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«**Mixture distribution hypothesis and the impact of a Tobin tax on exhange rate volatility : a reassessment** »

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Mixture distribution hypothesis and the impact of a Tobin tax on exchange rate volatility: a reassessment[1]

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Abstract

From Olsen Financial Studies data on the Euro-Dollar currency pair (2008-2010), we conduct a time-series analysis to explain the role of trading volume on exchange rate volatility (Mixture Distribution Hypothesis), taking into account non-linearity. We find evidence that the MDH holds in turbulent periods, during which spreads and volume trading are high. When spreads and the volume are high, the relationship between trading volume and volatility tends to increase. Linking this result with the Tobin tax debate implies that a Tobin tax would be effective for curbing speculation and reducing exchange rate volatility, even in turbulent periods. This paper provides the first empirical corroboration of this proposition and seems to confirm some previous theoretical papers in the vein of Tobin. All in all, two main results emerged. First, the abundant literature on the MDH, but exclusively based on linear econometrics, should take into account non-linearities. Second, the effect of a Tobin tax on volatility would be slightly context-dependent and always negative. A Tobin tax would have been stabilizing and effective in the 2008 crisis when spreads, volume and volatility were very high.

JEL codes: E44, F31, C22

Key words: Tobin Tax, exchange rate volatility, STR models, non-linearity, Mixture Distribution Hypothesis

Introduction

The economic downturn following the sub-prime crisis and the recent sovereign debt crisis has led to renewed interest in a Tobin tax. Such a tax is viewed as a possible way of dampening down the deficits of the industrialized countries. Last September, the French President Nicolas Sarkozy and the German Chancellor Angela Merkel floated the idea of a European tax on financial transactions. The main reason for such a taxation project is that a Tobin tax can generate large revenues. However, the original purpose of the so-called Tobin tax was not to produce revenue for industrialized countries but to stabilize exchange rates.

In 1972, during the Janeway Lectures at Princeton, James Tobin suggested putting "some sand in the wheels of international finance" by imposing a tax on all foreign exchange transactions. The first aim of his proposal was to preserve and strengthen the autonomy of national monetary policies in the early 1970s, following the decision by the U.S. government to come off the gold standard and introduce floating exchange rates. As Tobin wrote: "monetary policy becomes, under floating rates, exchange rate policy" [1978, p. 156]. The second aim was to reduce foreign exchange rate and financial volatility. Tobin's underlying thinking (see Tobin [1974, 1978, 1984, 1996]) was that short term round-trip transactions (for instance, speculative transactions) are more destabilizing than long-term transactions. This idea had first been put forward by Keynes [1936] in his metaphor of the "beauty contest". This notion of harmful volatility created by speculative trading contrasts with the position taken by Friedman [1953], who argued that speculation is in general not destabilizing but, on the contrary, helps stabilize prices. Tobin suggested that a tax would reduce volatility by discouraging short-term transactions (thereby curbing destabilizing speculative trading) to a greater extent than long-term transactions (and investments) and thus crowding out speculators and noise traders from foreign exchange markets (Forex hereafter) in favor of fundamentalists and long-term investors.

However, this argument has been challenged by both proponents and opponents of the tax[3]. There are two main objections to it. First, not all short-term transactions are speculative, but may be the result of the "hot potato" phenomenon (see, for instance, Lyons [2001]). Consequently the large daily turnover of Forex ($4.0 trillion, BIS [2010]) would not only

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[3] As recently shown by a recent survey (see McCulloch and Pacillo [2011]), the Tobin tax is an emotive issue.

reflect speculative behavior but liquidity and risk-sharing behavior. Second, the Tobin tax is an indiscriminate tax and would penalize not only destabilizing transactions but also transactions that provide liquidity and information. Therefore, by crowding out short-term transactions, a tax would be counterproductive. Indeed, by reducing the liquidity of Forex and the financial markets, it would increase volatility. In fact, as underlined by Davidson [1997], Bianconi et al. [2009] and Hanke et al. [2010], a liquidity market is likely to be more stable than a thin market.

In this paper, we seek to assess the impact of a Tobin tax on volatility. In other words, we try to see whether a reduced volume of transactions might have a destabilizing or a stabilizing effect. To this end, we examine two empirical relationships. On the one hand, we look at the influence of a tax on trading volume on the assumption that the tax increases spreads. On the other, we assess the relationship between trading volume and Forex volatility given the expected decrease in the trading volume subsequent to the tax. The reason for examining the relationship between trading volume and volatility comes from Mixture Distribution Hypothesis (MDH) studies. This literature posits that price volatility and trading volume dynamics are both coordinated by the same information arrival rate. This question is initially not connected to our research problematic, but by evaluating the relationship between trading volume and volatility, we can derive some policy recommendations concerning the functioning modalities of a Tobin tax. Since the tax will necessarily lead to a reduction in the trading volume, if we can assess the impact of the volume on volatility, we will then shed some light on the Tobin tax debate in regard to its impact on exchange rate volatility.

