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High Frequency Analysis of Macro News Releases on the Foreign Exchange Market: A Survey of Literature ☆

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ABSTRACT

Most previous literature focuses on proving market impacts of macro news and price discovery process of the FX market. In general, the literature is divided into two camps. The first one attempts to explain directions of exchange-rate changes (the first moments). The second one attempts to explain exchange rate volatility (the second moments). There are many studies addressing the first camp of research, while there is a limited number of studies addressing the second camp of research. In the future, researchers may further investigate the following issues regarding the release of macro news: (a) their impacts on FX volatility; (b) their impacts on FX derivatives; (c) profitability of trading strategies arising from news releases; (d) price patterns associated with selected news announcements, non-scheduled news and selected headline news; and (e) machine learning on the impacts with advanced computer technologies.

1. Introduction

Asset prices are affected by arrivals of new information. This is one of the accepted cornerstones of modern finance theory and provides a foundation for a rich literature on the role of information in financial markets [1,19]. One stream of the literature focuses on effects of macroeconomic data announcements on various markets including equities, bonds, and currencies. Macroeconomic data announcements are always used to test market efficiency and rational expectations hypotheses and, more recently, to investigate the microstructure of financial markets and the role of information in the formation of asset prices. Many related studies confirm that macroeconomic data announcements have significant impacts on financial markets, although their impacts vary across markets and types of announcements. There is a growing interest in studying market impacts of economic data releases in the last decade, both among academics and professional market participants. In particular, it interests those monitoring financial markets, such as central banks using asset prices to gauge investors' macroeconomic expectations, and fund managers and traders exploring trading opportunities from prices fluctuations. Among all asset classes, foreign exchange (thereafter "FX') has much stronger association with macroeconomic news announcements than others. One reason is that FX prices are mostly driven by fundamental factors of an economy and economic policies of governments.

This paper aims to survey literature on the impacts of macroeconomic news release on the FX market from both academic and industry participants' point of view. This is the first survey paper on this subject in the FX market. Although Menkhoff [21] provides very good literature review on high-frequency analysis of macro news intervention from mid-1990s to 2008, the paper focuses on the central bank interventions rather than impacts of macro news. Its review covers studies ending in 2008. Almost all the papers we review are published after 2000, especially after the 2008 crisis. The FX market has undergone remarkable changes in its microstructure after the financial crisis in 2008. Our survey on literature after 2008 in this regard can provide researchers up-to-date insights about the subject matter.

There are several fundamental microstructure changes in the FX market after 2008. First, daily trading volume of the FX market has increased substantially from 1.9 trillion USD to 5.3 trillion USD since 2009. Second, many institutional investors now focus on algorithmic trading strategies that rely heavily on big data analysis and/or high-speed trading technologies. A recent survey shown about 48% investment strategies are algorithmic trading strategies. About 30% are traditional discretionary strategies and the last about 22% are purely "buy and hold". Third, with easy access to online trading platforms, retail investors play an increasing role in the FX market. Today around 30% daily volumes come from retail investors who tend to have their investment behavior different from institutional investors. Therefore, research papers before the 2008 crisis may have little reference value to the FX market.

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Both financial news analysis and high frequency trading data analysis are now required to deal with massive amount of both structured and unstructured data on real time basis. Financial news in global media has huge coverage both in depth and breadth included. New publications include online editions of newspapers, journals and trade magazines, specialist financial news sites, trading platforms and blogs. All these mean that investors applying news analytics to enhance returns and to manage risk from systematic or discretionary applications encounter big data issues. Theories and methodologies regarding big data analysis can be intensively applied to research on this subject matter.

Overall speaking, if one wants to study short-horizon price behavior, to conduct big data analysis on the FX market, and to develop algorithmic trading strategies for FX, this literature review will be a good reference. Also, those surveyed findings of this paper can provide researchers insights for future study in big data analysis and financial research.

The remaining of the paper is organized as follows. The next section will review selected research papers one by one in two categories: macro news impact on FX rates only and macro news impact not only on FX rates but also volatility (or volatility only). Contributions and limitations of each paper will be discussed. The last section will provide summary and future research directions. For making easy search and reference, we list all the papers reviewed in Table 1 at the end of this paper, which summarizes more details of the papers, such as data period and frequency, FX pairs, types of news, and models.

2. The literature

As mentioned before, Menkhoff [21] surveys literature on high-frequency analysis of macro news intervention from the mid-1990s to 2008. This paper summarizes evidence for the debate on transmission channels of intervention: the portfolio balance channel and the signaling channel. The signaling channel regards interventions as a tool to signal information to market participants. The volume of government interventions may not matter on price changes. The paper seems to confirm that macro news has greater impact in the FX market than central bank interventions. This paper applies high-frequency data and allows better identification of the impacts from interventions. Intraday data focuses on a narrow time window which may contain less noise. In other words, there may be less influence from other news on exchange rates during the day. Such an approach can mitigate the endogeneity problem of interventions.

This literature has two branches. The first addresses the direction of exchange-rate changes (the first moments) and the second, later branch addresses exchange-rate volatility (the second moments).

2.1. Impacts on FX rates

Andersen, Bollerslev, Diebold and Vega [2] focus mainly on intraday FX prices and studies how fundamental news is incorporated into FX prices. It shows that conditional mean adjustments of exchange rates to news occur quickly, effectively amounting to "jumps," in contrast to conditional variance adjustments, which are much more gradual, and that an announcement's impact depends on its timing relative to other related announcements, and on whether the announcement time is known in advance. It also finds that adjustment responses are characterized by a sign effect: bad news show greater impact than good news. The study provides insights on the association between news announcements, price discovery and asset volatility.

Andersen, Bollerslev, Diebold and Vega [3] further investigate the above-mentioned issues and find that announcement surprises produce conditional mean jumps and supports the argument that high-frequency stock, bond and exchange rate dynamics are all linked to fundamentals. The paper documents highly-significant contemporaneous cross-market and cross-country linkages are not fully explained by the macroeconomic announcement effects by using a "structural GARCH" estimation approach. This paper studies tick-by-tick FX futures return data and estimates a system of equations using the two five-minute returns before each announcement and eighteen five-minute returns in the one-and-a-half-hour immediately following each announcement. Its conclusions are very enlightening because of limited number of research papers studying tick-by-tick data.

Ehrmann and Fratzscher [10] argue that standard or fundamentals-based models of the exchange rate usually have their shortcomings of not studying the true information that market participants get access to and make trading decisions with. This paper analyzes the link between economic fundamentals and exchange rates using a linear regression model. It finds that the importance of US macroeconomic news is partly explained by their earlier release time than that of the news relating to German and euro area. It shows that exchange rates respond more strongly to news in periods of higher market uncertainty and when negative or large shocks occur. Overall, the model of the paper, which is based on real-time data, explains around 75% of monthly directional changes of the USD/EUR exchange rate, although it does not explain adequately the magnitude of the exchange rate returns. This paper differs from others in a way that it does not use high frequency data. It mainly studies daily FX prices. The results may be more valuable to most investors such as mutual funds, pension funds, and retail investors because they mostly do not apply high-frequency trading strategies. The paper provides two reasons why it does not choose high-frequency data but choose daily data. First, there is evidence that some German releases are "leaked" to the markets prior to their official release time. A second reason is that the full reaction of asset prices to news may not occur immediately. For instance, the news may be incorporated gradually into FX prices over subsequent minutes or even hours. This implies that permanent effect of news on exchange rates may be different from initial and immediate price reactions. However, the real-time data model of the paper does a good job in explaining the direction of FX price change but not their magnitude. Their results may be explained by their use of daily data because the biggest jumps always happen right after news releases and the market prices may then revert. With daily data alone, the paper may have missed all the biggest price jumps.

