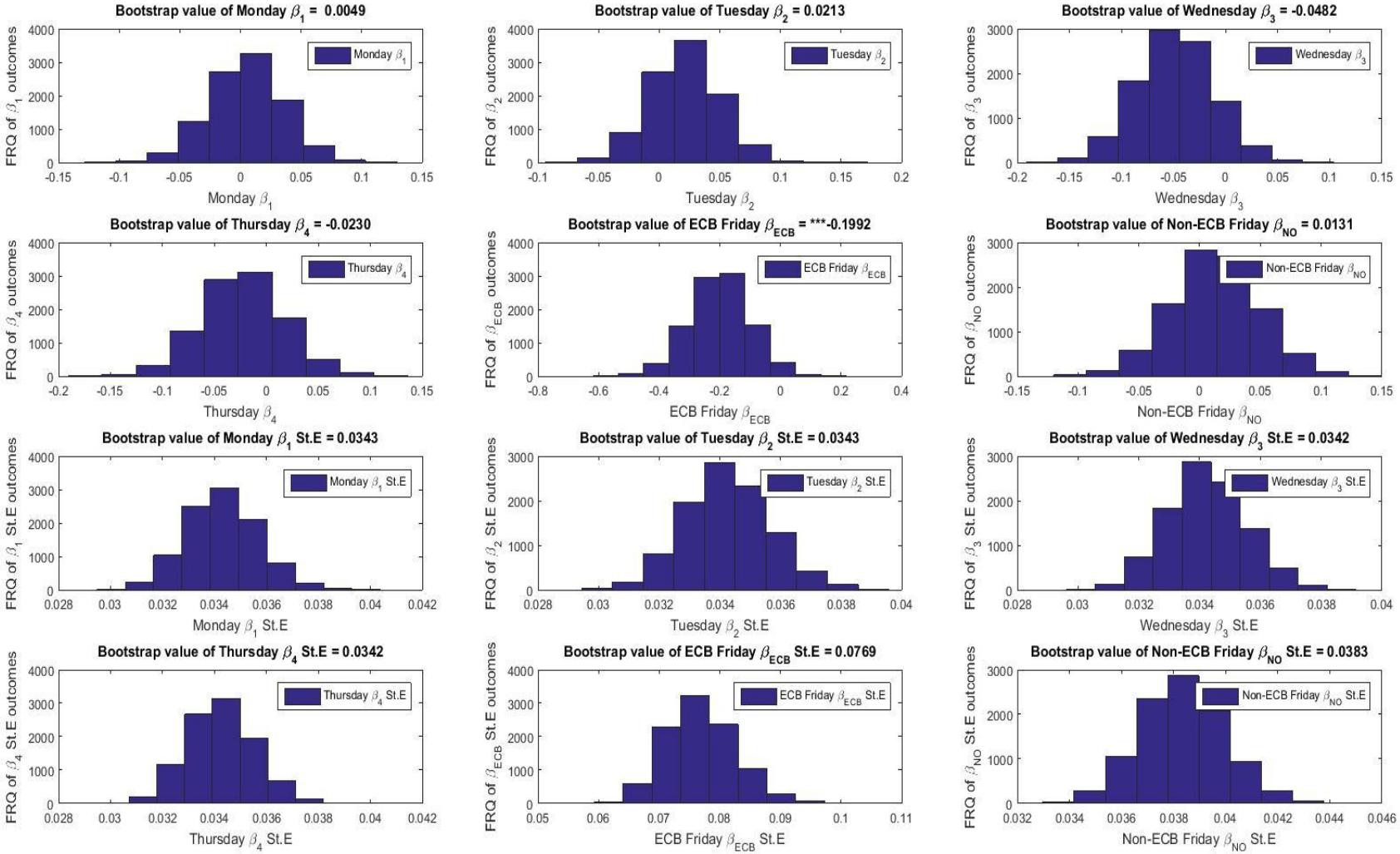
Appendix C3

The figure below reports bootstrapped regression coefficients and standard errors for the OLS estimation of equation (4.2). The dependant variable from which the initial model is estimated is the return (R_t) on the EUR/USD from 2300 CET on date $t-1$ to 2300 CET on the date t. The sample period is from January 01, 2011 to November 20, 2015. For subsample results, please contact the authors.



