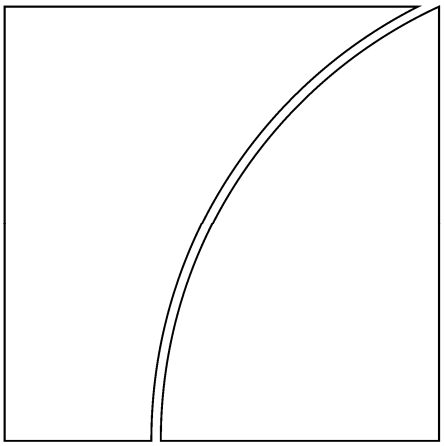
BANK FOR INTERNATIONAL SETTLEMENTS



BIS Working Papers

No 271

Private information, stock markets, and exchange rates

by Jacob Gyntelberg, Mico Loretan, Tientip Subhanij and Eric Chan

Monetary and Economic Department

February 2009

JEL classification: C22, E58, F31, F37, G14.

Keywords: Exchange rate models, market microstructure approach, asymmetric information, Thailand, generated regressors, impulse response functions, I(1) measurement error.

BIS Working Papers are written by members of the Monetary and Economic Department of the Bank for International Settlements, and from time to time by other economists, and are published by the Bank. The views expressed in them are those of their authors and not necessarily the views of the BIS.

Copies of publications are available from:

Bank for International Settlements
Press & Communications
CH-4002 Basel, Switzerland

E-mail: publications@bis.org

Fax: +41 61 280 9100 and +41 61 280 8100

This publication is available on the BIS website (www.bis.org).

ISSN 1020-0959 (print)

ISSN 1682-7678 (online)

Private information, stock markets, and exchange rates*

Jacob Gyntelberg† Mico Loretan‡ Tientip Subhanij§ Eric Chan¶

February 2009

Abstract

Explaining exchange rates has long been an important but vexing issue in international economics and finance. In recent years, a number of studies have shown that investors' private information plays a central role in determining exchange rates. We demonstrate in this paper that the private information of investors relevant for exchange rates is largely connected to the stock market, and that this information is conveyed to foreign exchange (FX) markets by order flow that is induced by investors' transactions in the stock market. We establish these results by analyzing several novel unused datasets on nearly two years' worth of daily-frequency capital flows of nonresident investors in the foreign exchange, stock, and bond markets of Thailand. We present compelling evidence that FX order flow that is induced by nonresident investors transactions in the Stock Exchange of Thailand—which we show are driven largely by private information—has far greater explanatory power for the exchange rate than other order flow has, both in the short run and the long run. In contrast, FX order flow of nonresident investors that is related to their transactions in Thai government bonds—which we find are not driven appreciably by private information—does not have a statistically significant effect on the exchange rate.

JEL classification: C22, E58, F31, F37, G14.

Keywords: Exchange rate models, market microstructure approach, asymmetric information, Thailand, generated regressors, impulse response functions, I(1) measurement error.

* The authors wish to thank Eli Remolona for detailed discussions and thorough critiques of earlier versions of this paper. We are grateful for comments by Philippe Bacchetta, Claudio Borio, Mark Carey, Michael King, Jaime Marquez, Bob McCauley, Pichit Patrawimolpon, Lucio Sarno, Elvira Sojli, Eric van Wincoop, Giorgio Valente, Clara Vega, Jonathan Wright, and seminar participants at the Bank of Thailand, the Federal Reserve Board, the Fourth Central Bank Workshop on the Microstructure of Financial Markets, the Bank for International Settlements, the Swiss National Bank, the University of Warwick Business School, the 16th Securities and Financial Markets conference in Kaohsiung, and the Reserve Bank of New Zealand. We thank the Bank of Thailand's Data Management Group and the Stock Exchange of Thailand's Research Institute for providing much of the data used in this study. All remaining errors are our own. The views expressed in this paper are those of the authors and need not reflect those of any other staff or of the principals of the Bank of Thailand or the Bank for International Settlements.

† Bank for International Settlements, Basel, Switzerland. Email: jacob.gyntelberg@bis.org.

‡ Bank for International Settlements, Asia-Pacific Office, Hong Kong SAR. Email: mico.loretan@bis.org.

§ Chief Researcher, Economic Research Department, Bank of Thailand. Email: tientips@bot.or.th.

¶ Bank for International Settlements, Asia-Pacific Office, Hong Kong SAR. Email: eric.chan@bis.org.

1 Introduction

The determination of exchange rates has long been an important but vexing topic in international finance and economics. The recent exchange rate literature has demonstrated that exchange rates are determined importantly by investors' private information, and that macroeconomic data and other public information items play a comparatively minor role once order flow, which conveys private information to the market, is incorporated in the models. We define order flow as the difference between the volume of buyer- and seller-initiated trades in a financial market.[1]

In recent years, economists have become increasingly aware that not all components of order flow in foreign exchange (FX) markets are equally important; some components matter far more for price formation than others. Progress on identifying which order flow components convey the most private information has been slowed by the fact that private information is, by its nature, rarely observed directly. In this paper, we propose and provide strong empirical evidence for the view that the private information of relevance for exchange rate determination is associated far more with stock markets than with other financial markets, such as government bond markets.

Our view is consistent with three main findings reported in the literature regarding the importance of various types of order flow for the exchange rate; see Osler (2008, pp. 30f.) for an overview. The first finding is that customer order flow carries more information than inter-dealer order flow. The second related finding is that financial customer order flow carries more information than commercial customer order flow. The third finding is that order flow driven by leveraged investors carries more private information than other institutional investor order flow does. Thus, our view is also consistent with empirical claims that (i) FX market order flow related to equity market transactions to a large extent tends to be initiated by leveraged financial-sector customers and (ii) FX market order flow related to bond market transactions is driven more by other financial-sector participants, such as pension funds and insurance companies.

The basic intuition for our view is that equity market order flow to a large degree reflects transactions by investors who are very active in collecting private information, whereas investors in other asset classes rely less on private information. Clearly there are various types of private information that stock market investors, domestic as well as foreign, may have about the fundamental determinants of a firm's value. These include knowledge of the quality of the firm's products, the prospects for successful product innovation, management quality, and the strength and likely strategies of the firm's competitors. However, as suggested by Lyons (2001), Evans and Lyons (2002), and Evans and Lyons (2007), private information may also include passively collected information about macro-variables and other exchange rate fundamentals which may be dispersed among customers. Private but dispersed information characterizes many variables at the center of exchange rate modeling, such as output, money demand, and consumer preferences. These variables are first realized at the micro or household/firm level and only later aggregated by markets and/or governments. For some of these measures, such as risk preferences and money demand functions, government-provided aggregations of the underlying micro-level shocks do not exist, leaving the full task of aggregation to markets. For other variables, government-provided

[1] This is also the definition proposed by Lyons (2001, pp. 6f.).

aggregations exist, but their publication lags the underlying realizations by weeks and months, leaving room for market-based aggregation in advance of their eventual publication.

The transmission of private information from capital markets to the FX market is done by FX dealers, who observe their own customers' FX transactions. In addition, the dealers frequently have a reasonably good idea as to why their customers undertake these transactions. In particular, they may know (or may be able to infer) whether their customers' FX order flow is driven by private information, if it occurs in response to public information, or it is a "noise" trade. To build some intuition for the decision-making problem that FX dealers face, consider the following stylized stories that focus on the information content of order flow. First, suppose that an FX dealer based in Thailand believes that her customer's purchase of baht for dollars will be used to acquire shares of one or more firms listed on the Stock Exchange of Thailand (SET). This transaction conveys not only information about the investor's beliefs about the value of the firms in question, but also about the longer-term demand for baht-denominated assets in general. It is straightforward to infer that the dealer's optimal response to such order flow is to adjust her quoted bid and ask rates for the baht towards an appreciation of the baht.[2]

Alternatively, suppose that the FX dealer knows that a customer has sold Thai government bonds and is now selling the baht proceeds for dollars in order to comply with government regulations that limit permissible baht bank account balances. If the FX dealer has reason to believe that the underlying bond market transaction is a liquidity trade and is therefore not driven by her customer's private information about future government bond returns, the dealer will not be induced to adjust her bid and ask quotes for the baht against the dollar other than for a transitory period, thus generating only transitory inventory and liquidity effects. In the foreign exchange market, in addition to order flow reflecting private information, liquidity and "pure" inventory effects generated by order flow can certainly occur. In fact, as we report below, statistically significant short-run dynamics are clearly present in exchange rate returns. We interpret them as inventory and liquidity effects generated by order flow. We also show that these effects are transitory in nature and that they are numerically smaller than those of information-induced order flow.

We establish our results by formulating and empirically testing three hypotheses about the relationship between the exchange rate and components of FX market flows. The first hypothesis is that FX market flows that are induced by investors' transactions in the stock market, which we find are driven mainly by investors' private information, should have a larger contemporaneous impact on the exchange rate than other FX market flows have. The second hypothesis is that if FX market flows are known *not* to be driven by investors' private information, they should have at most only a small contemporaneous effect on the exchange rate. The third hypothesis is that the portion of FX order flow that conveys private information should have a permanent impact on the exchange rate; in contrast, other order flow should have at most a transitory impact on the exchange rate.

Our empirical work strongly supports all three hypotheses. First, we report that flows in the two-day spot segment of the FX market that are driven by equity market variables have

[2]Models that derive explicit optimal decision rules for FX traders have been proposed, *inter alia*, by Richards (2005), Evans and Lyons (2005), Bacchetta and van Wincoop (2006), and Vitale (2007).

a contemporaneous effect on the exchange rate that is three to four times as large as that of other components of two-day spot order flow. Second, we find that FX flows related to foreign investors' bond market transactions do not have a statistically significant contemporaneous effect on the exchange rate. Third, we find that the effect on the exchange rate of stock-market related FX flows is permanent, whereas that of other FX flows is transitory. We interpret these results as providing strong support for the view that investors' private information that induces FX flows and drives the exchange rate is largely centered on stock market.