In the period of 2003–2007, trading volume involving algorithmic grows by 60 percent for euro–dollar and dollar–yen trading, and to about 80 percent for euro–yen trading. Strategies designed to automatically react to news and data releases are still underdeveloped in the FX market before 2008. Chaboud, Chiquoine, Hjalmarsson and Vega [8] analyze effects of algorithmic (computer) trades and non-algorithmic (human) trades on the informational efficiency of FX prices. This is the first publicly-known empirical study on this subject in the FX market. Both the reduced-form and structural-form VAR estimations of the paper show that algorithmic trading activity causes a reduction in the number of triangular arbitrage opportunities and foreign exchange price discovery. This result is consistent with the view that algorithmic trading improves informational efficiency by speeding up price discovery, but that, at the same time, it may increase the adverse selection costs to slower traders. The paper also finds evidence that algorithmic traders do not trade with each other as much as a random matching model would predict. This may be due to the fact that many algorithmic trading strategies are highly correlated. Overall speaking, this paper makes remarkable contribution to this research topic and provides useful results and future research directions. However, the paper makes a couple of implausible assumptions

that we would like to discuss. First, traders can enter trading instructions manually, using an EBS keyboard, or, upon approval, via a computer directly interfacing with the system. The type of trader (human or computer) behind each trading instruction is recorded by EBS, allowing for our study. So an implausible assumption has been used in the paper: trades entered by computer directly interfacing (API) are computer automatically generated trades based on algorithms. In reality, it is not always the case. Banks, hedge funds and commodity trading advisors (CTA) could use the computer directly interfaces (API) to develop their own trading platforms, then manually operating by human – their traders, rather than automating in computers. Therefore, from EBS side, even the trades are recorded as from computer directly interfacing, it still could be humans behind them, not computers. There is no easy way to find out whether human or computer behind each trade instruction based solely on EBS records, unless each computer and its interface with user companies are investigated one-by-one. However, most industry participants would like to keep this information confidential. Another issue of the paper is related to its approach to calculate triangular arbitrage opportunities. It uses second-by-second quote data to construct a minute-by-minute measure of the frequency of triangular arbitrage opportunities for each second, and then calculate the maximum profit achievable from a round trip triangular arbitrage trade in either direction, starting with a dollar position. A minute-by-minute measure of the frequency of triangular arbitrage opportunities is then calculated as the number of seconds within each minute with a strictly positive profit. Market slippage and trade execution time have not been considered in the calculation. Quotations are not real trading prices. Even there are opportunities in quotations, it does not mean an opportunity in real transaction, and especially considering the quotation profit is tinny small.

Fatum, Hutchison and Wu [17] investigate the possible asymmetric response of intraday exchange rates (5-minute intraday JPY/USD) to macroeconomic news announcements during a very unusual period – Japan during 1999–2006 when the money market interest rate in Japan was effectively zero. Asymmetric exchange rate responses to news seem to be more likely to appear in economic and institutional settings such as the zero interest rate environment of Japan. When lower interest rates (below zero) are not feasible, endogenous policy reactions to macroeconomic shocks are constrained. Given the close linkages between interest rates and FX prices, these constraints, in turn, are likely to make FX prices respond to news asymmetric. Results show that, for several types of news, FX prices respond asymmetrically and the responses depend on country origin of related news. The paper finds that forward-looking news is especially important when emanating from the country where the monetary authority is restricted in the extent to which it can respond to shocks, even overall Japanese macro news are as important as U.S. macro news in influencing the JPY/USD exchange rate. The results of the paper also provides evidence of asymmetries in the exchange rate response to Japanese news across different Japanese business cycle stages, consistent with the idea that an institutional setting that limits the possibility of endogenous policy responses to news makes asymmetries more likely. Last but not least, the paper finds some evidence of asymmetric effects across positive and negative U.S. news surprises. This finding is not in itself surprising as it is consistent with existing literature on U.S. news and exchange rates. However, in light of its finding that positive–negative asymmetries are not present in the Japanese news even though such asymmetries would seem particularly likely during the zero interest rate period under study, this could indicate that asymmetries in regards to positive versus negative news particularly pertains to U.S. news. Overall this paper illustrates the necessity of taking into account the country of origin of news, business cycle asymmetries, and the direction of news, in order to more accurately assess the intraday exchange rate responses to macroeconomic news surprises.

Among the microstructure determinants of exchange rate, order flow is instrumental in understanding exchange rate behavior and in the microstructure modeling of exchange rate determination. There is increasing evidence to suggest that the relation between exchange rate and its macroeconomic and microstructure determinants is nonlinear and asymmetric. Nguyen and Shin [22] find strong evidence of a nonlinear co-integrating relation between exchange rates and (cumulative) order flows: the price impact of negative order flows (selling pressure) is overwhelmingly stronger than that of the positive ones (buying pressure). Through its dynamic multiplier analysis, the paper finds two typical patterns of the price discovery process. The markets following overreactions tend to display a delayed overshooting and a volatile but faster adjustment towards equilibrium, while the markets following underreactions are generally characterized by a gradual but persistent adjustment. In its model, heterogeneous adjustment patterns reflect different liquidity provisions associated with different market conditions following under- and overreactions. It shows that the larger the mispricing, the faster the overall adjustment speed. The paper also finds that under-reactions are followed mostly by positive feedback trading while overreactions are characterized by delayed overshooting in the short run but corrected by negative feedback trading at longer horizons. According to previous research done by Evans and Lyons [12], daily frequency is appropriate in integrating transitory pricing error effects of order flow, which are likely to be present at intraday frequency. Therefore, the paper applies daily FX rate data rather than high-frequency data.

Evans and Lyons [13] provide forceful evidence that currency markets are still absorbing news after several days. This may be good news for traders who respond quickly to news and benefit from prolonged price reactions after the news. The paper identifies news with the trades of end-user customers: non-financial corporations – henceforth “Corporations”, unleveraged financial institutions (primarily mutual funds) henceforth “Investors”, and leveraged financial institutions (primarily hedge funds) – henceforth “Traders”. Many papers on this topic do not consider that both prices and quantities are following joint processes. Other papers that have addressed these joint dynamics focus exclusively on trades between market makers i.e., interbank trades rather than on trades of end users. This is relevant for the question that we address because, relative to those of end users, reactions of market makers to news are unlikely to be as what is described in the paper. In addition, with regard to research methodology, the paper introduces a novel identification approach for isolating news shocks and their effects on trades and prices. Specifically, the paper provides a method to project extreme changes or value-at-risk (VAR) arising from shocks of news. The paper applies daily FX prices as sample in the research. Although the results with daily data do not permit intraday analysis, there is an important advantage of analysis with daily data. Daily data provides solid indication of price effects at lower frequencies (i.e., those more familiar to macroeconomists, such as monthly) because daily frequency is the highest at which the nominal exchange rate can be reliably described as a martingale. Any empirical model that explains daily price increments is therefore relevant for explaining exchange rate levels at long horizons (i.e., one cannot sensibly argue that daily price movements are rapidly dissipating). This martingale property at the daily frequency does not apply to intraday prices, which may exhibit mean reversion.