The main distinctive feature of our analysis is the application of the MDH literature to the Tobin tax debate. Indeed, the MDH literature has not addressed the issue of instituting a Tobin tax. Another distinctive feature of our work is the non-linear environment we used. While previous studies in the MDH literature have empirically examined the link between trading volume and volatility in foreign exchange transactions, none of them has addressed the issue of regime switching. Our intuition is that regime-switching models describe this relationship better than single-regime models because of the heterogeneity of the trading behaviors of traders. Furthermore, until now empirical studies on the volatility impact of a Tobin tax have used a linear framework and have concentrated only on the spread-volatility relationship. In the present study, we overcome these limitations by allowing for the possibility of non-linearities in the volume-volatility relationship, consistently with the

theoretical work of Jeanne and Rose [2002], Haberer [2004] and Shi and Xu [2009] among others.

In other words, based on smoothed threshold regression models (STR), the main research questions tackled in this paper are the following. What is the effect of a Tobin tax on exchange rate volatility? Is this effect uniformly distributed across the different Forex regimes (high appreciation of the Euro, low volume trading, the financial crisis, etc.)? What policy recommendations can be derived as a consequence?

The paper makes two important contributions. First, we show that the MDH – i.e. the positive relationship between volume and volatility – depends on the level of the volume trading and to a lesser extent on the level of cost transactions (spreads), and that it holds in both "normal" and "turbulent" times. In addition, we find evidence of an increasing mixture distribution in turbulent times with high volume and spreads, as in the crisis of autumn 2008. The paper thus challenges the MDH literature based only on linear frameworks. Second, our results enable us to assess the stabilizing effect of a Tobin tax on exchange rate volatility. A Tobin tax could decrease volatility by crowding out noise traders, chartists and speculators, as proposed by advocates of the tax. This effect is, however, more pronounced in "turbulent periods" than in "normal times", that is, when the volume of trading increases. In other words, a Tobin tax would be more effective in turbulent periods, when the number of speculators is very high, as expected by Tobin [1974]. Moreover, a Tobin tax would have been stabilizing in the 2008 crisis when spreads, volume and volatility were very high.

The paper is structured as follows. Section 2 details the theoretical and empirical literature assessing the link between a Tobin tax and volatility. Section 3 introduces the methodology used. Section 4 deals with the empirical results. Section 5 expounds the policy implications of our results in regard to introducing a Tobin tax on Forex transactions.

2. Literature review

2.1 Theoretical studies

There are a wide range of theoretical studies with different frameworks and assumptions providing different results (see McCulloch and Pacillo [2011], for a detailed survey). It emerges from the Tobin tax literature that the main group of theoretical works is based on heterogeneous agent models, with a view to demonstrating that a tax could reduce the destabilizing part of volume trading. These studies are most often derived from the literature on foreign exchange market microstructure. Microstructure models depart from conventional exchange rate models based on rational expectations, where volatility simply reflects volatility in macroeconomic fundamentals (see for instance Mussa's [1976]) macroeconomic model). Indeed, no model based on fundamentals (real income, money supply, inflation and interest rates, etc.) "will ever succeed in explaining or predicting a high percentage of the variation in the exchange rate" (Frankel and Rose [1994]). In microstructure models (see Hommes [2006] for a survey), some traders have incomplete information about market conditions (for example, the risk premium) and are boundedly rational. Heterogeneous agent models help to solve the "exchange rate determination puzzle" (Lyons [2001], Bacchetta and Van Wincop [2003]), that is, the disconnection of the exchange rate from its underlying fundamentals[4] most of the time and thus the emergence of excess volatility.

This class of models assumes the coexistence of various kinds of fundamental/chartist and informed traders in Forex. The most often cited studies are those by Frankel and Rose [1994], Frankel and Froot [1990] and De Long et al. [1990]. Briefly, volatility is driven by the proportion of fundamental traders (sophisticated traders in the terminology of De Long et al. [1990] or informed traders in the Jeanne and Rose [2002] study) compared to the proportion of chartists (or noise traders), who use technical analysis, behave irrationally or lack correct information about prices, volatility and macroeconomic fundamentals.

To our knowledge, the main studies assessing the potential effects of a Tobin tax on volatility, dealing with heterogeneous models, are Frankel [1996], Hau [1998], Haberer [1994] and more recently Shi and Xu [2009]. These studies generally seek to evaluate changes

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[4] See also Frankel and Rose [1994].

in the composition of Forex traders resulting from the introduction of a Tobin Tax. The seminal paper by Frankel [1996] distinguishes two groups of traders in the market: investors and speculators. Investors are assumed to be long-term oriented and make transactions only on deviations of the exchange rate from its fundamental equilibrium value, while speculators are short-term oriented and buy currencies that are already overvalued. The model is constructed to bring out the rationale of a Tobin tax: if a Tobin tax were instituted, it would reduce exchange rate volatility by crowding out the short-term transactions.

However, while Frankel's [1996] approach has been very fruitful, the model holds only for the covered interest parity condition and thus the expectations of traders are not taken into account. More recently, Shi and Xu [2009] go further by modeling the microeconomic behavior of risk-adverse heterogeneous traders[5] in a paper closely related to the contribution of Jeanne and Rose [2002]. The benchmark model of Jeanne and Rose [2002] is very interesting because it mixes elements from the macroeconomic theory of exchange rates (Mussa [1976]) and the noise trading approach of financial volatility (De Long et al. [1990]) by modeling traders' heterogeneous expectations and the microeconomic specifications of their portfolio optimization. Jeanne and Rose [2002] have shown that exchange rate volatility can be expressed as a function of fundamental (or macroeconomic) volatility due to the transactions of informed traders and excess volatility due to the transactions of non-informed traders (or noise traders[6]). The salient output from their model is the derivation of three possible exchange rate equilibria with low to high entry by noise traders and thus low to high exchange rate excess volatility. In such a context, their model can generate different levels of aggregate volatility for the same levels of fundamental volatility, because the excess variance is a function of the number of noise traders.