We obtain our results using novel and comprehensive datasets on nearly two years' worth of daily-frequency capital flows of nonresident investors in the onshore FX, stock, and secondary bond markets of Thailand. The data and the structure of these markets are sufficiently rich and diverse that we can generate our results without having to have direct knowledge of either the private or the public information sets that influence investors' decisions. A key identifying assumption, which we verify empirically, is that foreign investors' transactions in the bond markets of Thailand (which involve mainly trading in government and central bank paper) is driven either by public information or by liquidity or "noise" trades, but not by private information. The second assumption, which is also supported empirically, is that foreign investors' order flow in the Stock Exchange of Thailand (SET)—while also responding to public information and being subject to liquidity or noise trades—is driven mainly by private information related to the firms whose shares are bought and sold.

Because of government regulations that strictly limit permissible baht-denominated bank balances of nonresident investors in Thailand, foreign investors' transactions in the stock and bond markets are associated fairly closely with related flows in the FX market. This lets us construct simple proxies for the portions of FX order flow that are driven by foreign investors' stock and bond market order flow. This, in turn, lets us run order flow regressions in which we include these proxies as explanatory variables, and it enables us to test which parts of order flow have larger influences on the exchange rate than others, both contemporaneously and in the long run.

The structure of the financial system in Thailand provides an excellent basis for uncovering systematic relationships between the exchange rate, order flow in the FX market, and order flows in the domestic capital markets. Licensed FX dealing banks in Thailand must report on a daily basis all transactions with all counterparties to the Bank of Thailand (BoT), the country's central bank. This allows the construction of comprehensive daily-frequency capital flow series, in which one can distinguish between FX dealers' transactions with other dealers, their foreign customers, their domestic customers, and the BoT. For this study, we were given access to the series of transactions between FX dealers and their foreign customers, which are mainly financial companies. We obtained similarly comprehensive daily-frequency datasets of the transactions of foreign investors in the stock and bond markets of Thailand. Government regulations in Thailand place strict limits on foreign investors' participation in domestic money markets and on their permissible bank balances. These regulations create unusually close and synchronous linkages between foreign investors' net purchases of assets in the domestic capital markets and their order flow in the FX market. This feature of the financial system, combined with the high frequency and quality of the data, enabled us to inquire which subsets of order

flow have especially large effects on the exchange rate, using data from a relatively short period of two years during which structural breaks in the data generating processes did not appear to occur. In economies with less restrictive rules governing the ability of foreign investors to participate in the banking system and money markets, one would likely not be able to detect such effects unless one has access to data spanning much longer time periods. Of course, having to rely on data that span longer periods raises the likelihood that structural breaks occur during the sample period, questioning the validity of the econometric analysis.

Our study contributes to the exchange rate literature in several ways. First, we provide a previously missing piece to the exchange rate determination puzzle, by showing that the stock market provides much of the private information of relevance to the determination of the exchange rate. To be sure, we do not claim to be the first ones to notice the existence of statistically significant links between foreign investors' order flow in a stock market and exchange rate returns. For instance, FX dealers routinely state that they study their own customers' order flow carefully in order to discern its information content.[3] However, previous empirical studies of these links have generally lacked the comprehensive high-frequency flow data that are needed to fully establish the nature of the dependence of exchange rate fluctuations on stock market variables and their relationship to investors' private information. Second, to the best of our knowledge, our study is the first that analyzes the exchange rate determination puzzle empirically by combining comprehensive data on order flow and returns from three separate financial markets—FX, stock, and bond markets. Third, our study broadens the geographical range of data used in exchange rate determination studies by utilizing data from Thailand, a major emerging market economy. The vast majority of existing studies on this issue have used data from industrial economies.

The remainder of the paper is structured as follows. The following section reviews the related literature and presents the hypotheses tested in this paper. Section 3 provides an overview of the three Thai financial markets of interest and introduces the datasets. In Section 4, we examine the empirical evidence related to the hypotheses presented in Section 2. Section 5 concludes.

2 Related literature and hypotheses

2.1 Related literature

Portfolio balance models of the determination of exchange rates, which began to be formulated beginning in the second half of the 1970s, occupy an important place within the international economics field in part because they provide plausible scenarios in which capital flows should help explain both the sign and the magnitude of exchange rate fluctuations.[4] Early attempts to verify empirically this implication of these models were generally unsuccessful; see, e.g., Frankel (1983). This lack of empirical support reflected, in part, the fact that many of the early studies relied on low-frequency data. Because capital flows can fluctuate considerably from day to day and are somewhat mean-reverting at high frequencies, the use of lower-frequency data—such

[3] See, e.g., Goodhart (1988) and Gehrig and Menkhoff (2004).

[4] In Gyntelberg, Loretan, Subhanij, and Chan (2009) we consider the impact of equity market portfolio rebalancing on the exchange rate, employing framework suggested by Hau and Rey (2006).

as monthly or quarterly data—reduces the signal-to-noise in the data and makes the detection of links between capital flows and exchange rates more difficult. In addition, the use of low-frequency data makes it more difficult to distinguish between short-run phenomena, such as liquidity and inventory effects caused by the microstructure of financial markets, and longer-run issues such as information effects. Finally, users of early portfolio balance models, whether they worked with asset demand functions that were postulated or derived explicitly from investors' optimizing behavior, did not yet possess the analytical tools (as these tools were developed only subsequently) to investigate rigorously how one might incorporate demand for risky assets, such as equity claims on capital stocks, into these models. It was therefore unclear how phenomena such as private information about asset returns and differences in sophistication across investors should be modelled or what their effects on exchange rates might be. Moreover, the early portfolio balance models—as well as the earlier "monetary" models of exchange rate determination—were found to perform poorly out of sample, and their ability to forecast exchange rates was no better and often worse than that of the random walk model; see Meese and Rogoff (1983) and Cheung, Chinn, and Garcia Pascual (2005).

Subsequent research focused on developing models of the cross-border demand for risky assets that explicitly incorporate important institutional features, i.e., the microstructure of asset markets and of the information held by investors.[5] The market microstructure literature and the noisy rational expectations literature established the critical importance of taking into account both the structure and organization of markets as well as the heterogeneity of information held by investors in order to explain price formation. A fundamental insight that emerged from these studies is that traded quantities and prices reflect institutional constraints as well as the heterogeneity of information held by market participants. Thus, both aspects need to be modelled in order to understand fully the price formation process. The market microstructure literature also established that order flow is a key factor in explaining asset prices.

Beginning with the work of Evans and Lyons (2002), a number of studies have shown that models of exchange rate determination that include contemporaneous order flow as an explanatory variable vastly outperform models which rely exclusively on public information, such as macroeconomic data.[6] Osler (2008) groups the reasons why order flow helps explain asset returns into three categories: (i) inventory effects, (ii) liquidity effects, and (iii) private information effects. In the FX market context, inventory effects arise because foreign exchange dealers, who provide liquidity to other dealers and to their customers, may experience unwanted fluctuations in their desired inventories as a result of order flow and thus incur inventory risk. Dealers charge

[5]For general introductions to the market microstructure literature, see O'Hara (1995) and Madhavan (2000). For introductions to the market microstructure analysis of FX markets, see Lyons (2001), Sarno and Taylor (2002), Osler (2006), and Osler (2008).

[6]Brooks, Edison, Kumar, and Sløk (2001) provide an early discussion of some of the empirical relationships between exchange rate fluctuations and portfolio capital flows. More-recent studies that consider linkages between stock markets, private information, and exchange rates are Richards (2005), Froot and Ramadorai (2005), Dunne, Hau, and Moore (2006), Francis, Hasan, and Hunter (2006), Vitale (2007), Albuquerque, de Francisco, and Marques (2008), Berger, Chaboud, Chernenko, Howorka, and Wright (2008), Bjønnes, Osler, and Rime (2008), Chai-Anant and Ho (2008), Chinn and Moore (2008), Evans and Lyons (2008), Gradojevic and Neely (2008), Love and Payne (2008), Reitz, Schmidt, and Taylor (2008), Siourounis (2008), and Tille and van Wincoop (2008). Of these, the contributions of Richards and Chai-Anant and Ho consider Asian emerging market economies, and the others consider mainly developed economies.

a bid-ask to compensate for this risk. The existence of a bid-ask spread as well as the need of FX dealers and market makers to restore their inventories to desired levels following shocks can create systematic short-run relationships between order flow and returns; see Stoll (1978) and Cao, Evans, and Lyons (2006). Liquidity effects in FX markets can stem, for instance, from the tendency of the FX dealer community as a whole to take on relatively little overnight FX risk, requiring other market participants to supply overnight liquidity; see, e.g., Bjønnes, Rime, and Solheim (2005).

Turning to private information effects, Evans and Lyons (2007) have noted that order flow aggregates and conveys investors' private information that is only revealed later in aggregate economic statistics. Information of relevance to market makers and FX dealers is therefore not only publicly-available news but also what they can learn from the order flow initiated by customers acting on (what the dealers believe to be) private information. A number of recent studies, such as Bacchetta and van Wincoop (2006), have modeled the behavior of FX dealers as solving a dynamic signal extraction problem, in which their optimal strategy is to change their bid and ask quotes permanently if the order flow comes from informed market participants but not to change their quotes if the flows are initiated by liquidity traders, because the latter transactions are not based on information about the value of the asset.

This model of price formation is generally made in the context of a stock exchange with designated market makers; see, e.g., Kyle (1985) and Glosten and Milgrom (1985). However, it is applicable to other organizational models of financial markets as well. For instance, Anand and Subrahmanyam (2008) show that market intermediaries in a fully-electronic stock exchange without market makers—such as the Tokyo Stock Exchange—contribute disproportionately to the price discovery process. Similarly, in many over-the-counter markets (including many FX markets) there usually are dealers that act as de-facto market makers. Theoretical models that explain how market makers in organized exchanges should set prices in reaction to various types of news should apply, with only minor adjustments, to such markets as well.