Most research papers on macro news market impact are based on event study. Rigobon and Sack [23] argue that results from event study share one shortcoming in understanding market dynamics: measured data surprises solely explain a small portion of the variation in asset prices and monetary policy expectations. It

argues that this shortcoming may reflect mis-measurement of the macroeconomic news. The paper explores measuring both reaction of asset prices and monetary policy expectations on the "true" economic news embedded in the major U.S. data releases. Rather than attempting to better measure the data or the expectations, the paper focuses on developing econometric techniques that adequately deal with the measurement problems associated with the data surprises used in the existing event study literature. First, it modifies the standard event study regression framework to account for the possibility that the measured surprises contain error. The measurement issues considered lead to a classical error-in-variables problem of a standard regression and to downward biases of estimated sensitivity of asset prices to the incoming data. The paper develops a new estimator to allow for measurement error and, hence, to eliminate this downward bias. The procedure could be used in other applications to correct for the error-in-variables problem. Second, it employs a principal components approach that eliminates the need to measure the data surprises. In effect, this approach uses observed market reactions to infer what the true data surprises were. Such an approach may be appealing if one regards the incoming data as being complex and having many dimensions that could affect asset prices – conditions that make it difficult to measure the data surprise in the manner of the standard event study exercise. Although the paper does not study FX market, the econometric techniques it develops are very useful and are definitely helpful in FX market macro news impact research. The results of the paper provide unbiased estimates of the response of monetary policy expectations and asset prices to the "true" surprise contained in all of the major data releases. It also allows researchers to recover the importance of those true surprises. An important finding from the paper is that macroeconomic data releases matter to a much greater extent than what is found in previous studies. That is, they account for a greater portion of the fluctuations in market interest rates. Moreover, using these estimators, researchers are able to refine a set of patterns in the responses that should be explained by models addressing the interactions between economic variables, monetary policy, and asset prices.

2.2. Impacts on not only FX rates but also volatility (or volatility only)

Bauwens, Omrane and Giot [5] study the impact of nine categories of scheduled and unscheduled news announcements on the EUR/USD return volatility instead of return itself. It analyzes pre-announcement, contemporaneous and post-announcement reactions. Using high-frequency intraday data and within the framework of ARCH-type models, it shows that volatility increases in the pre-announcement periods, particularly before scheduled events. Market activity also significantly impacts return volatility as expected by the theoretical literature on the order flow. Such results show that the EUR/USD return volatility increases before the announcement of scheduled news, which can be explained by speculative/anticipatory trades, the possible flow of private information or the re-balancing of positions by traders who prefer to avoid announcement 'surprises'. When an announcement is not scheduled, the evidence of volatility increase during the pre-announcement phase is tenuous, except for rumors of central bank interventions. Moreover, for four categories of announcements, volatility increases in total over the pre-announcement and post-announcement periods. A major contribution of the paper comes from its analysis on both scheduled and unscheduled announcements. The scheduled announcements contain US macroeconomic figures, more specifically employment reports, producer and consumer price indices, gross domestic product and other important figures. This group also includes European macroeconomic figures, scheduled speeches of senior officials of the government and of public agencies, such as the Chairman of the Federal Reserve, the Chairman of the European Central Bank, and economy and finance ministers and US and European interest rate reports, although exact time of the announcements is not pre-determined. The news coverage of this paper is much wider than that of many other papers.

Bergera Chaboud and Hjalmarsson [6] continue the research on factors driving FX volatility. The paper develops a model to link volatility to information flows, measured by order flows in the market, and price sensitivity to that information. Its empirical results strongly demonstrated that the model is able to explain almost all of the long-run variation in volatility. The results show variations over time of market sensitivity to information and their role in explaining the persistence of volatility after arrivals of information. By using not only prices but also the trading volumes and high frequency signed order flows, the paper estimates time-varying market sensitivity parameter by regressing high-frequency returns to high-frequency order flows. This approach of analysis differs remarkably from those in other works on the topic. In this research, arrival of information (news) has not been modeled directly. Instead, the paper applies the number of international Dow Jones news stories per day. The paper concludes with its statistical results that the Dow Jones variable is unable to explain any of the persistence in volatility, either by itself or jointly with the order flow. This is a very interesting finding, worth further attention. We guess that Dow Jones news has many news stories unrelated to that FX market and it may distract the regression results.

Ref. [7] is the first research to study how U.S. and domestic macroeconomic announcements affect exchange rates in emerging markets: Czech Republic, Hungary, Indonesia, Korea, Mexico, Poland, South Africa, Thailand, and Turkey. It finds, except for Thailand and Turkey which have their currencies not sensitive to news, the other 7 currencies show consistent reactions to news. First, U.S. news matters much more than domestic news. Second, most emerging market currencies are getting more sensitive to U.S. news in recent years. For instance, in Korea, few U.S. news has significant impact on Korean won before the end of 2002, while U.S. news show persistent and significant impacts on the currency in recent years. Third, market sentiments on these currencies play an important role in their impact of news surprises. Good (bad) news matters more when optimism (pessimism) prevails. One explanation for this phenomenon is investor overconfidence. Investors are more likely to accept news in line with their prior beliefs and to ignore information contradictory to their prior beliefs. These finding are robust across countries and types of news. The paper also studies impacts of news on FX volatility and concludes their association.

Evans and Lyons [14] continue to find out whether any part of the effect of news on exchange rates is transmitted via transactions and, if so, what share is transmitted that way versus the traditional direct channel. This involves jointly testing (1) whether macro news flow increases order flow volatility and (2) whether the induced order flow has signed (first moment) effects on the exchange rate. The answer to both questions is yes: in both daily and intra-daily data, order flow is considerably more volatile when macro news is flowing, and these signed orders have theoretically-predicted effects on the exchange rate direction. With regard to total price effects of news, induced order flow accounts for two-thirds. Direct news affects accounts for one-third. In terms of total exchange rate variation, the order flow channel brings explanatory power of news up to 30 percent. Some other papers estimate 1 to 5 percent only. This paper resolves a puzzle of missing news effects. It seems that news is more important than scheduled announcements in explaining FX.