Similarly to Jeanne and Rose [2002], Shi and Xu [2009] endogenize the entry decision of traders in the foreign exchange market, but they assume that the relative proportion of noise traders already present in Forex affects the overall benefit of entry differently for informed traders than for noise traders. Indeed, intuitively, informed traders need to take the relative noise component into consideration when forming rational expectations, while noise

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[5] Palley [1999] also used a microeconomic model, but he assumed two groups of risk-neutral traders (fundamentalists and speculators). As a result, a Tobin tax would increase market efficiency by reducing the noise trading component of the market. Moreover, although a Tobin tax would hit both kinds of traders, speculators would be affected more as a result of their higher trading frequency.
[6] Noise traders are a type of misinformed traders because they perceive only the second moment of the excess return correctly.

traders do not. When they introduce a Tobin tax which interacts with existing entry costs (that is, the spreads in practice), they find a very interesting result that it may not necessarily lead to a decrease in the relative noise component and may be ineffective in reducing volatility. In fact, three possible equilibria are derived. In the first equilibrium, there are the same number of noise and informed traders entering the market, so the introduction of a Tobin tax leads them to exit the market in pairs. Since the tax does not influence the composition of traders, it only reduces liquidity without changing volatility. In the second equilibrium, the tax affects the composition of traders, but the burden of the increasing transaction costs due to the new taxation is heavier for informed traders than for noise traders. Intuitively, the tax will discourage the entry of both types of traders, but the exit of traders will have a relatively positive externality on the overall entry benefits for noise traders. Indeed, the exit of informed traders increases the relative noise component, which in turn increases the entry benefit for all traders. Consequently, aggregate volatility increases and the Tobin tax turns out to be ineffective. In the third equilibrium, Shi and Xu [2009] argue that the entry cost is sufficiently high to prevent the entry of noise traders. Thus the composition of the market as well as volatility are unchanged after introducing the tax.

In the last decade, another set of studies have attempted to examine the impact of a Tobin tax[7] within the framework of a simulation model of heterogeneous interactive agents (Westerhoff [2003], Westerhoff and Dieci [2006], Pellizzari and Westerhoff [2009]), through the use of "zero intelligence" models (Ehrenstein [2003], Ehrenstein et al. [2005], Mannaro et al. [2008]), laboratory experiments (Bloomfield et al. [2009], Hanke et al. [2010]) and game theoretical study as minority games (Bianconi et al. [2009]).

The studies by Westerhoff [2003], Ehrenstein et al. [2005], Westerhoff and Dieci [2006], Mannaro et al. [2008] and Pellizzari and Westerhoff [2009] have the common feature of developing certain simulated financial markets of heterogeneous interactive agents (for instance, chartists/fundamentalists). Westerhoff [2003], using a model with chartists and fundamentalists, found that the tax can crowd out chartists and then reduce exchange rate volatility, but warns that the tax rate needs to be at a moderate level because stabilizing fundamental traders are likely to exit the market if the tax is too high. While previous studies concentrate on a single market, Westerhoff and Dieci [2006] investigate the case of a global

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[7] These papers deal with securities transaction taxes, but not only with the Tobin tax levied especially on foreign exchange transactions.

tax and find that if a tax is imposed on one market, speculators leave this market, which becomes less distorted and less volatile; however, agents may reappear in another market, which in turn becomes destabilized. Finally, if regulators impose a tax on all markets, speculation is dampened and all markets are thus less volatile. More recently, Pellizari and Westerhoff [2009] show that the effectiveness of a Tobin tax depends on the market microstructure[8]. In highly dealership markets where liquidity is provided by specialists, a transaction tax may reduce volatility by crowding out speculative transactions. In contrast, in limit order markets, the reduction in liquidity as a consequence of a tax amplifies the average price impact of a given order and thus has no effect on volatility.

Ehrenstein et al. [2005] and Mannaro et al. [2008] used zero intelligence agent models. The interesting feature of these models is they assume that traders place orders to trade at random rather by maximizing behavior. The use of zero intelligence models leads to mixed results. Ehrenstein et al. [2005], on the basis of the Cont-Bouchaud[9] herding model, take into account that a reduction of liquidity is likely to increase the price responsiveness of a given transaction and show that a Tobin tax would reduce volatility, as long as the tax rate is below a critical value and does not significantly reduce market liquidity. Mannaro et al. [2008] first consider a single market case in a model with four kinds of agents (random, fundamentalists and two kinds of chartists). It follows that price volatility increases consistently with the tax rate, but only when chartists are present in the market. When there are two markets, the findings conflict with those of Ehrenstein et al. [2005] using a similar approach and of Westerhoff and Dieci [2006][10], who also investigate the case of a global tax. Indeed, such a tax reduces trading volume and liquidity and the taxed market then becomes more volatile than the untaxed one.