Froot and Ramadorai (2005) use an approach to categorizing the relationships between FX market order flow and exchange rate movements which differs somewhat from that of Osler (2008). According to what Froot and Ramadorai label the "strong" flow-centric view, order flow may be related to exchange rate movements because it is correlated with the fundamental value of the currency and hence conveys fundamental macroeconomic and other market-wide pieces of information to market participants. In contrast, according to what Froot and Ramadorai call the "weak" flow-centric view, order flow could be related to *deviations* of the exchange rate from its fundamental value rather than to the fundamental value itself. In their framework, information effects conform to the "strong" flow-centric view and inventory and liquidity effects fall into to the "weak" flow-centric category.

As Berger, Chaboud, Chernenko, Howorka, and Wright (2008) note, it is of course possible that order flow could fit into both categories, with a portion of order flow being informative about economic fundamentals and the remainder reflecting only deviations from fundamentals.[7] Killeen, Lyons, and Moore (2006) observe that if order flow does convey information about the

[7]The model of Bacchetta and van Wincoop (2006) analyzes the case of order flow having both weak and strong flow-centric components.

fundamental value of the exchange rate, *cumulative order flow* should be cointegrated with the log *level* of the exchange rate. Conversely, if order flow does not convey such information but is only related to short-run deviations from exchange rate fundamentals, cumulative order flow should not be cointegrated with the log level of the exchange rate. In Section 4, we report that whereas a large fraction of observed order flow is indeed "weakly flow-centric"—in the sense that its cumulated series is not cointegrated with the exchange rate—the relatively small portion of FX order flow that is related to foreign investors' activity in the stock market *is* cointegrated with the exchange rate and hence has a permanent effect. In the terminology of Froot and Ramadorai, we would conclude that the portion of foreign investors' FX market order flow that is explained by stock market variables is strongly flow-centric whereas the remainder is (at most) weakly flow-centric.

2.2 Empirical regularities and hypotheses

A preliminary analysis of the FX, stock, and bond market data revealed several empirical regularities that we wish to explain and relate to each other.[8] First, the order flow patterns of nonresident customers in the FX and stock markets in Thailand exhibit mild short-term flow momentum and return chasing; this is consistent with them being driven by private information.[9] Second, foreign investors' trading patterns in the Thai bond market do not exhibit these features, suggesting that foreign investors' bond market order flow is not driven by private information but only by public information (as well as, possibly, by liquidity or noise trades).[10] Third, the contemporaneous correlation between foreign investors' stock and bond market order flow is only 0.05 in the sample. If stock market order flow was determined importantly by macroeconomic data releases and other pieces of public information as well, one should find that stock market and bond market order flow were more highly correlated. The fact that the correlation, although positive, is so low indicates either that vast portions of the two order flow series consist of noise trades not linked to either public or private information or, far more likely, that only a small portion of foreign investors' stock market order flow is based on public information and that a much larger portion reflects investors' private information.[11]

The link between these empirical regularities and foreign investors' activity in the foreign exchange market stems from their need to conform to government regulations that strictly limit

[8] These empirical regularities are established in greater detail in an earlier version of this paper. It is available from the authors on request.

[9] For much of our analysis to go through, we only require that that there be systematic asymmetry in the amounts of private information held by domestic and nonresident stock market investors. As we discuss in greater detail at the end of Section 4, our data are actually consistent with foreign stock market investors in Thailand being at an informational disadvantage relative to domestic investors. Similar informational asymmetries are reported by Hau (2001) for Germany, Dvořák (2005) for Indonesia, and Choe, Kho, and Stulz (2005) for Korea.

[10] While corporate bonds exist in Thailand, trading in the secondary bond markets during the sample period was overwhelmingly concentrated in central bank and government paper.

[11] FX dealers are presumably also aware of these patterns. If dealers are able to adjust their foreign currency inventories across days, they will find it advantageous to try to buy baht and sell dollars from customers and other dealers (leading to an appreciation of the baht) on a day when they observe an upswing in stock-market related capital inflows of their nonresident customers. This adjustment puts the dealers in a position to sell further baht to (and buy dollars from) their foreign customers over the next few days as the capital inflows continue. This mechanism helps explain the small amount of positive serial correlation in baht returns that was revealed in our preliminary analysis of the data. We note that while this transmission mechanism works in the same direction as the basic information story, it is a liquidity-provision rather than a "pure" information story.

their permissible baht-denominated bank account balances. These regulations induce an unusually close link in Thailand between capital-market order flow and foreign exchange market order flow. To explain these phenomena and their implications for the determination of the exchange value of the baht, we propose three hypotheses. The first two concern the contemporaneous effects (or lack thereof) of stock- and bond-market related order FX order flow on the exchange rate, and the third posits that only order flow that is based on and conveys private information should have a long-term or permanent effect on the exchange rate.

Because the stock market order flow of foreign investors appears to be based largely on private information, FX order flow that is induced by their stock market order flow should be a valuable source of information to FX dealers as they set their bid and ask quotes.

Hypothesis 1 *FX order flow of foreign investors that is driven by their Thai stock market operations should have a large contemporaneous impact on the Thai baht.*

Conversely, because the bond market transactions of foreign investors that induce order flow in the FX market are assumed not to be based on private information, they should not provide a reason to FX dealers to adjust their quoted bid and ask prices other than for inventory and liquidity reasons. Such flows should have at most only a small contemporaneous influence on the baht.

Hypothesis 2 *FX order flow that is driven by foreign investors' Thai government bond market operations should have at most a small contemporaneous impact on the Thai baht.*

In addition to studying differences in the contemporaneous impacts of subsets of FX order flow on the exchange rate, we may also examine whether the long-run influences of these order flow subsets are the same. If stock market investors act on private information about firms, their induced FX order flow should not only have a contemporaneous effect on the exchange rate but also a permanent effect. In contrast, order flow that does not convey private information should have, at most, a transitory effect. Our third empirical hypothesis is therefore:

Hypothesis 3 *FX order flow that is driven by foreign investors' Thai equity market transactions should have a permanent effect on the exchange rate, whereas other portions of FX order flow should at most a transitory effect on the exchange rate.*

3 The markets and the data

In this section, we provide a brief overview of the onshore FX, stock, and government bond markets in Thailand, focusing mainly on aspects of the markets and data that are important for the empirical analysis conducted in Section 4. We also note certain regulatory features of the financial markets in Thailand that induce a relationship between foreign investors' capital market transactions and their FX market transactions that is closer in Thailand than in many other economies.

3.1 Sample period and definition of nonresident investors

All observations are daily. The data cover the period from the beginning of January 2005 through Friday, 15 December 2006. The data we received initially run through mid-2008. However, after conducting a preliminary analysis we decided not to use data after mid-December 2006. On Tuesday, 19 December 2006, the Thai authorities imposed additional and very stringent capital control measures, highlighted by a 30% unremunerated reserve requirement (URR) on nonresident investors' financial holdings apart from stock market holdings. The introduction of these measures caused a severe structural break in the behavior of financial markets in Thailand. For instance, following the introduction of the URR measures, foreign investors' participation in the onshore financial markets of Thailand dropped off sharply, the volume of offshore baht trading increased, and a large differential opened up between onshore and offshore baht-dollar quotes.[12]

Throughout this paper, we focus on the transactions of foreign or, more precisely, nonresident investors in Thailand. Formally, nonresident investors comprise (i) corporations, institutions, funds, financial institutions or juristic persons located outside Thailand; (ii) entities of foreign governments located outside Thailand; (iii) branches and agents of domestic juristic persons located outside Thailand; and (iv) natural persons not of Thai nationalities who do not have alien identity or residence permits. According to information we received from the BoT's Data Management Group, financial institutions are the dominant group—with a share well in excess of 90% of total transactions—among the nonresident end-users in Thailand.

Nonresident investors that hold bank balances in Thailand are required to do so by holding so-called nonresident baht accounts, or NRBAs. During the sample period, NRBA regulations were broadly stable.[13] For our paper, the most important of the NRBA rules is that balances held in NRBAs may not exceed THB 300 million per nonresident customer at the end of each day.[14] This upper bound covers all accounts of that customer with all domestic financial institutions.[15]

If nonresident investors in Thailand, as a group, wish to build up (or unwind) their positions in long-term baht-denominated financial assets such as bonds or shares, they can do so in the short run only in the following three ways: (i) by drawing down (or building up) their existing baht-denominated bank balances held in NRBAs; (ii) via selling (buying) of shorter-term fixed income assets, including money market claims, to domestic market participants, or (iii) by engaging in baht-denominated FX transactions. Because of the fairly stringent limits on allowable balances in NRBAs and a general lack of liquidity in the private money markets in Thailand, the most straightforward method by which nonresident investors may acquire (or liquidate) the funds involved in the purchase (or sale) of baht-denominated shares and bonds is by transacting in the FX market. This institutional feature is one of the keys to our ability to link foreign customers' order flow across markets.

[12] The URR regulations were repealed by early March 2008. However, the stretch of post-URR data available at the time of the initial writing of this paper was not long enough to allow us to conduct a reliable econometric analysis with them.

[13] The NRBA regulations went into effect in October 2004, i.e., shortly before the start of the sample period.

[14] At the exchange rates that prevailed during the sample period, this limit amounted to US$7.1 to US$8.6 million.

[15] Foreign currencies converted into baht by nonresident customers are normally (though not necessarily) credited to their NRBAs before being spent on equities and bond securities and, conversely, the proceeds of sales of equities and bonds by nonresidents are frequently credited first to NRBAs before being converted into foreign currencies.

3.2 The onshore FX market

The structure of the onshore FX market in Thailand is similar to that in many other countries. There is no single organized exchange that handles FX transactions. Rather, the wholesale market is over-the-counter. Licensed currency dealers, which can be domestic or foreign-owned banks and brokers, provide wholesale FX trading services in Thailand.[16] In addition to conducting interdealer transactions, the FX banks also conduct FX purchases and sales with both domestic and nonresident customers.

The onshore FX market in Thailand is closely monitored by the BoT. First, onshore commercial banks are required by the BoT to limit their net FX positions in any one currency to no more than 15% of capital (individual currency limit) and also to maintain a net overall FX position across all foreign currencies of no more than 20% of capital (aggregate currency limit) at the end of each day. The position limits tend to be particularly important for the branches of foreign banks that operate in Thailand. FX dealing usually manage to adhere to these limits by conducting FX swaps.