The paper adopts a heteroskedasticity approach that mitigates a source of measurement error, in that it does not rely on mea-

suring ex-ante news expectations (in contrast to the event study approach). A base model is as below:

$$\Delta p_t = \partial x_t + \xi_t + \kappa_t$$

$$x_t = e_t + \eta_t$$

where Δp_t is the change in the exchange rate (DEM/USD) from the end day $t-1$ to end day t and x_t is order flow between market makers realized over the same period. The parameter ∂ captures the price impact of order flow, i.e., it reflects the information content of order flow (the assumption of a constant price-impact parameter is relaxed below). The ξ_t and κ_t shocks represent information that is impounded in price directly. ξ_t is the common knowledge effect of macro news arrivals on the exchange rate. κ_t represents other factors directly impounded in prices, i.e., factors unrelated to both order flow or macro news events (possibly noise). Order flow is driven by the e_t and η_t shocks. The e_t shocks represent order flow effects from macro news arrivals – the non-common-knowledge effect of the news. Shocks to order flow that are unrelated to macro news (i.e., portfolio shifts arising from other sources such as changing risk tolerances or hedging) are represented by the η_t shocks. This model distinguishes three sources of exchange rate variation. The first source mirrors traditional models – public news that is impounded in price immediately and directly (i.e., with no role for order flow). The second source is an indirect effect of public news that 31 operates via induced order flow. The third source of exchange rate variation is caused by order flow that is unrelated to public news arrival. No previous work has disentangled these three sources empirically.

Lahaye, Laurent and Neely [20] propose tests to extract jumps and cojumps from three types of assets: stock index futures, bond futures, and exchange rates. Its basic idea is that standardized returns are too large to plausibly come from a standard Brownian motion. It finds assets differ in how they depend on fundamentals and on the possible sources of shocks arising from fundamentals. Considering theses variations, it explains how (co)jump behavior varies across markets. FX prices experience frequent changes but relatively small jumps because prices changes are subject to news from two countries. FX prices probably experience more idiosyncratic liquidity shocks during slow trading in the 24-hour markets. FX jumps tend to be smaller than bond or equity jumps because national macro shocks produce much smaller changes in expected relative fundamentals between currencies. Therefore a generic US announcement is less likely to create a jump in forex markets. As there is a wider variety of shocks affecting FX prices, the set of 25 U.S. news announcements thus generate relatively less impacts on forex jumps than bond or equity jumps. However, as the time interval of FX rates used in the research is 15-min, its results may be less useful for FX traders because the biggest jumps mostly happen right after news release in milliseconds.

Most research studied the impacts of macro news intervention on spot FX rather than derivatives. Hutchison and Sushko [18] similarly investigate market perceptions of the risk of large exchange rate movements by using information gleaned from risk reversal contracts and macroeconomic news surprises. The study differs from previous works in several important ways. First, it focuses on the height of the carry trade period in Japan (March 2004 through December 2006), where the sample is delimited at the beginning by the cessation of the Bank of Japan large-scale intervention operations and ends before the financial crisis emerged. It concerns about sharp yen appreciation that is particularly obvious during the period of heavy carry trade activity and are more likely to show up in the price of risk. Second, it focuses on “big” news surprises (greater than one standard deviation movements) that are more likely to convey information about the risk of large changes in the exchange rate. Third, it considers a broader set of news than previous work – thirty three sources (18 U.S. series and 15 Japan series) – and is the only study that investigates the direct impact of news other than intervention for the value of JPY/USD risk reversals. Fourth, it considers the asymmetric impact of news possibly stemming from loss aversion when the cost of hedging yen appreciation is increasing. Finally, it studies the indirect effect of news through the value of risk reversals on the yen carry trade, using (non-commercial) open interest positions in futures markets as a proxy for carry trade activity. The investigation of the link between macroeconomic news and futures positions through the risk-reversals channel may provide an explanation on the finding by Chen and Gau [9] that the contribution of futures prices to overall price discovery in foreign exchange markets increases markedly around the times of macroeconomic announcement.

3. Summary and implications

So far most previous literature focuses on proving market impacts of macro news and price discovery process of the FX market. In general, the literature is divided into two camps. The first one attempts to explain directions of exchange-rate changes (the first moments). The second one attempts to explain exchange rate volatility (the second moments). There are many studies addressing the first camp of research, while there is limited number of studies addressing the second camp of research.

In the future, one direction which researchers should look into is to focus more on macro news impact on FX volatility and study its impact on FX derivative markets rather than the spot markets. Derivatives have been referred by Warren Buffett as ”weapons of mass destruction,” a term popularized by George W. Bush to describe nuclear arms. Volatility is one of the key factors driving the option price according to Black-Scholes framework. Correctly understanding the relation between macro news release and FX volatility can help market participants better manage their FX derivative risk. Furthermore, to study the relation between timing and approaches of macro news release and FX volatility will be very useful for central banks. It can help them prepare the optimal strategies of releasing macro news in order to minimize the market impact.

In addition, although previous study provides useful information on how markets react to economic data, it does not discuss or analyze trading strategies arising from its empirical results. Hence, researchers may take a more practical look at building related trading strategies. Ideal strategies should yield better risk-adjusted and cost-adjusted returns and demonstrate low correlation risk with commonly-used trading strategies. Researchers can quantify market impact direction and magnitude of price changes arising from individual macroeconomic data releases. These results will be helpful for fund management and risk management.

Another potential research area is to scrutinize the effects of non-scheduled, qualitative “headline news,” as opposed to the regularly scheduled quantitative macroeconomic announcements that many research previously studied. Machine readable news and high-frequency market data may be used for future research because market impacts of news mostly happen in the first few mini-seconds after release of the news. By studying a wider scope of news, we can get a better and more complete picture of how news release affects the FX market.

Tradition asset valuation models such as CAPM and ICAPM describe the relation between asset return and systematic risk. The importance of FX return and systematic risk has been studied by Atanasov and Nitschka [4]. Sensitivities to macro news can be compensated with a risk premium. However it hasn’t been considered as a factor in most tradition asset valuation models. Adding macro news release factor into the existing asset valuation models will help build more realistic models with better explanation of sys-

Table 1
A summary table of reviewed papers.