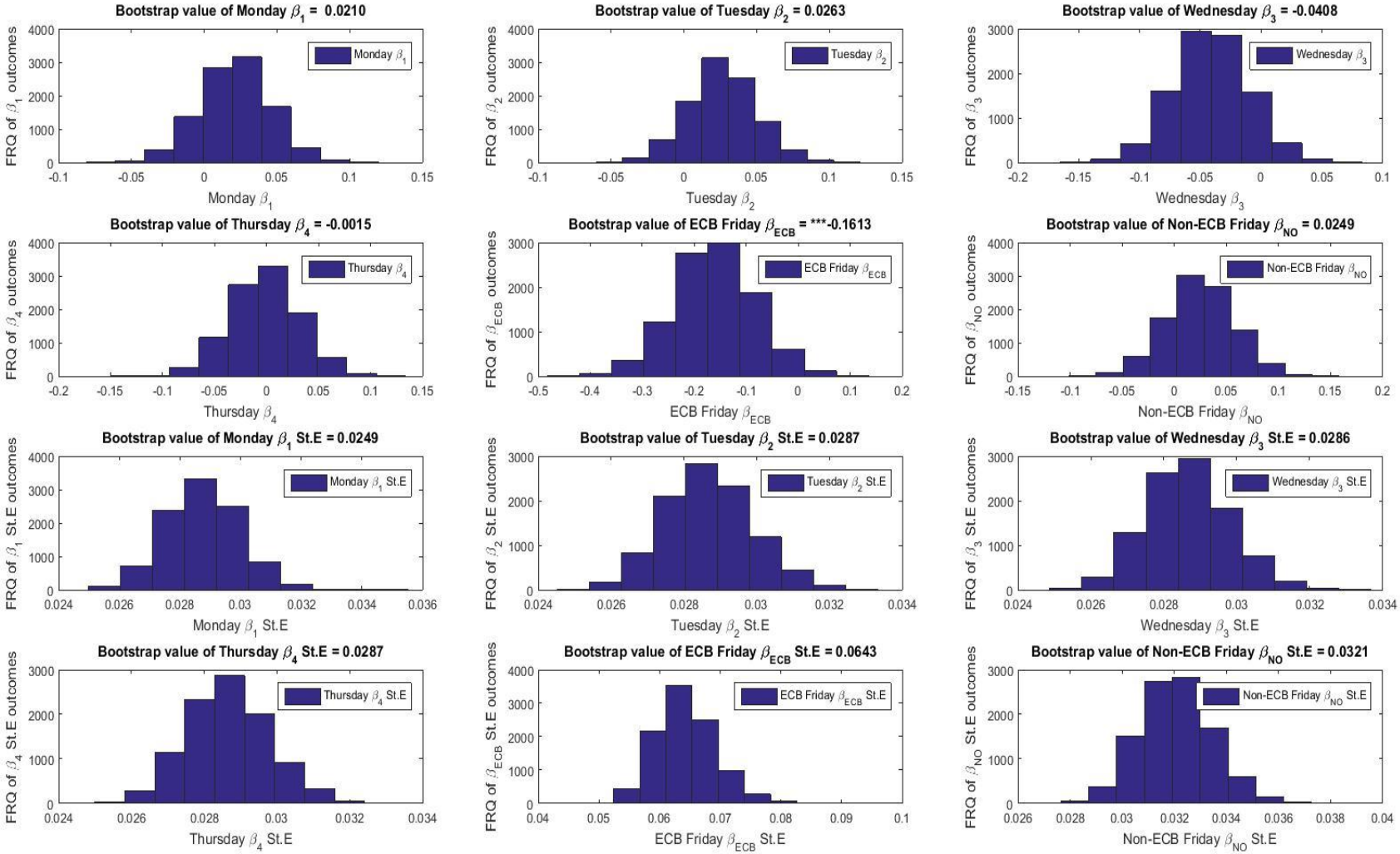
Appendix C3

The figure below reports bootstrapped regression coefficients and standard errors for the OLS estimation of equation (4.2). The dependant variable from which the initial model is estimated is the return (R_t) on the EUR/USD from 0800 CET on date t to 2300 CET on the same date. The sample period is from January 01, 2011 to November 20, 2015. For subsample results, please contact the authors.