Second, all licensed FX dealing banks must submit detailed reports of all FX transactions on a daily basis to the BoT. In the banks' daily reports, each transaction record states the counterparty, its type (other dealer, domestic customer, nonresident customer, and BoT), the volume (in dollar equivalent), the currencies involved (by far the majority of all transactions are in Thai baht vs. U.S. dollars), the applicable exchange rate, and the type of transaction. The five types of transactions are spot (separated further into same-day, "tomorrow" or $T+1$, and "next" or $T+2$ transactions), outright forwards ($T \geq 3$), and FX swaps. Of crucial importance for our study is that each transaction is classified as either a "buy" or a "sell." Because transactions are recorded from the point of view of the reporting bank, a "buy" consists of a *purchase of dollars* (or other foreign currency) by the reporter and hence a sale of baht to the counterparty.[17]

Based on this information, the BoT constructed for us daily-frequency gross and net capital flow series for all 5 types of FX contracts. This was done by aggregating across reporters to obtain the gross series and taking the difference between aggregate buys and sells to obtain the net capital flow series. This measure of net capital flows does not match perfectly the theoretical definition of order flow, which focuses on which counterparty *initiates* the buy or sell transactions. From conversations we held with FX dealers in Thailand, however, we believe that the vast bulk of "spot-tomorrow" ($T+1$), "spot-next" ($T+2$), and outright forward transactions between dealers and their nonresident customers is initiated by customers. Hence, the net capital flow series should match the theoretical concept of order flow very well for these types of transactions. In contrast, FX dealers told us that FX swaps tend to be initiated by either the FX dealing banks or their non-bank customers. In consequence, in the case of FX swaps our net capital flow measure may not be a good proxy for order flow. This feature may

[16] licensed FX dealers; 21 were domestic financial institutions, and 18 were subsidiaries of foreign financial institutions. After a couple of mergers in late 2005, the number of FX dealers in Thailand was 37 during all of 2006 (20 domestic and 17 foreign).

[17] The banks' daily transaction records do not contain information on which counterparty—the reporter or the customer—was the initiator of the transaction, the bid-ask spread, or whether the transaction took place at the bank's bid or ask quote. In addition, the transaction records do not contain time-stamp information. We therefore could not reconstruct intraday times series of prices or volumes.

help explain some of the results reported in the following section, such as the fact that net purchases of FX swaps by foreign investors do not help explain exchange rate fluctuations.

In addition to aggregating the FX dealers' transaction reports into daily-frequency time series according to whether they are "buys" or "sells" and according to their settlement maturity, they may also be aggregated by the type of counterparty—other FX dealers, nonresident customers, domestic customers, and the BoT.[18] For this study, our access to the aggregate data was limited to gross and net flows between dealers and their nonresident customers.

The daily average transaction volume between dealers and nonresident end-users was US$ 780 million in 2005 and US$ 1,155 million in 2006. In both 2005 and 2006, two-day spot transactions made up roughly 45 percent of the nonresident customer total, FX swaps accounted for an additional 33 to 35 percent, spot-tomorrow transactions contributed 11 to 13 percent to the total, and spot-today (same-day settlement) and outright forwards ($T \geq 3$) each accounted for about 4 percent of the total transaction volume between dealers and their nonresident customers. In both 2005 and 2006, all three daily spot FX net capital flow series were positive on average, i.e., nonresident customers were net buyers of spot baht in both years. Conversely, nonresident customers were net sellers of baht through outright forwards and FX swap contracts in both years.

As is the case with most other emerging market economies, FX trading in Thailand occurs almost exclusively during Thai business hours, and virtually no transactions occur overnight. The bilateral THB/USD spot exchange rate used in this study is collected by the BIS as of 7:15 pm Bangkok time (corresponding to 2:15 pm Central European time). This choice of collection time—shortly after equity, bond and onshore FX trading has ended in Bangkok—allows the daily FX returns series to reflect all relevant intraday information without being affected by global market developments that occur after the close of business in the onshore market.[19]

3.3 The equity market

Our stock market price data consist of the daily closing values of the SET index, which is the main share price indicator of the Stock Exchange of Thailand. The SET index is a market capitalization-weighted index and is based on the stock prices of companies listed on the main board of the exchange. The mean daily return of the SET index was very close to zero in both 2005 and 2006. Other than during a brief bout of heightened global market volatility during May and June 2006, stock price volatility was fairly low and constant during the sample period.

We also have daily-frequency gross buy and sell transaction volumes on the SET by nonresident investors.[20] Investors can trade securities on the SET through any of 39 brokerage houses, many of which are foreign-owned. Settlement for equities is performed on a $T+3$ basis. As with

[18] Transactions between the BoT and FX dealer banks generally consist of intervention operations. See Bank of Thailand, Financial Markets Operations Group (2005) for an overview of its goals with respect to the conduct of its FX interventions. To the extent that the BoT's intervention operations conform to the "leaning against the wind" metaphor, the findings we report in this paper would be even stronger if BoT intervention did not occur.

[19] Other data sources generally report FX rates as of 5 pm New York time, the conventional end of a 24-hour trading day in major FX markets.

[20] Albuquerque, de Francisco, and Marques (2008) used firm-by-firm equity transactions data to construct proxies for firm-specific and marketwide private information. Because of the aggregate nature of our data, we could not perform such calculations and hence cannot distinguish separately between these motives for trading activity.

the FX datasets, we terminate the sample period on 15 December 2006. Average daily gross transaction volume (buys+sells) on the SET by nonresident investors in 2005 and 2006 was the equivalent of US$ 229 million and US$ 286 million, respectively, or less than a third of average daily gross FX flows between dealers and nonresident customers.

3.4 The bond market

Nonresident investors' participation in the Thai bond markets in 2005 and 2006 was quite limited. Daily transaction volumes by nonresident investors averaged only US$55 million and US$88 million in these two years, amounting to roughly 15% and 19%, respectively, of all bond market trades. In 2005 and 2006, trading volume in the secondary bond markets was overwhelmingly (about 98%) concentrated in BoT paper and in government bonds and bills. Even though the stock of outstanding corporate bonds in Thailand has grown rapidly in recent years, trading in corporate bonds was very limited during the sample period.

Our bond market dataset consists of daily-frequency buy and sell transaction totals by nonresident investors in the secondary bond market. Bond market transactions are classified according to whether they are "outright" (or ordinary) or "other" transactions. In our sample, "outright" transactions make up about 70% of all transactions. According to information we received from private-sector dealers and staff of the Bank of Thailand, these transactions are mainly associated the one-day ($T+1$) settlement segment of the spot FX market, although some transactions settle on a $T+2$ or $T+3$ basis.

"Other" bond trades occur mainly in connection with banks' financing transactions; we were told that they settle mostly on a same-day or a $T+1$ basis. They make up about 30% to the total bond market volume of nonresident customers. A preliminary data analysis revealed that "other" bond transactions of nonresident investors are closely associated with contemporaneous FX swap transactions. As we noted earlier, during our sample period FX swaps transactions tended to be initiated by banks. Our data suggest that a large part of foreign investors' "other" bond market transactions appear to be related to banks' money market operations.

We found that foreign investors' net stock market flows were nearly uncorrelated over the sample period with their "outright" bond flows as well as with their "other" bond flows (with correlations below 0.05). In addition, foreign investors' net flows in "outright" and "other" bonds were also only slightly positively correlated with each other, with a correlation coefficient of about 0.15. These low numbers suggest that these three forms of domestic capital market transactions are driven by different considerations.

During the sample period, nonresident investors did not appear to hedge—or did so only to a minor degree—the FX risk they incurred when undertaking either equity or "outright" bond transactions. This may be because nonresident investors in Thailand face binding restrictions—such as prohibitions on short-selling of many classes of financial assets—that make the hedging of FX market risk either expensive or infeasible. In contrast, the FX risk embedded in "other" bond transactions does appear to be hedged, mainly through offsetting FX swap transactions. This is again consistent with "other" bond market transactions being used mainly in conjunction with banks' local money market operations. We discuss the possible role that differences in hedging behavior may have for explaining our results at the end of Section 4.

4 Empirical results

4.1 Methodological preliminaries

If each FX transaction record submitted by the FX dealing banks to the BoT contained auxiliary information to denote whether the customer's transaction was associated with a transaction in the domestic stock or bond markets, it would be straightforward to test our hypotheses directly: One would run an order flow regression with FX returns as the dependent variable and the FX order flow series as regressors; the latter would be split into components related to stock market transactions, bond market transactions, and a remainder. The null hypothesis to be tested would be that the coefficients of the three components are equal to each other, and the alternative hypothesis of interest would be that the coefficient on the stock-market related component of FX order flow is larger (in absolute value) than either of the other two. Unfortunately, the transaction records do not contain these auxiliary pieces of information.

FX dealers, of course, observe their customers' order flow in real time, and they presumably "know" from experience whether or not the components of their customers' order flow have the same influence on the exchange rate.[21] Our data do not let us reconstruct the FX dealers' information about their customers' transactions. Relative to the FX dealing banks, though, we possess the important informational advantage of having complete rather than only partial data on each day's aggregate order flow of all nonresident customers in the FX, stock, and bond markets. Having data from these three financial markets enables us to construct simple proxies for the subsets of nonresident investors' FX order flows that are driven by their stock and bond market transactions.[22] Of course, because the constructed series are proxies rather than the unobservable series of interest, they will contain measurement error. From basic regression theory, it is known that if regressors are measured with error, their coefficient estimates are biased toward zero, i.e., one will *underestimate* the regressor's effect on the dependent variable. In our study, one would tend to underestimate the effect of the constructed order flow components on the exchange rate. However, if one does find statistically significant effects using the proxy regressors, one may conclude safely that the effect of the "true" (but unobserved) order flow variable is also nonzero.