Study	Paper	Period/frequency	FX Pair	Central Bank	Model	Analysis and results
Lukas Menkhoff, 2010 [21]	High-frequency analysis of foreign exchange interventions: what do we learn?	Literature review for papers from mid of 1990s to 2008	N/A	N/A	N/A	Knowledge about interventions has much improved. Even if central banks may not feel like operating in a laboratory, they are well informed about important effects of their decisions and also about the necessary requirements to be successful. Nevertheless, several issues require further investigation, among them a better coverage of intervention effects on spreads (in order to learn more about possible intervention costs), a more systematic understanding of intervention effects in emerging markets (where interventions are presently mainly exercised) and a deeper look into the functioning of intervention channels by the application of order flow data (which allow for the most precise measurement).
Alain Chaboud, Ben Chiquoine, Erik Hjalmarsson, Clara Vega, 2013 [8]	Rise of the machines: algorithmic trading in the foreign exchange market	September 2003 to December 2007 minute-by-minute trading data 1997 through 2007 1 second frequency quotation data	EUR/USD, USD/JPY, EUR/JPY	28 US macro announcements from Bloomberg	Both a reduced form of the high-frequency vector autoregression VAR and a structural VAR which uses the heteroskedasticity identification approach have been used to test the algorithm trading impact on FX price discovery and triangular arbitrage opportunities	Studied the impact of algorithmic trading on the price discovery process in the foreign exchange market. Found clear evidence that algorithmic trading causes an improvement in two measures of price efficiency in this market: the frequency of triangular arbitrage opportunities and the autocorrelation of high-frequency returns. The reduction in arbitrage opportunities is associated primarily with computers taking liquidity, while the reduction in the autocorrelation of returns owes more to the algorithmic provision of liquidity.
Jon Faust, John H. Rogers, Shing-Yi B. Wang, Jonathan H. Wright, 2007 [15]	The high-frequency response of exchange rates and interest rates to macroeconomic announcements	1987–2002 inclusive – 14 years – of high frequency data is considered, 5 min exchange rate return data	DEM/EUR, DEM/GBP	10 US macroeconomic announcements	A regression equation describes asset price changes over 20 min periods covering a particular type of announcement. Price change depends on two variables. One is the traditional state variables like the capital stock and level of productivity, but also includes variables such as non-auction-market prices, which might not want to view as fixed over, say, a day or a week. The other is the public's best estimate of the first variable at t, then estimates the second variable's value based on the arrival of macro news using Kalman updating	The first to consider the term structure in multiple currency denominations. There is a clear and consistent pattern in the responses to real (e.g., nonfarm payrolls, GDP, housing starts) and to nominal (e.g., CPI and PPI) announcements. Stronger-than-expected announcements for U.S. real activity consistently raise the value of the dollar and raise short-term and long-term interest rates in the U.S. and, to a lesser extent, overseas.

Table 1 (*continued*)

Study	Paper	Period/frequency	FX Pair	Central Bank	Model	Analysis and results
J. Lahaye, S. Laurent, C.J. Neely, 2011 [20]	Jumps, cojumps and macro announcements	01/01/1987–10/01/2004, origin FX data are in 5 min frequency, sampling data are in 15 min frequency	USD/EUR USD/GBP JPY/USD CHF/USD	25 US macroeconomic announcements	A continuous time jump-diffusion data-generating process is used to test jumps and volatility is modeled as a multiplier of two components: slowly varying component and a deterministic circadian component. And model jumps and cojumps formally as a function of macro news releases using Tobit-GARCH and probit models, respectively. The Tobit model can be motivated as the result of a two-step data-generating process for jumps. A probit model first determines whether the asset price jumps and then – if there is a jump – a truncated regression model determines the magnitude of that jump. The probit and truncated regression models must have the same explanatory variables and proportional coefficients. The Tobit likelihood function can be written as the product of the probit and truncated normal likelihood functions.	Studied financial price discontinuities and macroeconomic announcements. Found most of macro news studied does not cause jumps. A generic announcement from the dataset only produces an exchange rate jump about 1–2% of the time and a bond or equity jump only about 3–4% of the time. News creates a lower proportion of jumps than cojumps because liquidity shocks and foreign news tend to be market-specific and unlikely to create cojumps. Therefore, the set of announcements drives a higher percentage of cojumps than jumps.
Torben G. Andersen, Tim Bollerslev, Francis X. Diebold, Clara Vega, 2003 [2]	Micro effects of macro announcements: Real-time price discovery in foreign exchange	5-minute FX return data, January 3, 1992–December 30, 1998, defining "news" as the difference between expectations and realizations	CHF/USD, DEM/USD, EUR/USD, GBP/USD JPY/USD	US and German macroeconomic announcements from multiple government departments such as Bureau of Labor Statistics (BLS), Bureau of the Census	Linear regression model between return and news surprise with a lagged value of return itself, estimate the model using a two-step weighted least squares (WLS) procedure	Announcement timing matters, which indicate that only seven of the forty announcements significantly impacted all the currency specifications. The reason is that many of the announcements are to some extent redundant, and the market then only reacts to those released earlier. exchange rates adjust to news immediately. It is interesting to note, however, that exchange rate volatilities adjust only gradually, with complete adjustment occurring only after J 12 5-minute periods, or one hour (very useful finding).
Michael Ehrmann, Marcel Fratzscher, 2005 [10]	Exchange rates and fundamentals: new evidence from real-time data	Daily data, 1 January 1993–14 February 2003	USD/DEM, USD/EUR	25 news from Fed, ECB and Bundesbank	Iterative, weighted least squares (WLS) procedure to solve a linear model	This paper analyzes the link between economic fundamentals and exchange rates by investigating the importance of real-time data. The authors find that economic news in the United States, Germany and the euro area have been a driving force behind daily US dollar–euro/DEM exchange rate developments in the period 1993–2003. The larger importance of US macroeconomic news is at least partly explained by their earlier release time compared to corresponding German and euro area news. The exchange rate is also shown to respond more strongly to news in periods of large market uncertainty and when negative or large shocks occur. Overall, the model based on real-time data explains about 75% of the monthly directional changes of the US dollar–euro exchange rate, although it does not explain well the magnitude of the exchange rate changes.

Table 1 (*continued*)

Study	Paper	Period/frequency	FX Pair	Central Bank	Model	Analysis and results
R. Fatum, M. Hutchison, T. Wu, 2012 [17]	Asymmetries and state dependence: the impact of macro surprises on intraday exchange rates	5-minute intraday 1 January 1999 to 31 October 2006	JPY/USD	16 types of Japanese and 19 types of U.S. time-stamped macroeconomic announcements and preceding survey expectations obtained from Bloomberg News Service	A linear regression function with J lagged values of the return itself and K lags of each of the Q news variables. J and K are selected according to Schwarz Bayesian Information Criteria (SBIC). The 3 different methods are used to estimate the parameters in the regression.	Results illustrate the necessity of taking into account the country of origin of news, business cycle asymmetries, and the direction of news, in order to more accurately assess the intraday exchange rate responses to macroeconomic news surprises. This seems particularly important in contexts where institutional settings limit the endogenous policy response to news.
Martin D.D. Evans, Richard K. Lyons, 2005 [13]	Do currency markets absorb news quickly?	Daily data, April 11, 1993 to June 30, 1999	Citibank executed in the USD/EUR (Prior to the euro's launch in January, 1999, these trades correspond to the trades of all the euro component currencies against the USD)	30 US and 13 German scheduled Announcements When studied order flow impact, narrowed down to 18 news items that have a significant impact on order flow on the day of the announcement	Model the daily dynamics of prices and order flows as a 7-variable, kth-order VAR projection of the VAR innovations on news shocks	By examining the effects of news on subsequent trades by end-user participants (such as hedge funds, mutual funds, and non-financial corporations), induced changes remain significant for days.
Martin D.D. Evans, Richard K. Lyons, 2008 [14]	How is macro news transmitted to exchange rates?	Using the Reuters D2000-1 daily trading data for eight currency markets over a four-month period from 1 May 1996 to 31 August 1996. Both daily frequency and the intraday frequencies (tick by tick transaction)	DEM/USD	Both scheduled and unscheduled U.S. or German news events from Reuter's Money Market Headline News. 4 types of news are excluded (i) announcements of upcoming known holidays, (ii) announcements that a scheduled release would take place (e.g., "Monthly employment report due out tomorrow"), (iii) duplicate announcements (the same news is repeated with a slight change in wording), and (iv) announcements referring to the dollar/DEM exchange rate.	Two models are developed to describe the relationship between order flow and price change based on conditional heteroskedasticity. One is daily model, the other is intraday model. In the daily model, a linear model using Generalized Method of Moments (GMM) to estimate parameters. A state-dependent 6th order polynomial has been used to model intraday news effect. GMM has been used to estimate parameters as well.	Order flow is considerably more volatile when macro news is flowing, and these signed orders have the theoretically predicted effects on the exchange rate's direction. News' total price effect, induced order flow accounts for two-thirds, with direct news effects accounting for one-third.