Bloomfield et al. [2009] do not directly assess the impact of a Tobin tax on volatility, but through a controlled laboratory experiment they show that a transactions tax leads to less noise trading and has at most a weak effect on the informational efficiency of prices and then on volatility. Their study nonetheless suffers from a major shortcoming: it is restricted to only one market. The experiment therefore does not take into account other untaxed markets, i.e.

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[8] Mende and Menkhoff [2003] would not be able to curb speculation of asset managers and simultaneously maintain a certain level of liquidity.

[9] See also Ehrenstien [2002].

[10] Mannaro et al. [2008] explain the divergence of the results they obtained by the greater sophistication of the Westerhoff and Dieci [2006] model in accounting for informed speculators switching between markets, while their model assumes zero intelligent traders.

the potential issue of tax havens. Hanke et al. [2010] deal with this issue by considering two distinct markets (denoted LEFT and RIGHT); a transactions tax is then introduced into one or both markets. The authors also try to determine whether certain effects of introducing the tax are likely to persist after it is abolished. Their key findings are the following. In the case of an unilateral tax, volatility on the taxed market may decrease or increase depending on the market size, while volatility in the untaxed market is reduced due to liquidity increasing. On the other hand, if a tax is introduced simultaneously on both markets, price volatility and market efficiency remain unchanged.

Bianconi et al. [2009] used minority games to model financial markets as an ecology of different agents interacting in an "information food chain". In this model, each agent is willing to be in the minority, i.e. to place a bid price with an opposite sign to the aggregate bid of all the other agents (Bianconi et al. [2009]). In their study, only a sufficiently large tax would have an impact on volatility. More interestingly, they have shown that the impact of a tax on volatility is highly dependent on the size of the market. Thus, the effect of a tax would be much stronger in a thin market than in a liquidity market. It follows that a tax can reduce exchange rate volatility only if the rate of composition of traders is slow.

2.2 Empirical studies

Empirical research on the effects of a Tobin tax on Forex volatility is quite sparse. As underlined by Lanne and Vesala [2010], existing studies predominately concentrate on the stock market (see for instance Umlauf [1993][11], Jones and Seguin [1997], Song and Zhang [2005], Hau [2006] and Su and Zheng [2011]). This sparsity may firstly be explained by the decentralized nature of Forex and thus the difficulty of collecting data about trading volumes and prices (bid, ask quotations). Secondly, a Tobin tax, envisaged as a tax on Forex transactions, has never been implemented, unlike equity and securities transaction taxes. However, two studies have attempted to tackle this question in the Forex context: Aliber et al. [2003] and Lanne and Vesala [2010]. Aliber et al. [2003] used futures data obtained from datastream from 1 January 1977 to 31 December 1999. The data set consists of daily prices of per unit of four major currencies in the US Dollar: the British Pound, the German Mark, the Japanese Yen and the Swiss Franc. For each currency, they constructed time series of future

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[11] Umlauf [1993] is the only direct test of a transaction from the Swedish stock market experience (the so called "puppy-tax" imposed between 1984 and 1991) and found evidence that the impact of a transaction tax increased volatility.

prices traded on the Chicago Mercantile Exchange (CME). They then showed that transactions costs and volatility are positively correlated, except for the German Mark. Hence an increase of 0.02 percent in transaction costs following the introduction of a tax[12] leads to an increase in volatility of 0.5 percentage points. Nonetheless, this study by Aliber et al. [2003] suffers from three shortcomings. First, they used aggregated futures data, whereas Hartmann [1998 a, b] has shown that there is no link between spots and futures on the foreign exchange market. In addition, the choice of contracts from a centralized market as proxy for the whole market may lead to the omission of variable issues. Second, as underlined by Werner [2003], the authors interpret their results as evidence that changes in transactions costs cause reductions in volatility and increasing trading volume and liquidity. The direction of causality may be the reverse: reductions in volatility and uncertainty may lead to higher liquidity and lower trading costs.

Lanne and Vesala [2010] have suggested addressing this endogeneity issue by including a measure of fundamental volatility as the news count variable. Using a high frequency data set compiled by Olsen and Associates for the Deutsche Mark-Dollar and Yen-Dollar exchange rate from 1 October 1992 to 30 September 1993, they carried out daily and intradaily regressions and found evidence that an increase in transaction costs tends to increase the realized volatility. Note that the data set had been previously examined by Andersen and Bollerslev [1998 a, b].

All in all, existing studies are limited in number and suffer from various shortcomings. Since time series data on current trading volume and bid/ask prices are very difficult to collect (the market is highly decentralized), Aliber et al. [2003] used futures data as a proxy, since they are traded on a centralized market and are easily available. However, the turnover of foreign exchange futures is only 3% of total Forex turnover and is less liquid. Lanne and Vesala [2010] did not use futures data, but followed Andersen and Bollerslev. Unfortunately, their data set is somewhat obsolete (1992-1993). Furthermore, all these studies assume that the relationship between the tax and volatility is linear, whatever the liquidity and the economic environment. We, on the other hand, would intuitively surmise that the relationship is by no means uniform.

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[12] A Tobin tax can be regarded as an increase in transaction tax (see for instance Mende and Menkhoff [2003]).