To be sure, transactions of nonresident customers in the stock market and the FX market need not be driven solely by investors' private information. Their transactions could also be driven by public information releases or by hedging and liquidity needs that are unrelated to economic conditions in Thailand. We do not include measures of contemporaneous public information in our regressions. Given that the public and private information sets are orthogonal by construction, the omission of variables that proxy for public information, while causing the R^2 numbers to fall, does not create bias or inconsistency in the estimates of the coefficients and their standard errors.

[21] In addition, quants in the banks' back offices may have solved the applicable signal extraction problem and derived precise rules on how dealers should adjust quotes in response to various types of order flow.

[22] In economics, the practice of splitting a time series into two components—one constructed as the fitted part from a preliminary regression and the other defined as the residual from that regression—and using both the fitted and residual components as explanatory variables in lieu of the original series, dates back at least to Barro (1977).

If the measurement error in the order flow series is stationary or I(0), the measurement error in the *cumulative* order flow series will be I(1). This has important consequences for testing for cointegration. Suppose that a series $X_t^* = \sum_{j=0}^{t} \chi_j$, where the innovations $\{\chi_j, j = 0, 1, \dots\}$ are I(0), is cointegrated with an I(1) series Y_t, but that the series X_t^* is not observed directly. Instead, one observes a series $X_t = \sum_{j=0}^{t} (\chi_j + \xi_j) = X_t^* + \Xi_t$, say. Unless the I(1) variable Ξ_t is also cointegrated with Y_t, the long-run relationship between X_t and Y_t is spurious in the sense of Granger and Newbold (1974) and Phillips (1986), and the cointegrating vector between X_t^* and Y_t is not estimable consistently. In consequence, the null of a unit root in the residuals from the cointegrating regression of Y_t on X_t will not be rejected asymptotically, i.e., a unit root test has asymptotically no power against the alternative of cointegration.

In finite samples, the tests will be biased towards non-rejection of the null of a unit root in the residuals of a cointegrating regression, i.e., the tests' true size will be smaller than their nominal size. In the context of testing for cointegration with significant I(0) measurement errors, Fischer (1990) recommends raising the critical level of the tests above the conventional values of 5% or 10% in order to preserve power against the alternative hypothesis of cointegration. This recommendation should apply, *a fortiori*, if the measurement error is I(1).[23]

Table 1 lists the acronyms, descriptions, and units of measurement of all variables shown in Tables 2, 3, and 4. The reported standard errors in Tables 2 and 4 are based on the assumption that the regression model errors are homoskedastic and serially uncorrelated. None of the inferences we conduct would change if the standard errors were computed using methods that are robust to heteroskedasticity and serial correlation.[24] The models used in the first-stage regressions and in the main order flow regression also passed several tests for structural breaks and other forms of misspecification.

4.2 Contemporaneous impact of FX order flow

We tested hypotheses 1 and 2 using a two-stage procedure. In the first stage, we constructed proxies for the portions of daily FX order flow that are driven by stock and bond market variables. In the second stage, we regressed daily baht-dollar returns on these constructed order flow series as well as on additional control variables and tested the null hypothesis that the coefficients on constructed regressors are equal.

To determine which of the five FX order flow series are affected by either the stock or bond market (or both), we regressed the FX order flow series on our bond and stock market variables. The stock and bond-market variables used in these regressions consisted of the contemporaneous and 3 lagged values of own-market order flow and returns.[25] We found that two-day spot, or spot-next, FX order flow was related systematically to stock market variables but not to bond market variables. We also found that one-day spot, or spot-tomorrow, FX order flow was related

[23] A recent, rigorous treatment of the case of testing for cointegrating relationships in the presence of I(0) measurement error is provided by Hassler and Kuzin (2008). How to test for cointegration in the presence of I(1) measurement errors in one or more of the cointegrated variables appears to be a subject that has not yet been studied in depth by econometricians.

[24] We checked this by using the robust methods proposed by White (1980) and Newey and West (1987), the latter with a Bartlett-type smoothing kernel and a choice of 5 for the lag-length parameter.

[25] In all cases, the contemporaneous regressors had the statistically largest influences.

Table 1: Description of variables shown in Tables 2, 3, and 4

All order flow series refer to transactions between banks and nonresident customers. Order flow is defined as the difference between banks' "buy" and "sell" transactions with customers.

Variable name	Description	Units
THB	First difference of log of baht-dollar exchange rate	
SET	First difference of log SET stock market index, in dollar terms	
OF_SPOT_TOM	Order flow, FX spot-tomorrow	USD million
OF_SPOT_NXT	Order flow, FX spot-next ($T+2$)	USD million
OF_SPOT_TOM_FIT_BND	Fitted values from regression of spot-tomorrow order flow on bond market variables	USD million
OF_SPOT_TOM_RES_BND	Residuals from regression of spot-tomorrow order flow on bond market variables	USD million
OF_SPOT_TOM_FIT_SET	Fitted values from regression of spot-tomorrow order flow on stock market variables	USD million
OF_SPOT_TOM_RES_SET	Residuals from regression of spot-tomorrow order flow on stock market variables	USD million
OF_SPOT_NXT_FIT_SET	Fitted values from regression of spot-next order flow on stock market variables	USD million
OF_SPOT_NXT_RES_SET	Residuals from regression of spot-next order flow on stock market variables	USD million
CUMUL(·)	Cumulative sum series	
OF_FX_SWAPS	Order flow, FX swaps	USD million
OF_SET	Order flow, Stock Exchange	USD million
OF_OUTR_BOND	Order flow, "Outright" bonds	USD million
OF_OTHR_BOND	Order flow, "Other" bonds	USD million

systematically to bond market order flow generated by nonresident investors "outright" bond transactions, but not to investors' "other" bond transactions, and only barely to stock market variables. The R^2 statistic of the regression of the spot-next series on the stock market variables alone was 0.19, and the R^2 of the regression of the spot-tomorrow series on the bond market variables was 0.11. For comparison, the R^2 value for the regression of spot-tomorrow order flow on just the stock market variables was only 0.05.[26]

[26]In addition, we determined that foreign investors' FX swap order flow was linked statistically to investors' "other" bond market transactions. We also found that that the *overall* influence of FX swap order flow on baht-dollar returns is insignificant. Splitting the overall swap order flow series into two components—a portion that is explained by bond market variables alone, and a residual—yields statistically insignificant coefficient estimates for both the fitted and the residual regressors.

We offer two, not mutually exclusive, interpretations of this (negative) result: First, the lack of influence of the FX swap order flow variable (and its components) on the exchange rate could be due to the fact that FX swaps are used frequently in banks' money market operations; such transactions do not convey investors' private information about future baht-denominated asset returns. Second, the lack of influence could also be due to the fact that our net purchase series is not a good proxy for order flow in the case of FX swaps, because FX swaps tend to be initiated by banks as well as by their customers; the lack of statistical significance could therefore also be due in part to measurement error.

Table 2: FX order flow regression

The dependent variable is the log-first-difference of the baht/dollar exchange rate. The regressors are measured in millions of US dollars. Positive values of the regression coefficients imply a depreciation of the baht versus the dollar. The numbers in the p-value column denote the significance of the associated t-statistics against the two-sided alternative that the coefficients in question are different from zero.

Regressor	Coeff.	Std. Error	t-statistic	p-value
OF_SPOT_TOM_FIT_BND	0.08×10^{-5}	8.98×10^{-6}	0.083	0.934
OF_SPOT_TOM_RES_BND	-0.78×10^{-5}	2.36×10^{-6}	−3.286	0.001
OF_SPOT_NXT_FIT_SET	-3.06×10^{-5}	2.54×10^{-6}	−12.084	0.000
OF_SPOT_NXT_RES_SET	-0.99×10^{-5}	1.14×10^{-6}	−8.668	0.000
	R^2	0.487	F-statistic	18.71
	Adj. R^2	0.461	Prob. F-statistic	0.00

Additional regressors: constant term, two lags of dependent variable, same-day spot FX order flow, outright FX forwards order flow, FX swap order flow, first lag of all order flow regressors.
Number of observations: 332 after adjustments.

In the second stage, we ran an order flow regression with baht-dollar returns as the dependent variable and the constructed FX order flow series as the regressors.[27] Because the fitted values and residual values of the spot-tomorrow and spot-next series are generated from first-stage regressions, the resulting dependence between the generated regressors and the regression's error term renders analysis using OLS-based standard errors invalid. In consequence, we estimated the equation using a two-stage least squares procedure, in which we used instruments for the fitted regressors to obtain consistent estimates of the standard errors.[28]

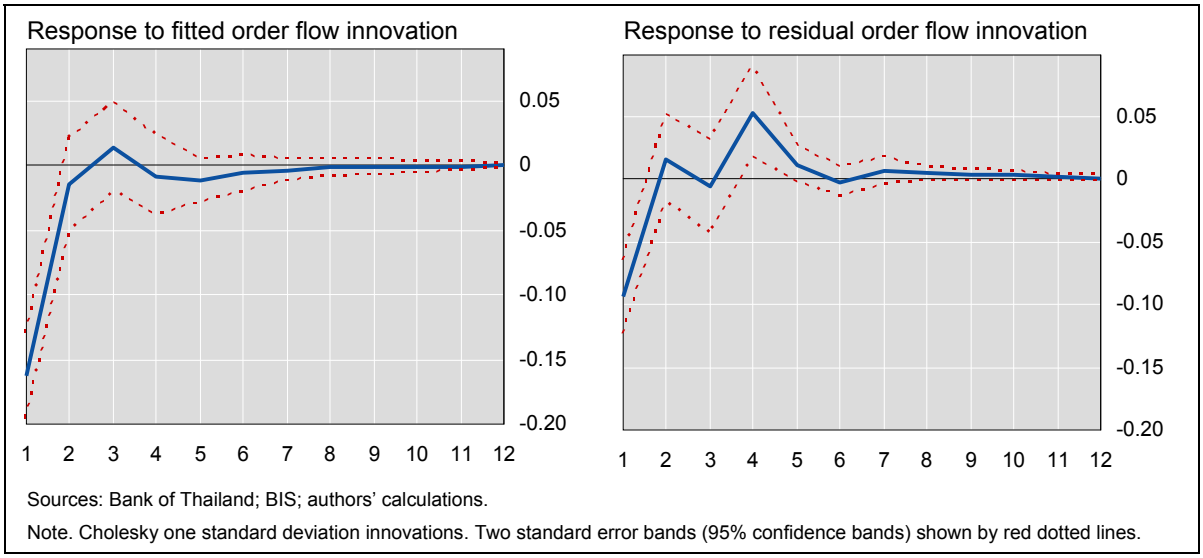
Hypothesis 1 is strongly supported by the data. The coefficients of both the fitted and the residual regressors for spot-next order flow derived from the first-stage regressions, shown in Table 2, are both statistically significant and are negative. However, the coefficient of the fitted spot-next regressor is more than three times as large in absolute value the coefficient of the residual spot-next regressor, and the difference between the two estimated coefficients is statistically significant. The coefficient estimates, which show the marginal influence of the various order flow types, indicate that an increase in the fitted portion of foreign customers' spot-next order flow of US$ 100 million would, on average, lead to an appreciation of the baht against the U.S. dollar of ca. 0.31%, whereas an equal-sized increase in the residual portion of this series would generate an appreciation of the baht of 0.10%.