Table 1 (*continued*)

Study	Paper	Period/frequency	FX Pair	Central Bank	Model	Analysis and results
Viet Hoang Nguyen, Yongcheol Shin, 2011 [22]	Asymmetric price impacts of order flow on exchange rate dynamics	Used the same source as the above paper and did research following its path. This is the latest paper related to order flow. But it only used daily 4 PM GMT trade price (not high frequency data)	DEM/USD, GBP/USD, JPY/USD, CHF/USD, FRF/USD, BEF/USD, ITL/USD NEG/USD	Studied the relationship between exchange rate, inventory and order flow without using any macro news directly. Macro news impacts are reflected in order flows and inventory levels.	Proposed the Generalized Asymmetric Portfolio Shifts (GAPS) model, which is derived the Asymmetric Portfolio Shift (APS) model by modifying and extending the Evans and Lyons [11] model. In particular, the model explicitly allows for the asymmetric pricing impacts of order flow on exchange rate under different market states, up and down markets. To this end order flows are decompose into positive and negative ones, signaling 'buying pressure' and 'selling pressure', respectively.	Tested the asymmetry in price impacts of trades through the varying market liquidity condition between up and down markets. In particular, the varying liquidity is attributed to the different risk aversion levels of the public under these two market conditions. Found strong evidence of a nonlinear cointegrating relationship between exchange rate and order flow. The results indicate that negative order flows have stronger price impacts than positive order flows, suggesting that price is more sensitive to trades in down market than in up market. Also suggest that equilibrium price level is not reached instantly at the end of each trading day but after a period of adjustments, reflecting the varying short-term market liquidity condition.
R. Rigobon, B. Sack, 2008 [23]	Noisy macroeconomic announcements, monetary policy, and asset prices	1/7/1994–12/31/1999 30-min data interval beginning five minutes before the time of an announcement	Did not study FX market, but studied rates and equity market. As rates directly affect FX, the results have strong reference value to FX markets	13 US macro news releases	Two new approaches to better account for the influence of the macroeconomic news under the assumption that the measured surprises are noisy are developed. The first is a new econometric technique for accounting for error-in-variables, one that has the potential to be used in other applications as well. The second is a principal components approach that takes advantage of the ability of using intraday data to zero in on the asset price movements right around the release.	Focuses on measuring the reaction of asset prices and monetary policy expectations to the "true" economic news embedded in the major U.S. data releases. Developing econometric techniques that will adequately deal with the measurement problems associated with the data surprises used in the existing event study literature, and based on this new technique, they found macroeconomic data releases matter to a much greater extent than found in previous studies.

Table 1 (*continued*)

Study	Paper	Period/frequency	FX Pair	Central Bank	Model	Analysis and results
Torben G. Andersen, Tim Bollerslev, Francis X. Diebold, Clara Vega, 2007 [3]	Real-time price discovery in global stock, bond and foreign exchange markets	Tick-by-tick basis for foreign exchange future January 2, 1992 through December 31, 2002	USD/GBP, USD/JPY and USD/JPY futures contracts listed in CME	25 U.S. macroeconomic news	Linear regression model with 5 min return and news surprises, with two lagged values of return itself in order to model news releases at different time, a two-step weighted least squares (WLS) procedure has been used to estimate result, "structural GARCH" estimation approach to test the contemporaneous cross-market and cross-country linkages	Found that announcement surprises produce conditional mean jumps; hence high-frequency stock, bond and exchange rate dynamics are linked to fundamentals. This contrast with many previous studies that find asset prices and comovements to be driven primarily by private information and contagion effects rather than public information. Both immediate impact and the dynamic effects of U.S. macroeconomic news announcements for each of the different markets. Immediate impact uses the five-minute futures return right after the announcement. In order to more fully analyze the dynamic effects of the news, the authors also estimate a system of equations using the two five-minute returns before each announcement and the eighteen five-minute returns in the one-and-a-half-hour immediately following each announcement. Using a "structural GARCH" estimation approach, the authors also documented highly significant contemporaneous cross-market and cross-country linkages not directly explained by the macroeconomic announcement effects (need to look into more).
Michael Hutchison, Vladyslav Sushko, 2013 [18]	Impact of macro-economic surprises on carry trade activity	715 daily observations excluding weekends from 03/18/2004 through 12/31/2006	daily data on 1-month and 1-year 25-delta JPY/USD risk reversal, weekly futures positions data in yen	15 types of Japanese macro news and 18 types of U.S. macro news	Galati and Humpage's model to price European option and risk reversal. Both OLS and ARMA are used to estimate the linear regression of impact of macroeconomic surprises on the value of risk reversals	Investigated market perceptions of the risk of large exchange rate movements by using information gleaned from risk reversal contracts and macroeconomic news surprises.
Luc Bauwens, Walid Ben Omrane, Pierre Giot, 2005 [5]	News announcements, market activity and volatility in the euro/dollar foreign exchange market	'Tick-by-tick' EUR/USD quotes for the period ranging from May 15 to November 14, 2001 to calculate 5 min mid-quote prices return	EUR/USD	Both scheduled and unscheduled announcements of FED and ECB, IMF, the World Bank, the IFO institute, OPEC members, also includes the rumors of central bank interventions and other extraordinary events	Use an EGARCH model where could control for intraday seasonality, news arrival (represented by dummy variables) and quoting frequency	Study the impact of nine categories of scheduled and unscheduled news announcements on the euro/dollar return volatility. The authors highlight and analyze the pre-announcement, contemporaneous and post-announcement reactions. Using high-frequency intraday data and within the framework of ARCH-type models, the authors show that volatility increases in the pre-announcement periods, particularly before scheduled events. Market activity also significantly impacts return volatility as expected by the theoretical literature on the order flow.