3. Methodology

3.1 Tobin tax, trading volume and volatility

Previous empirical studies have examined the impact of a Tobin tax on volatility by focusing only on the volatility/spread relationship. In contrast, in this paper we concentrate on the link between volatility and trading volume, and for two main reasons. First, some studies (see, for instance, Demos and Goodhart [1996]) have emphasized the existence of two-way causality between volatility and spread, thereby giving rise to an endogeneity problem that must be taken into account to evaluate without bias the relationship between volume and volatility in the foreign exchange market. Although GMM estimators provide an interesting alternative to this problem (see Hartmann [1999] for instance), it is nonetheless the case that it is difficult to acquire the right instruments. On the contrary, when we focus on the relationship between volume and volatility, it is reasonable to view volume as weakly exogenous. Furthermore, it is easier to understand the transmission channels running from the Tobin tax to volatility in this context. Theoretical studies of the effects of a Tobin tax on volatility have show that this effect is conditional on the size and depth of the market as well as on the structure of the transaction volume.

Hence our analysis of the impact of a Tobin tax on volatility may be broken down as follows.

$$\text{Tobin tax} \rightarrow \text{Volume} \rightarrow \text{Volatility}$$

From an econometric point of view, two different relationships need to be estimated:

$$volume_t = \alpha_1 + \alpha_2 spread_t + Z_{1,t} + \varepsilon_{1,t} \ (1)$$
$$volatility_t = \beta_1 + \beta_2 volume_t + Z_{2,t} + \varepsilon_{2,t} \ (2)$$

where $Z_{1,t}$ and $Z_{2,t}$ are vectors of control variables. $\varepsilon_{1,t}$ and $\varepsilon_{2,t}$ are not correlated errors terms. In the first step, equation (1) postulates the impact of a Tobin tax – that is, an increasing spread – on volume. When the volume and the spread are directly expressed in logarithmic form as in our paper, α_2 is the elasticity of volume to the Tobin tax. We thus expect a negative sign for this coefficient. This elasticity has already been empirically tested by Bismans and Damette [2008]. Using time series and panel co-integration techniques and SURE (Seemingly Unrelated Regressions Estimations) for four currency pairs (Euro/US Dollar, Euro/Yen, Euro/GBP and US Dollar/Canadian Dollar) for two days in November 2004 (1493 observations), they showed that volatility is stronger for major currency pairs (-

0.61 for the Euro/US Dollar) than for small currency pairs (-0.30 for the Canadian Dollar/US Dollar). In order to check the robustness of this prior result, we estimate currency transaction tax elasticity with our new data set in section (4.1).

In the second step, equation (2) postulates the impact of the trading volume on volatility, and is based on the Mixture Distribution Hypothesis (MDH) literature. In this equation, volume is thus considered as an exogenous variable. As a consequence, given the decrease in trading volume after the introduction of a Tobin tax (equation (1)), we are able to assess the impact of the trading volume on exchange rate volatility. In line with the MDH literature, we expect a positive sign for the β_2 coefficient, at least in "normal times". In other words, a decreasing volume following the introduction of the Tobin tax would lead to a decrease in exchange rate volatility.

In the remainder of the paper, we re-estimate equation (1) and find α_2 negative. Given α_2 negative, we estimate equation (2) using non-linear methods for the first time. First though, we focus on the MDH literature and the econometric methods we used.

3.2 Mixture Distribution Hypothesis

We assess the impact of a Tobin tax on volatility by focusing on the volatility/volume relationship, which has been extensively analyzed in the Mixture Distribution Hypothesis (MDH) literature. The MDH was originally investigated only in equity markets, but in recent years a number of papers have addressed the volume-volatility relationship in foreign exchange markets. Melvin and Yin [2000] find evidence that quote frequency and volatility of the Mark/Dollar pair and the Yen/Dollar pair (December 1993 to April 1995) are both affected by the rate of public information arrival. Bauwens et al. [2005], for the Euro/Dollar exchange rate (May 2001 to November 2001), Bjonnes et al. [2005] for the Swedish Krona/Euro exchange rate (1995-2002) and Bauwens et al. [2006] for the Norwegian Krone/Euro exchange rate (January 1993 to December 1993) also confirm the MDH and thus derive a positive relationship between trading volume and volatility. Unfortunately, previous studies examine the MDH only in linear frameworks.

One study, however, is in line with our non-linearity intuition. Using Forex data from BIS and carrying out rolling regressions for seven emerging countries (January 1999 to July 1999), Galati [2000] found that the positive link between volume and volatility – in other

words, between information arrival and volatility – is different in times of severe market stress compared to normal periods. In times of stress, the link between volatility and volume becomes negative. A more recent contribution by Mougoué and Aggarwal [2011], that allows for non-linearities by assessing the relationship between trading volume and volatility for three major currency futures contracts (the British Pound, the Canadian Dollar and the Japanese Yen), finds no confirming evidence for the MDH. More specifically, they carry out linear and non-linear Granger causality tests to reveal strong significant two-way non-linear causality between return volatility and trading volume as a consequence of the heterogeneity of beliefs among traders regarding new information in foreign exchange markets.