[27] In this regression, we also included—but do not report separately in Table 2—a constant term, two lags of the dependent variable, contemporaneous same-day, outright-forward and FX swap order flow, and 1 lag of each of all order flow regressors. Adding several regressors that serve as proxies for public information led to a small increase in the overall goodness of fit of the model, but the quantitative and qualitative results for the order flow regressors were unchanged.

[28] See, e.g., Mishkin (1982) and Pagan (1984) for a thorough discussion of issues that arise in models with constructed regressors. Pagan shows that whereas the OLS-based estimates of all coefficients as well as the OLS-based standard errors of the *residual* regressors are consistent in such a model, the OLS-based standard errors of the *fitted* regressors are inconsistent.

Figure 1: Impulse response functions of THB/USD returns to order flow innovations

Vertical axes: Percent change in exchange rate across days



Sources: Bank of Thailand; BIS; authors' calculations.

Note. Cholesky one standard deviation innovations. Two standard error bands (95% confidence bands) shown by red dotted lines.

We interpret these results as clear evidence that—dollar for dollar—the portion of spot-next FX order flow that is driven by equity market activity has a more pronounced contemporaneous effect on the exchange value of the baht than the residual component of spot-next order flow has. Given that private information appears to be an important driver of equity market activity, it also exerts an important influence on FX market activity and returns as well.

Hypothesis 2 is also supported by the regression results: the portion of spot-tomorrow order flow that is related to foreign investors' transactions in the bond market does not have a statistically significant impact on returns. Instead, all of the explanatory power of the overall spot-tomorrow order flow variable is contained in the residual component. We interpret this as indicating that because private information is known not to drive nonresident investors' activity in the bond market, the portion of FX order flow that is induced by foreign investors' bond market activities does not induce FX dealers to change their quotes in response to such order flow; hence, it does not systematically affect the baht's exchange value.[29]

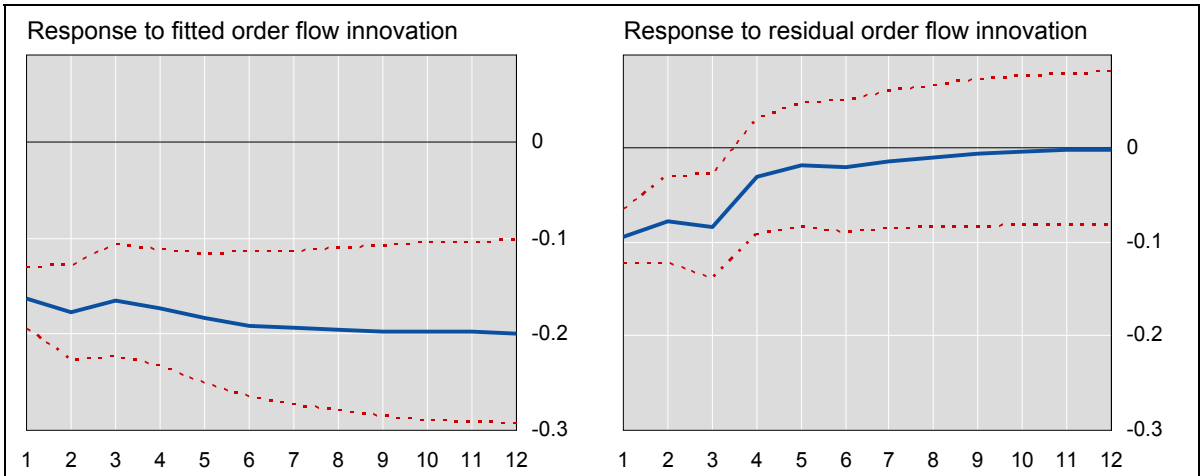
4.3 Permanent versus transitory influences of FX order flow

Do the effects on the exchange rate of the fitted and residual portions of spot-next order flow differ not only in their initial magnitude but also in their persistence? To answer this question for the case of spot-next order flow, which constitutes by far the largest segment of the spot FX market, we estimated a three-variable vector autoregressive (VAR) model that includes the fitted values of the regression of spot-next order flow on stock market variables, the residual portion of spot-next order flow, and baht-dollar returns. Three lags of all variables were included in the VAR. We orthogonalized the impulse response function using the Cholesky decomposition to let

[29] Since September 2003, nonresident investors who bought bonds issued by domestic financial institutions in Thailand have been required to hold these bonds for at least 3 months. Although the size of nonresident investors' holdings of such bonds is small, it is possible that this constraint could be partly responsible for this empirical result.

Figure 2: Cumulative response functions of THB/USD level to order flow innovations

Vertical axes: Percent change in exchange rate across days



Sources: Bank of Thailand; BIS; authors' calculations.

Note. Cholesky one standard deviation innovations. Two standard error bands (95% confidence bands) shown by red dotted lines.

innovations in the order flow series drive FX returns, but not vice versa. The two order flow series were found to be weakly exogenous to the exchange rate returns series;[30] hence, our choice of ordering of the variables in the Cholesky decomposition is supported by the data.[31] We then computed the impulse response functions (IRFs) and cumulative response functions (CRFs) to trace the effects of innovations in the fitted and residual components of spot-next FX order flow on baht returns. The IRFs and CRFs show the effects out to 12 days after an innovation. At longer time horizons, the functions are essentially flat and do not provide additional information about the system's dynamic properties.

The IRFs in Figure 1 show that a 1 standard deviation innovation in the portion of spot-next order flow that can be attributed to equity market variables has an *initial* impact on baht returns that is almost twice as large (-0.16% vs. -0.09%) as that of a 1 standard deviation innovation in residual spot-next order flow. Taking into account that in the sample period the standard deviations of the fitted and residual portions of 2-day spot order flow were US$ 58.6 million and US$ 126.6 million, respectively, it follows that—dollar for dollar—innovations in the fitted portion of FX order flow have an initial impact on the baht that is *almost four times as large* as that of innovations in the residual portion.

The longer-term effects of these innovations on the *level* of the Thai baht's exchange value are shown by the CRFs in Figure 2. The left-hand panel shows that the initial impact of an innovation in spot-next FX order flow that is driven by equity market activity is not reversed and that it remains statistically different from zero. Hence, an innovation in the portion of spot-next order flow that is linked to stock market variables has a permanent and statistically significant effect on the level of the baht.

[30] Killeen, Lyons, and Moore (2006) also found weak exogeneity of order flow with respect to exchange rates, for the case of French franc/Deutsche mark exchange rate pair.

[31] To check the robustness of our conclusions to the choice of specification, we re-estimated the VAR with 6 lags instead of 3 lags, and we also constructed the IRFs and CRFs using a "structural" decomposition instead of the commonly-used Cholesky decomposition. Our conclusions were not affected by these alternative specifications.

In striking contrast, the right-hand panel of Figure 2 shows that the initial impact of an innovation in the residual portion of spot-next FX order flow on the *level* of the baht's exchange value is quickly undone over the next few days. The cumulative impact of such an innovation on the level of the baht is zero. Hence, even though the contemporaneous effect of the residual component of spot-next order flow is statistically significant (see Table 2), this variable has no *lasting* influence on the level of the baht. The purely temporary influence of the residual component of spot-next order flow on the exchange rate suggests that its influence on the exchange rate is composed of inventory and liquidity effects, rather than information effects which should be permanent. These results therefore confirm Hypothesis 3, which held that the portion of FX order flow that reflects transactions related to stock markets should have a permanent effect on the exchange rate, whereas other portions should not. We infer that capital flows driven by private information have a permanent effect on the exchange rate.

4.4 Cointegration analysis

A different way of examining which components of FX order flow have a permanent influence on the exchange rate has been proposed by Killeen, Lyons, and Moore (2006). They argued that if FX order flow, an I(0) variable, has a permanent effect on the level of the exchange rate, an I(1) variable, then cumulative FX order flow and the exchange rate must be cointegrated. Conversely, if a cumulative FX order flow series and the exchange rate are not cointegrated, then any effects this order flow series has on the exchange rate must be purely transitory.

Table 3 shows the results of unit root tests performed on several univariate time series and on the residuals from bivariate cointegrating regressions between the log exchange rate level and several cumulative order flow series.[32] Unsurprisingly, we find that the null hypothesis of a unit root in the log exchange rate and in the cumulative spot-tomorrow and spot-next order flow series is not rejected (lines 1–3). The same result holds for the cumulative series of the *fitted* values from the regressions of spot-tomorrow and spot-next on stock market variables (lines 4 and 6). For the residuals from these first-stage regressions, the null of a unit root *can* be rejected, at the 8% and 4% levels of significance, respectively. Therefore, the components of the spot-tomorrow and spot-next order flow series that are uncorrelated with stock market variables *cannot* have a long-run effect on the exchange rate. Because series of different orders of integration are trivially cointegrated, we do not report the results of cointegration tests for residuals of cointegrating regressions between the log exchange rate (an I(1) series) and the two components of spot-tomorrow and spot-next order flow that are not explained by stock market variables, as they appear to be I(0) series.