Table 1 (*continued*)

Study	Paper	Period/frequency	FX Pair	Central Bank	Model	Analysis and results
David Bergera, Alain Chaboud, Erik Hjalmarsson, 2009 [6]	What drives volatility persistence in the foreign exchange market?	January 1999 through December 2004. Not only data on the exchange rate itself, but also to the volume of trade and the order flow. The price data are at the 1 second frequency, from which construct time series sampled at either the 1-minute or the 5-minute frequencies, and the transaction variables are available at the 1-minute and 5-minute frequencies. The transactions data are proprietary and confidential, which were provided by EBS	EUR/USD	indirectly relating volatility to the flow of information, which is reflected in order flow	Kyle-model, which links volatility to the information flow, measured as the order flow in the market, and the price sensitivity to that information.	Movements in the market's sensitivity to information, jointly with movements in the rate of information arrival, can, to a very large degree, explain the long-run dynamics of realized exchange rate volatility.
Fang Cai, Hyunsoo Joo, Zhiwei Zhang, 2009 [7]	The impact of macroeconomic announcements on real time foreign exchange rates in emerging markets	5-minute intervals. January 2, 2000 to December 31, 2006	Exchange rates of the nine EM currencies: Czech Republic, Hungary, Indonesia, Korea, Mexico, Poland, South Africa, Thailand, and Turkey versus U.S. dollar	26 news for the U.S. news, 13 for Czech Republic, 11 for Mexico and Poland, 9 for Turkey, 8 for South Africa, 7 for Hungary, 6 for Korea, 5 for Thailand, and 4 for Indonesia (obtain news from Bloomberg)	Include lag terms of currency returns and news in an OLS linear regression model, and control for heteroskedastic errors	Measure how exchange rates in nine emerging markets react to macroeconomic news in the U.S. and domestic economies. Find that major U.S. macroeconomic news have a strong impact on the returns and volatilities of emerging market exchange rates, but many domestic news do not. Emerging market currencies have become more sensitive to U.S. news in recent years.
Kathryn M.E. Dominguez, 2003 [24]	The market microstructure of central bank intervention	1987–1995, 5-min intra-daily data	USD–DEM; USD–JPY	FED; BOJ, Deutsche Bundesbank	General linear regression of the returns of the pair over dummy variables of the announcements. Authors observe price actions before the time of Reuters announcements to infer whether prior informed market participants were acting in the market. To observe the effects on volatility, the authors take the square roots of the returns in windows of 5-min ahead of the announcements, and 2 hr before and after.	Some traders typically know that the Fed is intervening at least 1 h prior to the public announcement. 4 of 12 macro announcements have significant impact to exchange rates. Evidence of mean-reversion subsequent to FED interventions particularly to USD-DEM suggesting some over-reaction. FED interventions in markets with large trading volume (i.e. overlapping hours) have greater of announcements than those of other times of the day. Coordinated actions among Central Banks have large effects on exchange rates. Little evidence that large banks are price reaction leaders to FED intervention. Volatility is substantially higher in the 4-hr window of the announcement, and especially at $\pm$30 min, peaking at 20–5 min ahead of the news. Volatility normalizes after 1 h of the announcement.

Table 1 (*continued*)

Study	Paper	Period/frequency	FX Pair	Central Bank	Model	Analysis and results
Richard Payne, Paolo Vitale, 2003 [25]	A transaction level study of the effects of central bank intervention on exchange rates	1986–1995, 1 min data; 1986–1999 tick data	USD/CHF	Swiss National Bank	Data are observed as interventions and customer transactions. Authors conduct an ARMA(2) linear regression on 15-min returns of the USD/CHF over 8 leads and lags of intervention indicator (+1 when SNB purchases US$ and −1 sold dollars), thus capturing the 2 hr period before and after the intervention event. To test whether the size of the interventions has effect on the exchange rate, author add the 8 leads and lags of the amount transacted. Authors also observe the same type of regression based on the 8 lead and lags of the transaction amount and the 8 lead/lag of it signed a squared amount. To test the effects of joint intervention, authors use a indicator in the same fashion as before, whereas the indicator takes value 1 when interventions from other banks are within 1 h from the SNB intervention.	1. When the SNB purchases (sells) US dollars, the American currency appreciates (depreciates). 2. Effects of intervention are in the first 5 min, 15 min later the event is reported, the effects last for few hours. 3. Market moves in the anticipated direction, partial reversals are also observed in the 15 min window. 4. SNB actions are larger and more persistent when operations are conducted with FED and Bundesbank. 5. Median intervention size is $5 m and size matters, average 30 points change for intervention of $50 m. 6. Relation between the exchange rate and intervention size is not linear indicating an expensive instrument of policymaking.
David Berger, Alain Chaboud, Sergey Chernenko, Edward Howorka, Jonathan Wright, 2008 [26]	Order flow and exchange rate dynamics in electronic brokerage system data	1999–2004 1 min	USD/JPY; EUR/USD	FED	Authors study the behavior of order flow at times of U.S. macroeconomic announcements that come out at 8:30 am. Order flow from 8:30 to 8:31 on the day of a news announcement regressed on the surprise component of the data that were released at 8:30 that day. The variable window of 5 min, is changed from 08:35 to 09:00 am on separate regressions for each announcement. News are calculated as the standard news surprise indicator. Relation between order flow and news are investigated as a lead/lag linear regression.	1. In the 8:30 to 8:31 minute, all announcement surprises are estimated to have a negative effect on euro–dollar order flow and a positive effect on dollar–yen order flow, meaning news of stronger economic activity is associated with orders by market “takers” to buy dollars. However, the headline data surprise only impacts order flow for a very short interval after each type of announcement. In the windows from 8:31 to 8:35 and from 8:35 to 8:40, most announcement surprises do not have a significant correlation with the order flow, though some are significant and with the expected sign. Beyond 8:40, there is very little sign of any relation.

Table 1 (*continued*)

Study	Paper	Period/frequency	FX Pair	Central Bank	Model	Analysis and results
Dagfinn Rime, Lucio Sarno, Elvira Sojli, 2010 [27]	Exchange rate forecasting, order flow and macroeconomic information	Feb 2004–Feb 2005 tick	USD/EUR; USD/JPY; USD/GBP	FED	Lognormal model of the returns of the exchange rate as discounted present value of the current and future expectations of the fundamentals (for several periods ahead). This implies that the future exchange rate change is a function of (i) the gap between the current exchange rate and the expected current fundamentals, and (ii) a term that captures changes in expectations about fundamentals.	The basic hypothesis tested is that if order flow reflects heterogeneous expectations about macroeconomic fundamentals, and currency markets learn about the state of the economy gradually, then order flow can have both explanatory and forecasting power for exchange rates. 1) Order flow is intimately related to a broad set of current and expected macroeconomic fundamentals; 2) more importantly, order flow is a powerful predictor of daily movements in exchange rates in an out-of-sample exercise, on the basis of economic value criteria such as Sharpe ratios and performance fees implied by utility calculations. In a hybrid order flow/news model with rational expectations and order flow, it is possible that the initial reaction of exchange rates to news fully captures the news or even over-reacts to it; in this case subsequent trading (order flow) may even be negatively related to positive news. In other words, the sign of the relation between news and order flow is ambiguous since it will depend on the extent to which the exchange rate adjusts directly in response to the news. The estimated coefficients reported are statistically significant at least at the 10% level, suggesting that news are an important determinant of order flow. Moreover, our results suggest that demand for a currency is stronger in response to good news, i.e. positive news on the US economy are associated with a decrease in order flow (stronger demand for USD), whereas positive news on foreign economies are associated with an increase in order flow (stronger demand for the base currency). Macroeconomic news can explain up to 15% of the daily fluctuations in order flow. Authors find that the addition of order flow significantly increases the explanatory power for exchange rate fluctuations, as compared to news alone.