3.3 Smooth Transition Regression modeling

We now detail further the econometric method we used to estimate the model (2). The main distinctive feature of our study is the use of a non-linearity framework by conducting Smooth Transition Regressions (STR). In our view, threshold and non-linear effects have been neglected by existing empirical studies, though theoretical studies such as Jeanne and Rose [2002] and Shi and Xu [2009] have proven analytically the existence of a U shape between trading volume and volatility. Furthermore, simulation models of heterogeneous interactive agents and laboratory experiments (see the previous section) have shown that the impact of a tax on volatility is very dependent on the size of the market. As a consequence, mixture distribution may occur only above (or below) certain levels of volume activity (and liquidity) and thus the impact of a Tobin tax on volatility will be different. To empirically assess this phenomenon, we use a logistic smooth transition regression (LSTR) model initially developed by Bacon and Watts [1971] and more recently used by Teräsvirta [1994, 1998], Franses and van Dijk [2000] and van Dijk, Teräsvirta and Franses [2002].

In a time series framework, the LSTR model can be defined as follows:

$$y_t = \beta_1 z_t + \beta_2 z_t G(\gamma, c, s_t) + u_t, t = 1,...,T \ (3)$$

where z_t is a vector of explanatory variables that can be broken down, as suggested by Teräsvirta [2004], into two sub-vectors: $z_t = \left(w_t^{'}, x_t^{'} \right)$ with $w_t^{'} = \left(1, y_{t-1},...y_{t-p} \right)'$ and $x_t = (x_{1t},...,x_{kt})'$. β_1 and β_2 are parameter vectors and the error term is defined as an *iid* process: $u_t \ \square \ iid(0, \sigma^2)$. G is the transition function, i.e. a bounded function of the continuous

transition variable s_t, γ is a slope parameter and $c = (c_1, \ldots c_K)'$ is a vector of location parameters with $c_1 \leq \ldots \leq c_K$. The transition from one regime to another is then smooth given the values of the slope parameter and the location parameters. The transition function is usually a stochastic variable and an element of the vector $z_t = (w_t', x_t')$.

We assumed that the transition function is a general logistic function:

$$G(\gamma, c, s_t) = \left(1 + \exp\left\{-\gamma \prod_{k=1}^{K} (s_t - c_k)\right\}\right)^{-1} \text{ with } \gamma > 0.$$

K=1 (the LSTR model becomes the LSTR1 model) and K=2 (the LSTR model becomes the LSTR2 model) are usually the most common choices. In the first case, the parameters change monotically and smoothly (not instantly when the transition variable surpasses its threshold value) from β_1 to $\beta_1 + \beta_2$, while in the second case, they change symmetrically around a midpoint which corresponds to the minimum value of the logistic function. The LSTR1 model is thus useful to characterize two different regimes, for instance the dynamics of behavior in expansions and in recessions. On the other hand, the LSTR2 model is able to model situations where the behavior of a given process is similar at both small and large values of the transition function and different in the middle. The LSTR2 model is thus capable of characterizing three different regimes. When $\gamma \to \infty$, the LSTR2 model approaches the switching regression model with three regimes such that the outer regimes are identical and the midregime is different from the other two (Teräsvirta [2004]).

3.4 Application to the Euro-Dollar and to the Euro-Yen currency pairs

To assess the impact of a Tobin tax on volatility, we revisit the MDH in a non-linear set-up by estimating an LSTR model. To this end, we use daily data from *Olsen Financial Technologies* consisting of the Euro-Dollar and Euro-Yen exchange rate quotations from 1 October 2008 until 1 October 2010. The length of this data set (513 observations after having cleaned the data set) is comparable to Lanne and Vesala [2010], though our data are very recent and are able to capture recent features of the foreign exchange market dynamics. Furthermore, we use the most frequently exchanged currency pairs in the market. We compute the relative returns as percentage differences of the averages of the logarithmic

median[13] bid and ask prices and then derive a measure of the daily realized variance by summing squared returns. Thus the volatility can be written as:

$$vol_t = \left[\log\left(R_t / R_{t-1} \right) \right]^2$$

where vol_t is the volatility in period t and R the relative returns of the exchange rates.

Since the MDH states a relationship between volatility and trading volume, we need to construct a trading volume variable. Because the current volume of transactions is not readily available for foreign exchange markets (the foreign exchange market is decentralized), we needed to use proxies. The most common proxies used in the literature for the volume of transactions[14] are the quoting frequency and the number of contracts transacted. In our paper, as in Bauwens et al. [2005], we use the quoting frequency and more precisely a tick by tick variable to proxy the trading volume.

The model (1) can be rewritten as

$$vol_t = \beta_1 z_t + \beta_2 z_t G\left(\gamma, c, s_t \right) + u_t, t = 1,...,513 \quad (4)$$
$$z_t = (w_t^{'}, x_t^{'})^{'}$$

where $w_t^{'} = \left(1, y_{t-1},..., y_{t-p} \right)^{'}$ denotes the vector of lagged values of the endogenous variable (here the volatility) and $x_t^{'}$ is a vector of values of the exogenous variable, i.e. the trading volume variable. As previously explained, it is assumed that the trading volume is exogenous in equation (4). This assumption is needed for consistency of the conditional maximum likelihood estimator of the nonlinear models we used. The results of the table 2 below are in accordance of this assumption. In addition, previous studies on MDH assume the weak exogeneity of the trading volume (see for instance Bauwens et al. [2005] for a recent work).