Applying the same test procedure to the residuals from the cointegrating regressions, we find that cumulative *total* spot-next order flow is not cointegrated with the exchange rate (line 8). In contrast, the null hypothesis that the portion of cumulative spot-next order flow that is explained by stock market variables is not cointegrated with the exchange rate can be rejected (line 9), but only with a nominal p-value of 0.11. As we noted earlier, this cumulative order flow series

[32] We used Augmented Dickey-Fuller tests. We included a constant term and 10 lags of the dependent variable to eliminate the effects of short-run dynamics. We found that our results were not sensitive to slight variations in the number of lags.

Table 3: Augmented Dickey-Fuller unit root tests

We show the ADF t-statistics of the null hypothesis that the series in question has a unit root. The associated p-values are for the one-sided alternative that the series in question is stationary.

	t-statistic	p-value
(a) Univariate unit root tests		
LN(THB/USD)	0.875	0.995
CUMUL(OF_SPOT_TOM)	−0.487	0.891
CUMUL(OF_SPOT_NXT)	−1.621	0.471
CUMUL(OF_SPOT_TOM_FIT_SET)	0.410	0.983
CUMUL(OF_SPOT_TOM_RES_SET)	−2.658	0.082
CUMUL(OF_SPOT_NXT_FIT_SET)	−1.960	0.305
CUMUL(OF_SPOT_NXT_RES_SET)	−2.917	0.044
(b) Unit root tests performed on residuals from cointegrating regressions		
LN(THB/USD) vs. CUMUL(OF_SPOT_NXT)	−0.646	0.437
LN(THB/USD) vs. CUMUL(OF_SPOT_NXT_FIT_SET)	−1.565	0.111
LN(THB/USD) vs. CUMUL(OF_SPOT_TOM)	−1.671	0.090
LN(THB/USD) vs. CUMUL(OF_SPOT_TOM_FIT_SET)	−1.547	0.115

must have an I(1) measurement error component because the order flow series is not observed directly but is estimated and is subject to estimation error. This biases the statistical tests towards non-rejection of the null hypothesis of no cointegration, even if the null hypothesis is false. To preserve some power against in a finite sample against the alternative of cointegration, one has to be willing to increase the Type I error rate or, equivalently, raise the critical p-values. We therefore judge that the exchange rate is indeed cointegrated with the portion of cumulative spot-next order flow that is explained by stock market variables. We also conclude that cumulative spot-tomorrow order flow and the spot exchange rate are cointegrated (line 10). Interestingly, even though the regression of spot-tomorrow order flow on stock market order flow has an R^2 value of only 0.05, the long-run stable relationship between cumulative overall spot-tomorrow order flow and the exchange appears to be due mainly to the portion of order flow that is fitted to the stock market variables (line 11).

4.5 Discussion

One might view differences in hedging of FX market risk across asset classes as a possible alternative explanation for our findings. If FX risk incurred by holding Thai equities is not hedged whereas FX risk incurred by holding baht-denominated government bonds is, would this not generate the same observations? If private information is driving changes in equity values, then it should generate order flow in the equity and, indirectly, in the FX market regardless of whether FX risk is hedged or not; hedging will only determine who bears FX risk. In our view, hedging of FX risk would only eliminate the need to execute FX flows that would be induced by investors' portfolio rebalancing across countries, but that is not a function of information.

Moreover, in the onshore Thai FX market, any hedging of FX risk typically takes place via FX swaps. If there is hedging of outright bond positions but not of equity positions, FX swap

Table 4: Determinants of FX swap order flow

The dependent variable is the FX swap order flow by nonresident investors in Thailand. The numbers in the p-value column denote the significance of the associated t-statistics against the two-sided alternative that the coefficients in question are different from zero.

Regressor	Coeff.	Std. Error	t-statistic	p-value
SET	−525.613	687.958	−0.764	0.445
OF_SET	0.380	0.217	1.750	0.081
OF_OUTR_BOND	0.313	0.138	2.262	0.024
OF_OTHR_BOND	0.830	0.215	3.865	0.000
	R^2	0.180	F-statistic	4.63
	Adj. R^2	0.142	Prob. F-statistic	0.00

Additional explanatory variables: Constant term and first three lags of regressors shown.
Number of observations: 353 after adjustments.

order flow should be driven more by outright bond flows than by equity flows. However, when we regress FX swap order flows on equity, outright bond, and other bond market order flow, we find that during the sample period nonresident investors did not appear to use FX swaps differently for hedging their equity and "outright" bond transactions; see Table 4 for the results of this regression. The point estimate of the coefficient on contemporaneous stock market order flow is actually slightly larger than that of outright bond order flow, but the difference between the point estimates is not statistically significant. The low extent to which FX risk incurred by holding equities or "outright" bonds is hedged may owe to the fact that nonresident investors in Thailand face binding restrictions that make the hedging of FX market risk either expensive or infeasible. Differences in hedging behavior therefore cannot explain our finding that FX order flow associated with stock market variables has a large and permanent effect on the exchange rate whereas FX order flow associated with outright bond transactions appears to have no effect.[33]

Another alternative explanation for our finding that bond market order flow does not appear to convey information relevant for the exchange rate, which does not necessarily contradict our explanation, is that foreigners could be buying and selling Thai bonds as part of a carry trade strategy. During the sample period, Thailand was an emerging market economy with strong economic growth and attractive interest rate differentials. If nonresident investors' bond transactions are mainly carry trades, their order flow would contain no private information. During the sample period, however, we found that interest rate differentials were not significant drivers of exchange rate movements. Thus, carry trades cannot explain our findings.[34]

We found that fluctuations of the Japanese yen against the US dollar help explain contemporaneous baht-dollar movements, with a 1 percent appreciation of the yen against the dollar being associated with a same-day 0.3 percent appreciation of the baht against the dollar. However, the inclusion of this regressor in order flow regressions has only a negligible impact on

[33]Table 4 also shows that the FX risk embedded in "other" bond transactions *does* appear to be almost fully hedged through offsetting FX swap transactions. This is consistent with "other" bond market transactions being used mainly in conjunction with banks' local money market operations as well as our finding that our inferences are not sensitive to the removal of "other" bond transactions from the order flow regressions.

[34]Sarno and Sojli (2008) and Sarno and Valente (2008) review the "feeble" or "footloose" connection between exchange rates and economic fundamentals such as interest rate differentials.

the coefficients of the order flow variables. This indicates that information conveyed by equity market order flow is an important driver of the exchange rate.

Some might suspect that econometric specification choices could be driving the results. In particular, one might be concerned that our proxies for the portions of FX order flow that are induced by investors' order flow in the stock and bond markets are too simplistic. The construction of our proxies is indeed very simple. Of course, one cannot gauge precisely how good the proxies are, as it is not possible to determine exactly which equity and bond market order flows drive which FX flows. However, the fact that the time series of the portions of spot-next and spot-tomorrow FX order flow that are driven by stock market variables are cointegrated with the exchange rate suggests that the proxy variables are in fact quite good. Nevertheless, it remains an open question whether more-precise proxies would weaken or strengthen our findings.

A final, more general point is that our assumption that nonresident investors in Thailand engage in the generation of private information does not imply that they are either better or worse informed on average than domestic investors, or that they earn higher or lower profits on average from their equity market strategies. In fact, for our analysis to apply, we only require that there be heterogeneity between nonresident and domestic investors with respect to private information that gives rise to transactions between these investor groups in the stock market and, indirectly, the FX market. In our dataset, we found that the patterns present in foreign investors' stock market order flow indicated that they had, on average, *less* private information about SET-listed firms than domestic investors had. This finding is consistent with the studies by Choe, Kho, and Stulz (2005), Dvořák (2005), Chan, Menkveld, and Yang (2007), and Taechapiroontong and Suecharoenkit (2008), who report that nonresident investors tend to have less private information in the local equity markets of Korea, Indonesia, China, and Thailand, respectively.

5 Concluding remarks

In this paper, we have proposed that what drives the exchange rate, other than public information, is investors' private information related to the stock market. We tested this proposition using daily-frequency data from three financial markets in Thailand, and we presented compelling evidence in favor of the proposition. As George Orwell (1945) might have been tempted to observe, some FX flows are more equal than others: The relatively small portion that is related to and conveys investors' private information about the stock market has lasting effects on the exchange rate, whereas the much larger portion of FX flows that is not explained by stock market variables plays at most a transitory role in determining the exchange rate.

Our findings suggest that data collection efforts on external capital flows might be made more informative if they were categorized according to their private-information content. Having such data would enable economists and policy makers to distinguish more readily between information-driven flows and those that are driven by liquidity or "noise" trades. Our results suggest that analysts should focus their attention on those flows that convey private information.

We close by mentioning several limitations to the generality of our findings. First, our empirical results are based on data from Thailand. It remains to be determined if similar results can be established for more-developed economies and for other emerging market economies. Second,

there was very little trading in Thai corporate bonds by foreign investors during the sample period. It will be interesting to examine whether exchange rates are related systematically to order flow induced by investors' order flow in economies with active corporate bond markets, as private information should also be relevant for investors' decisions in this segment of the capital markets. Third, our FX order flow dataset currently consists of the aggregate transactions between nonresident end-users and FX dealers, and thus covers only a part of the overall onshore Thai baht market. Going forward, it may become possible to broaden our analysis to transactions between domestic end-users and FX dealers and to inter-dealer transactions. Finally, our study covers a period of two years, 2005 and 2006. The structural break that occurred following the imposition of the URR capital control measures in mid-December 2006 made it impossible for us to model the subsequent data satisfactorily using the framework we developed for the pre-URR data. In March 2008, the URR controls were lifted and the system of capital market controls reverted roughly to its pre-URR state. An interesting issue is to determine whether the results we established for the pre-URR period in Thailand also apply to the post-URR period.

References

Albuquerque, R., E. de Francisco, and L. B. Marques, 2008, "Marketwide private information in stocks: Forecasting currency returns," *Journal of Finance*, 68(5), 2297–2343.