Table 1 (*continued*)

Study	Paper	Period/frequency	FX Pair	Central Bank	Model	Analysis and results
Yu-Lun Chen, Yin-Feng Gau, 2010 [9]	News announcements and price discovery in foreign exchange spot and futures markets	Jan 2004–Dec 2005 1 min	EUR/USD; JPY/USD	FED	Used measures for price discovery are the information share proposed by Hasbrouck (1995) and the common factor weight proposed by Gonzalo and Granger (1995). Both approaches rely on the vector error correction model (VECM) proposed by Engle and Granger (1987). Information shares for 100 min intervals are computed and then the results are observed to spot any change in value around times of announcements. Information shares are then regressed over a dummy variables for news (and separately for news surprises), spread for the spot market, and ratio of trading volumes of spot vs. futures markets.	FX spot rates provide more price discovery than do the CME FX futures rates overall. Contribution of the futures rates to price discovery increases in the time surrounding macroeconomic announcement releases. Empirical results indicate that after news announcements, the contribution of futures rates to price discovery is greater than it would be without any announcement; however, the contribution of the spot rates declines when news announcements are released. News surprises for the GDP, durable goods orders, and employment report all have positive influences on the futures market's relative share for both JPY–USD and EUR–USD. These results suggest that when there is an unexpected component in announcements, the FX futures market reveals more information relevant to the implicit, efficient exchange rate.
Marcel Fratzscher, 2009 [28]	What explains global exchange rate movements during the financial crisis?	July 2008–Jan 2009	54 currencies of advanced and emerging economies	FED; country specific	Simple regression and similar variants of the change of the currency rate over macroeconomic fundamentals, macroeconomic shock and a vector of external exposure of countries.	Unexpected feature of the financial crisis has been the sharp appreciation of the US dollar against virtually all currencies globally. The paper finds that negative US-specific macroeconomic shocks during the crisis have triggered a significant strengthening of the US dollar, rather than a weakening. Macroeconomic fundamentals and financial exposure of individual countries are found to have played a key role in the transmission process of US shocks: in particular countries with low FX reserves, weak current account positions and high direct financial exposure vis-à-vis the United States have experienced substantially larger currency depreciations during the crisis overall, and to US shocks in particular. Before the financial crisis, a negative US shock, i.e. a worse than expected performance of a US variable, led to a depreciation of the US dollar against foreign currencies. However, during the financial crisis this response pattern even switched its sign: a negative US shock during the financial crisis since July 2008 has induced, on average, an appreciation of the US dollar. This suggests that bad news for the US economy may either have been perceived as even worse news for other economies, or have triggered an actual or expected repatriation of capital from foreign markets, so as to induce a US dollar strengthening. The economic magnitude of the global FX response to US shocks is substantial. Moreover, these findings are robust to alternative model specifications, such as when excluding oil exporters and peggers, and hold equally for advanced economies as for EMEs.

Table 1 (*continued*)

Study	Paper	Period/frequency	FX Pair	Central Bank	Model	Analysis and results
Rasmus Fatum, Barry Scholnick, 2008 [16]	Monetary policy news and exchange rate responses: do only surprises matter?	1989–2000	DEM/USD; JPY/USD; GBP/USD		Previous literature on exchange rates and monetary policy news does not consider what can be described as an unrestricted dual test of whether exchange rates respond to the unexpected component of news and whether exchange rates respond to the expected component of news. The study makes use of all three components (the surprise component, the expected component, and the actual announcement) separately. Model regresses log returns of the rate on the expected and unexpected target rate, and a control variate that indicates if during the day the release of macroeconomic news coincides with policy change. To assess difference between surprise components from policy change, the log-returns of the rate are regressed over the actual monetary policy change in percentage points and the control variate. To test whether news are absorbed quickly, the same model is regressed over leads and lags of the data.	Exchange rates respond to only the surprise component of an actual US monetary policy change. Failure to disentangle the surprise component from the actual monetary policy change can lead to an underestimation of the impact of monetary policy, or even to a false rejection of the hypothesis that monetary policy impacts exchange rates. The unexpected component of a tightening (loosening) of US monetary policy is associated with a same-day appreciation (depreciation) of the USD. Authors find an absence of delayed effects which strongly suggests that the exchange rates under study absorb monetary policy surprises quickly and within the same day as the news are announced.
Carlo Rosa, 2010 [29]	The high-frequency response of exchange rates to monetary policy actions and statements	1999–2007 5 min	USD/EUR; USD/JPY; USD/GBP; USD/CHF	FED	Authors employ content analysis to classify the tone of the statement and a forecasting regression to identify the surprise component of the Fed's announcement. Policy surprises are calculated according to Gurnyak (2005), by looking at changes in the futures rate in narrow windows around FOMC announcements through two intraday measures, a "tight" window and a "wide" window, which begin 10 (15) min prior to the monetary policy announcement and end 20 (45) min after the policy announcement respectively. Surprise can be nonzero even when the policy interest rate was not changed, if the market placed at least some probability on there being a change. In order to measure the unexpected component of Fed communication, the FOMC statement is converted into a wording indicator variable, Index, on a three-value scale: negative (positive) values are assigned to communications that are perceived as dovish (hawkish), and zero to those that appear to be neutral. The forecast of FOMC announcements is through ML estimated linear regression of the statements values $(-1, +1)$. The surprise component is difference between the actual and the expected news. To examine the effects the returns of the rate are then regressed on the monetary policy shocks and the news surprise.	Estimation results show that both policy decisions and communication have economically large and highly significant effects on the exchange rates, with the surprise component of statements accounting for most of the explainable variation in exchange rate returns in response to monetary policy. This paper also shows that exchange rates tend to absorb FOMC monetary surprises within 30–40 min from the announcement release. Around 80% of the explainable variation in exchange rate returns in response to the Fed's monetary policy is due to unanticipated statements rather than to unexpected changes in the federal funds rate target. The volatility of exchange rate returns peaks at the FOMC announcement, and remains significantly higher than non-announcement days for about 40 min to 1 h. Moreover, there is a sharp spike in the impact of monetary policy announcements in the 10 min following the event, and monetary news is fully incorporated in about 30–40 min. Two factors are required to capture adequately the effects of the Fed monetary policy on exchange rates: the current federal funds rate target and the Fed's communication about the future monetary policy path. The ranking of the Fed's statements according to the assessment (tightening, neutral or easing) of its future policy rate setting behavior may still be influenced by personal judgment.

tematic risk. It can help market participants better evaluate their financial assets, also help regulators better estimate systematic risk and make regulation changes accordingly.

All the above future research areas have both significant academic and practical values and require analyzing massive data both in structured format and unstructured format. Advanced 'Big Data' computer technologies and machine learning methodologies can be employed for related research.

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