We test the following transition variables. Firstly we test $s_t = x_{t-1}$, i.e. whether the transition variable is the first-order lagged trading volume. Our thinking is based on the recent experimental studies by Pellizari and Westerhoff [2009], Bianconi et al. [2009] and Hanke et al. [2010] – who find evidence that the Tobin tax influence depends on market size – and on previous theoretical results in Jeanne and Rose [2002], Whesterhoof and Dieci [2006] and Shi and Xu [2009], who find evidence of a microstructure effect. For instance, in the Jeanne and Rose [2002] model, volatility is a decreasing function of volume when the volume of trading

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[13] To make comparisons, we also use the maximum value of the ask price and the minimum value of the bid price.
[14] See also Hartmann [1998b] for a survey of the available data set.

is low, but when the number of noise traders increases and exceeds a threshold value, volatility increases in the trading volume. In other words, we ask whether the relationship between volume and volatility is different at times of low and high noise trading volumes. In the first step, we take the aggregate volume of the foreign exchange market as the transition variable. In the second step, we use a decomposed model and obtain two different constituents of the trading volume: predictable volumes and unpredictable volumes. We use the second as a proxy of the noise trading activity.

Secondly, we also test spread as a transition variable: $s_t = spread_{t-1}$. The thinking behind this assumption is that the relationship between volume and volatility may be different in normal periods and in turbulent periods, as was shown by Galati [2000] for seven currency pairs from emerging markets by carrying out rolling regressions[15]. Since spread is a good indicator of turbulence, we thus test spread as a potential transition variable.

4. Empirical analysis

4.1 Estimation of the currency transaction tax elasticity

Our analysis focuses on the Euro/Dollar currency pair. We use daily data from 1 October 2008 until 1 October 2010 and we use two main variables: *volume* and *spread*. The *volatility* variable is also included in our analysis since volatility has an influence on the trading volume (see, for instance, Demos and Goodhart [1996]). The underlying idea is that turbulent or instable periods with high volatility level can reduce the trading volume. Both *volume* and *spread* are expressed in logarithmic form to directly obtain the coefficient as an elasticity. Consequently, it is possible to directly read the impact of a Tobin tax – equivalent to an increase in the *spread* – on the trading volume through the estimated elasticity.

In line with equation (1) above, we estimate the following equation:

$\ln(volume)_t = \beta_1 + \beta_2 \ln(spread)_t + \beta_3 \ln(volume)_{t-1} + \varepsilon_t$ (5).

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[15] We also carried out rolling regressions in a preliminary version of this paper.

Note that the variable $volume_{t-1}$ is needed to take into account the first-order autocorrelation of the residuals. In addition, all the variables are stationary[16], and so we are not exposed to the "spurious regression" issue identified by Yule and outlined by Phillips [1986].

For comparison purposes, we first estimate equation (5) by OLS (see the table 1) and find a smaller elasticity than indicated in the literature. Indeed, by controlling the effect of volatility[17], the elasticity amounts to -0.05, whereas Bismans and Damette [2008] get -0.33 and -0.61 using SURE (Seemingly Unrelated Regression) and co-integration techniques respectively. In addition, the five lagged volume of the dependent variable (or in a more parsimonious specification only first, fourth and fifth order lagged values of the dependent variable) are needed to take into account serial autocorrelation[18]. Robust standard errors are needed to correct heteroskedasticity (the Breush-Pagan test was used to test this issue). Furthermore, the impact of volatility is significantly positive in accordance with the Mixture Distribution Hypothesis we further develop.

The divergence between our results and the previous studies could be explained by the fact that these regressions were based on daily data and on a two-year sample, whereas Bismans and Damette [2008] used intraday data for two days in November 2004 only. We think it likely that the previous estimations capture more microstructural effects than our new estimations, and this increases the magnitude of the *spread* effect. Moreover, the estimation in Table 1 does not take into account the probable endogeneity of the *spread*.

To address those issues, and in line with the previous studies from Demos and Goodhart [1996] and Hartmann [1998, 1999], we estimate the following simultaneous dynamic equations model[19] with $k \geq 1$:

$$\begin{cases} \ln(volume)_t = \beta_1 + \beta_2 \ln(spread)_t + \beta_3 \ln(volume)_{t-k} + \beta_4 \ln(volatility)_t + \varepsilon_{1t} \\ \ln(spread)_t = \beta_5 + \beta_6 \ln(volume)_t + \beta_7 \ln(volatility)_t + \beta_8 \ln(Spread)_{t-k} + \varepsilon_{2t}. \end{cases} \quad (6)$$

The first equation is our equation of interest and is similar to equation (5) previously estimated; it captures the elasticity of the volume with respect to the spread, whereas the second equation focuses on the effect of the trading volume on the *spread* in line with, at least

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[16] We conducted Augmented Dickey Fuller (ADF) and DF-GLS unit root tests and the stationarity KPSS test. Results of these tests are not reproduced here in order to save space, but are available upon request.
[17] The results are very similar if we do not take into account this effect.
[18] Breusch-Godfrey LM test (with an AR(2) specification) is used here because Durbin Watson test is not valid if there are lagged values of the dependent variable on the right hand side of the estimated equation.