Appendix C3

The figure below reports bootstrapped regression coefficients and standard errors for the OLS estimation of equation (4.2). The dependant variable from which the initial model is estimated is the return (R_t) on the EUR/USD from 1200 CET on date t to 2300 CET on the same date. The sample period is from January 01, 2011 to November 20, 2015. For subsample results, please contact the authors.



Chapter 5. Conclusion

The central aim of this thesis is to improve the understanding within the financial economics literature of some of the most puzzling financial market price formation processes. The thesis does this by identifying a specific information set relevant to a complete price discovery process discerned by market agents but previously unaccounted for by researchers. Empirical results provide quite clear cut evidence that this information set can explain a sizeable share of absolute volatility for high frequency 1-minute financial series and daily excess stock market returns. The implication of the findings presented in this thesis is that price formation processes, previously identified as puzzles, are more likely price discovery processes for which information flows have not previously been observable to academics due to a lack of archived unregulated public market relevant information.

The thesis addresses the EMH in its strongest form as an economic principle. The EMH contends that for markets to be deemed efficient all new market relevant information private and public about the past, present or future must be priced. Crucially, this assertion indicates that information about the future information events must be priced. This includes best estimates of scheduled public information events. The thesis posits that if information exists which sufficiently changes these best estimates, then a price discovery process previously undetected by the literature occurs.

The central hypothesis of this thesis addresses the price formation process which takes place due to the arrival of unconventional (at least at the time of writing) information usable by market participants, yet not fully considered by financial economists. Such information, by nature is not strictly identifiable as regulates public information, but has the ability to change the '*priors'* held by market participants. This information can change the weighted average expectations market agents hold about the scale, timing and probability of future scheduled public information outcomes. Given that aggregate expectations of a future scheduled public information event, large enough in scope, change, then the fundamental valuation of a market traded asset must also change. And, a price formation process will be observed.

The thesis identifies market relevant information; not private but also not public in the regulatory sense. That is, it is not published and/or archived by mandated outlets such as Bloomberg or Reuters. This information consists of market rumour. The rumours considered in this thesis are relevant to upcoming large scope macroeconomic information events. Such macroeconomic information flows have not in the past been considered in literature as elements

of an intact price discovery process. These rumours are essentially chatter, broadcast by market agents and commentators on the microblogging website Twitter.com. The information is therefore public and archived, timestamped and fully observable to both academics and market agents. It is worth noting that market rumours are not necessarily fundamental to the valuation process, however, if market participants believe that rumours can change market consensus, therefore price, then it is rational for the profit motive to exploit this.

In chapter 2 a database of rumours pertaining to forthcoming scheduled ECB policy announcements is formed. For a 420-day trading period in the EUR/USD, 63 rumours are observed which gain significant traction and are widely broadcast on Twitter. The rumours are timestamped to within 1-minute accuracy of first broadcast. To test the price effect of these rumours, 1-minute intraday observations EUR/USD exchange rate are utilised. Accounting for intraday periodicity with a Flexible Fourier form regression and the arrival of other scheduled (regulated) public information flows, findings show that 25 of 63 rumour events result in a significant instantaneous jump in volatility. This rumour driven volatility is persistent for a further 60 minutes. The arrival of a rumour is found to increase excess volatility by up to 211%. Further, the resultant volatility persistence of the rumour event increases hourly volatility by as much as 2614%. While the FFF regression suffers from some potential weaknesses, the extensive use of the model in the intraday price discovery literature and Monte Carlo robustness exercise carried out in this thesis show that it is fit for purpose.

This chapter in effect confirms the central hypothesis of this thesis; that market relevant information, in the form of market rumour, exists and is discerned by market agents. That such information relating to a future large scope macroeconomic information event can alter the aggregate expectation of the scale, timing and probability of its outcome. And, that this change in the aggregate expectation results in a price formation process. The fundamental economics underpinning this price formation process are based on entrenched theories of market informational efficiency and investor rational expectations hypothesis. The rumour conditional price formation process can therefore be deemed an intact price discovery process, necessary for a functional financial market.

Chapter 2 sets out to identify *'prior'* altering information flows which may have previously gone undetected and test whether such information flows result in a price formation process. Empirical results show that large scale currency market volatility occurs at the time of rumours broadcast and persists for some time, thereby confirming the central hypothesis of the chapter.