Anand, A., and A. Subrahmanyam, 2008, "Information and the intermediary: Are market intermediaries informed traders in electronic markets?," *Journal of Financial and Quantitative Analysis*, 43(1), 1–28.

Bacchetta, P., and E. van Wincoop, 2006, "Can information heterogeneity explain the exchange rate determination puzzle?," *American Economic Review*, 96(3), 552–576.

Bank of Thailand, Financial Markets Operations Group, 2005, "Foreign exchange policy and intervention in Thailand," in *Foreign Exchange Market Intervention in Emerging Markets: Motives, Techniques and Implications. Proceedings of the BIS Deputy Governors' Meeting held on 2–3 December 2004*. Bank for International Settlements, Basel, BIS Papers 24, pp. 276–282.

Barro, R. J., 1977, "Unanticipated money growth and unemployment in the United States," *American Economic Review*, 67(2), 101–115.

Berger, D. W., A. P. Chaboud, S. V. Chernenko, E. Howorka, and J. H. Wright, 2008, "Order flow and exchange rate dynamics in Electronic Brokerage System data," *Journal of International Economics*, 75(1), 93–109.

Bjønnes, G. H., C. L. Osler, and D. Rime, 2008, "Asymmetric information in the interbank foreign exchange market," Manuscript, Department of Economics, Brandeis University.

Bjønnes, G. H., D. Rime, and H. O. Å. Solheim, 2005, "Liquidity provision in the overnight foreign exchange market," *Journal of International Money and Finance*, 24(2), 175–196.

Brooks, R., H. J. Edison, M. S. Kumar, and T. M. Sløk, 2001, "Exchange rates and capital flows," Working Paper 01/190, International Monetary Fund, Washington DC.

Cao, H. H., M. D. D. Evans, and R. K. Lyons, 2006, "Inventory information," *Journal of Business*, 79(1), 325–363.

Chai-Anant, C., and C. Ho, 2008, "Understanding Asian equity flows, market returns, and exchange rates," Working Paper 245, Bank for International Settlements, Basel.

Chan, K., A. J. Menkveld, and Z. Yang, 2007, "The informativeness of domestic and foreign investors' stock trades: Evidence from the perfectly segmented Chinese market," *Journal of Financial Markets*, 10(4), 391–415.

Cheung, Y.-W., M. D. Chinn, and A. I. Garcia Pascual, 2005, "Empirical exchange rate models of the nineties: Are any fit to survive?," *Journal of International Money and Finance*, 24(7), 1150–1175.

Chinn, M. D., and M. J. Moore, 2008, "Private information and a macro model of exchange rates: Evidence from a novel data set," Working Paper 14175, National Bureau of Economic Research, Cambridge MA.

Choe, H., B.-C. Kho, and R. Stulz, 2005, "Do domestic investors have an edge? The trading experience of foreign investors in Korea," *Review of Financial Studies*, 18(3), 795–829.

Dunne, P. G., H. Hau, and M. J. Moore, 2006, "International order flows: Explaining equity and exchange rate returns," Manuscript, Queens University, Belfast.

Dvořák, T., 2005, "Do domestic investors have an information advantage? Evidence from Indonesia," *Journal of Finance*, 60(2), 817–839.

Evans, M. D. D., and R. K. Lyons, 2002, "Order flow and exchange rate dynamics," *Journal of Political Economy*, 110(1), 170–180.

——— , 2005, "A new micro model of exchange rate dynamics," Working Paper 10379, National Bureau of Economic Research, Cambridge MA.

——— , 2007, "Exchange-rate fundamentals and order flow," Working Paper 13151, National Bureau of Economic Research, Cambridge MA.

——— , 2008, "How is macro news transmitted to exchange rates?," *Journal of Financial Economics*, 88(1), 26–50.

Fischer, A. M., 1990, "Cointegration and I(0) measurement error bias," *Economics Letters*, 34(3), 255–259.

Francis, B. B., I. Hasan, and D. M. Hunter, 2006, "Dynamic relations between international equity and currency markets: The role of currency order flow," *Journal of Business*, 79(1), 219–257.

Frankel, J. A., 1983, "Monetary and portfolio-balance models of exchange rate determination," in *Economic Interdependence and Flexible Exchange Rates*, ed. by J. S. Bhandari, B. H. Putnam, and J. H. Levin. MIT Press, Cambridge MA, chap. 3, pp. 84–115.

Froot, K. A., and T. Ramadorai, 2005, "Currency returns, intrinsic value, and institutional investor flows," *Journal of Finance*, 60(3), 1535–1566.

Gehrig, T., and L. Menkhoff, 2004, "The use of flow analysis in foreign exchange: Exploratory evidence," *Journal of International Money and Finance*, 23(4), 573–594.

Glosten, L. R., and P. R. Milgrom, 1985, "Bid, ask, and transition prices in a specialist market with heterogenously informed traders," *Journal of Financial Economics*, 14(1), 71–100.

Goodhart, C. A. E., 1988, "The foreign exchange market: A random walk with a dragging anchor," *Economica*, 55(220), 437–460.

Gradojevic, N., and C. J. Neely, 2008, "The dynamic interaction of order flows and the CAD/USD exchange rate," Working Paper 2008-006A, Federal Reserve Bank of St. Louis.

Granger, C. W. J., and P. Newbold, 1974, "Spurious regressions in econometrics," *Journal of Econometrics*, 2(22), 111–120.

Gyntelberg, J., M. Loretan, T. Subhanij, and E. Chan, 2009, "The exchange rate, portfolio rebalancing, and equity market capital flows in Thailand," Draft manuscript, Bank for International Settlements, Basel.

Hassler, U., and V. Kuzin, 2008, "Cointegration analysis under measurement errors," Manuscript, Goethe University Frankfurt.

Hau, H., 2001, "Location matters: An examination of trading profits," *Journal of Finance*, 56(5), 1959–1983.

Hau, H., and H. Rey, 2006, "Exchange rates, equity prices, and capital flows," *Review of Financial Studies*, 19(1), 273–317.

Killeen, W. P., R. K. Lyons, and M. J. Moore, 2006, "Fixed versus flexible: Lessons from EMS order flow," *Journal of International Money and Finance*, 25(4), 551–579.

Kyle, A. S., 1985, "Continuous auctions and insider trading," *Econometrica*, 53, 1315–1335.

Love, R., and R. G. Payne, 2008, "Macroenomic news, order flows, and exchange rates," *Journal of Financial and Quantitative Analysis*, 43(2), 467–488.

Lyons, R. K., 2001, *The Microstructure Approach to Exchange Rates*. MIT Press, Cambridge MA.

Madhavan, A., 2000, "Market microstructure: A survey," *Journal of Financial Markets*, 3(3), 205–258.

Meese, R. A., and K. S. Rogoff, 1983, "Empirical exchange rate models of the seventies: Do they fit out of sample?," *Journal of International Economics*, 14(1–2), 3–24.

Mishkin, F. S., 1982, "Does anticipated monetary policy matter? An econometric investigation," *Journal of Political Economy*, 90(1), 22–51.

Newey, W. K., and K. D. West, 1987, "A simple, positive semi-definite, heteroskedasticity and autocorrelation consistent covariance matrix," *Econometrica*, 55(3), 703–708.

O'Hara, M., 1995, *Market Microstructure Theory*. Blackwell, Cambridge.

Orwell, G., 1945, *Animal Farm. A Fairy Tale*. Secker and Warburg, London.

Osler, C. L., 2006, "Macro lessons from microstructure," *International Journal of Finance and Economics*, 11(1), 55–80.

——— , 2008, "Foreign exchange microstructure: A survey of the empirical literature," Manuscript, Department of Economics, Brandeis University.

Pagan, A. R., 1984, "Econometric issues in the analysis of regressions with generated regressors," *International Economic Review*, 25(1), 221–247.

Phillips, P. C. B., 1986, "Understanding spurious regressions in econometrics," *Journal of Econometrics*, 33(3), 311–340.

Reitz, S., M. A. Schmidt, and M. P. Taylor, 2008, "End-user order flow and exchange rate dynamics," Discussion Paper 05/2007, Deutsche Bundesbank, Frankfurt am Main.

Richards, A. J., 2005, "Big fish in small ponds: The trading behavior and price impact of foreign investors in Asian emerging equity markets," *Journal of Financial and Quantitative Analysis*, 40(1), 1–27.

Sarno, L., and E. Sojli, 2008, "The feeble link between exchange rates and fundamentals: Can we blame the discount factor?," Manuscript, Warwick Business School, University of Warwick, Coventry. Forthcoming, *Journal of Money, Credit and Banking*.

Sarno, L., and M. P. Taylor, 2002, *The Economics of Exchange Rates*. Cambridge University Press, Cambridge.

Sarno, L., and G. Valente, 2008, "Exchange rates and fundamentals: Footloose or evolving relationship?," Discussion Paper 6638, Centre for Economic Policy Research, London, Forthcoming, *Journal of the European Economic Association*.

Siourounis, G., 2008, "Capital flows and exchange rates: An empirical analysis," Working Paper 2008-028, Department of Economics, University of the Peloponnese, Tripoli, Greece.

Stoll, H. R., 1978, "The pricing of security dealer services: An empirical study of NASDAQ stocks," *Journal of Finance*, 33(4), 1153–1178.

Taechapiroontong, N., and P. Suecharoenkit, 2008, "Trading performance of individual, institutional, and foreign investors: Evidence from the Stock Exchange of Thailand," Manuscript, College of Management, Mahidol University, Bangkok.

Tille, C., and E. van Wincoop, 2008, "International capital flows under dispersed information: Theory and evidence," Working Paper 14390, National Bureau of Economic Research, Cambridge MA.

Vitale, P., 2007, "Optimal informed trading in the foreign exchange market," Discussion Paper 6553, Centre for Economic Policy Research.

White, H., 1980, "A heteroskedasticity-consistent covariance matrix estimator and a direct test for heteroskedasticity," *Econometrica*, 48(4), 817–838.