Chapter 3 investigates the central hypothesis of this thesis by focussing on a well-documented price formation puzzle. The pre-announcement window of scheduled central bank policy releases have been observed in literature to contain significant increases in price activity in the absence of new information. Such a price formation puzzle has been shown to contribute significantly to the overall level of excess returns in stock markets by Lucca and Moench (2015), thus posing a significant question over the informational efficiency of the relevant stock market.

The chapter asserted that a Bayesian updating process of traders' *prior* expectations is taking place in the pre-announcement window prior to large scope macroeconomic news events. Such updating is posited to be as a result of new information, perhaps public, which has been detected by market agents but not by academics. Should the content of such information change the weighted average expectation of market agents, about the scale, probability or timing about the forthcoming large scope central bank announcement, then pre-announcement price formation process should be observable.

Empirical findings in this chapter show that a pre-ECB announcement price formation process exists. Average excess returns earned on the DAX are in excess of 49 basis points for 50, 24-hour pre-announcements windows tested. However, when the 50 pre-announcement windows are categorise to account for observations of rumours, no price formation process is observable in the absence of rumours. Average excess returns earned during 24-hour pre-ECB windows where rumours are observed (30) are 80 basis points higher than all other days and statistically significant. Whereas, average excess returns for pre-ECB windows absent of rumours, are statistically insignificant. To quantify the economic significance of the rumour driven pre-ECB price discovery process; the excess returns on the DAX in the 24-hour pre-ECB window are tantamount to almost 60% of the annualised total excess returns on the DAX for the full sample period. The annualised Sharpe ratio of trading the ECB rumour and selling prior the announcement is 2.04. This is compared to 1.47 for simply buying the 24-hour pre-announcement period and 0.15 for holding the DAX for all other days of the year.

Solving such a large and puzzling price formation process using the central hypothesis of this thesis demonstrate its power as a theory of economics. Further price discovery processes such as the one identified in chapter 3, previously mischaracterised as price formation puzzles undoubtedly exist. Significantly, the application of the hypothesis developed in this thesis and

the rumour data source identified here, could solve a large number of financial economic puzzles.

Chapter 4 shows that such unresolved price formation processes exist with the discovery of a conditional day-of-the-week effect previously not documented in the literature.

Empirical results presented in this chapter show that 24 hours following scheduled ECB policy announcements the EUR/USD exchange rate drifts lower. This drift is statistically significant, but only on Fridays following scheduled ECB policy announcements. The post-ECB negative drift is not statistically significant when the day following the ECB announcement is a Thursday. The negative Friday afternoon drift is not observable for all other Fridays or any other day. This price formation process is therefore named the *'ECB conditional Friday effect'*.

A simple day-of-the-week effect model, standard in the literature, is used to test the existence of the ECB conditional Friday effect. Findings show that average excess returns on the EUR/USD during Friday trading hours following ECB announcements are over 17 basis points lower than all other days for a 5 year sample period. When the 5 year sample is split to account for the ECB's policy stance, findings show that the ECB conditional Friday effect is significant only during policy easing periods. It is worthy of note however, that during tightening periods a negative drift is observable but not statistically significant.

A simple trading strategy of selling the EUR/USD on 10 Fridays per year and buying back at market close, following ECB announcements, during policy easing periods, is calculated to generate annualised returns of over 135 basis points. The annualised Sharpe ratio, a measure of the risk weighted profitability on such a trading strategy, is 1.8. This is notably greater than the 0.14 annualised Sharpe ratio for remaining short the currency during all other days of the easing period.

The most plausible economic argument for this price formation process is determined to be one involving the Bayesian *prior* expectation updating information process defined in chapter 2 and observed in chapter 3. Market agents, aware of the ECB's accommodative policy stance update their expectations of potential weekend information flows from Governing Council members. The price formation resulting from this updating process appears to be taking place significantly after U.S macroeconomic data is accounted for. This updating process is simply defined as the pricing of weekend information risk, taking place only on Fridays due market structural properties of weekend trading.

The thesis sets out to investigate the price discovery process associated with information flows that can change market participant's prior expectations of future market events. The wider question posed by this thesis is if such information flows have been identified by market agents but not by academics, thereby resulting in observations of unexplained price formation puzzles. The thesis identifies a dataset of such information flows and shows empirically that an associated price formation process can be observed. As a result, price formation puzzles can, at least in part, be solved with the central assertion of this thesis. Although, as shown in chapter 4, further puzzles exist and further information flows are yet to be identified.

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