[19] We conduct robustness checks using a three simultaneous equations model with the following third equation: à mettre. However this third equation has a limited explanatory power.

partially, Hartmann's [1998] and Galati's [2000] studies. Since we assume a non-zero correlation between the errors ε_{1t} and ε_{2t}, a 3SLS (Three-Stage Least Squares) estimator is better than the individual equations methods (2SLS, LIML, ...) if the model is correctly specified[20].

Since diagnostic tests reveal the presence of heteroskedasticity in the system (especially in the first equation), we compute the GMM-3SLS (Generalized Method of Moments - Three-Stage Least Squares) estimator. Indeed, unlike the standard 3SLS method, which is a restricted version of the simultaneous equation GMM model, the GMM-3SLS estimator allows for heteroskedasticity in addition to cross correlation. It is besides consistent and efficient without any assumptions about the functional form of the errors terms.

The GMM-3SLS method combines a first estimation with instrumental variables in keeping with 2SLS (Two-Stage Least Squares) to obtain consistent estimators and a second estimation by GMM (Generalized Method of Moments) to address the problem of correlated error terms (see Zellner and Theil [1962]) and heteroskedasticity using the efficient weighting matrix. Overall, we follow a three-step method. The first two involve estimating each equation of the system individually by 2SLS and the third involves estimating the previous estimated equations (by 2SLS) by GMM. The results of the GMM-3SLS estimations are presented in Table 2 below. Note also that the J test of overidentifying restrictions is conducted to check the identification of the model.

Table 1. OLS estimation

	Coefficient	t-stat	Coefficient	t-stat
Intercept	1.12	2.74	1.092	2.20
Spread	-0.05	-1.96	-0.05	-2.10
Volatility	0.01	3.93	0.01	4.08
Volume (-1)	0.67	15.47	0.63	14.88
Volume (-2)	-0.09	-1.73	-	
Volume (-3)	0.07	1.31	-	
Volume (-4)	0.07	1.35	0.09	2.19

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[20] As underlined by Wooldridge (2010), the most important weakness of 3SLS estimators is that, if one equation in the system is mispecified, all parameters estimates become inconsistent because parameters are estimated for the whole system and not for each equation. To check the specification of our system, we first refer to the literature (Demos and Goodhart [1996] for instance) and second, we compute for comparisons purposes traditional 2SLS and 3SLS methods (available upon request). Since the parameters estimates are very similar in both estimations, we can conclude that the simultaneous equations model is correctly specified. For instance, the tax elasticity is equal to -0.27 in both estimations.

Volume (-5)	0.16	3.58	0.15	2.91
R2=0.66			R2=0.66	
T=508			T=508	
Autocorrelation LM test[21]=0.520 (0.77)			Autocorrelation LM test=3.269 (0.16)	

Note: Newey-West standard deviations and covariance correction are used.

Table 2. GMM-3SLS Estimation

Equation (1) Volume	Coefficient	z-stat	Equation (2) Spread	Coefficient	z-stat
Intercept	-0.12	-0.01	Intercept	-9.02	-4.69
Spread	-0.30	-1.83	Volume	-0.31	-2.73
Volatility	0.01	0.24	Spread(-1)	-0.35	-1.61
Volume (-1)	0.79	5.38	Volatility	0.13	2.09
Volume (-4)	-0.34	-1.77			
Volume (-5)	0.32	1.55			
T=494 Hansen's J chi2(16) = 13.3256 (p = 0.6488)					

Note : The set of instruments[22] includes constant and lagged values of the explanatory variables in the different equations : spread(-2) to spread (-6), volatility (-1) to volatility (-6), volume(-6).

The table 2 outlines that the elasticity is higher in GMM than in the previous OLS estimates (now -0.30). Furthermore, all the lagged volume coefficients are significant at a 10% level significance. In addition, the impact of volatility on volume is no longer statistically significant. This last result is important because it is in accordance with our previous assumption that $\varepsilon_{1,t}$ and $\varepsilon_{2,t}$ are not correlated errors terms in the system of equations (1)-(2) and that the volume can be considered as exogenous in the MDH relationship (equation (4)).

4.2 An estimation of the MDH in a non-linear framework

4.2.1 Testing linearity and choosing the appropriate STR model

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[21] We use the Breusch-Godfrey LM test (with an AR(2) specification) because Durbin Watson test is not valid if there are lagged values of the dependent variable on the right hand side of the estimated equation.

[22] Different sets of efficient (in the sense of no weak) instruments were used to check the robustness of the estimation. The coefficient of elasticity is always comprised between -0.29 and -0.33.

To detect non-linear patterns in equation (4), we carry out the LM-linearity test discussed in Teräsvirta [1994, 1998]. In the same way as in other non-linear models[23], the STR model is only identified under the alternative hypothesis of non-linearity. This identification problem can be solved by approximating the transition function by a third-order Taylor expansion under the null hypothesis that $\gamma = 0$ (in this case, the transition function G tends to 1/2). The Taylor expansion leads to the following auxiliary regression:

$$vol_t = \beta_0^{'} z_t + \sum_{j=1}^{3} \beta_j^{'} \tilde{z}_t s_t^{j} + u_t^{*}, t = 1,...,513 \ (5)$$

where $u_t^{*} = u_t + \underbrace{R_3 \left(\gamma, c, s_t \right) \theta^{'} z_t}_{remainder}$.

Under the null hypothesis of linearity, $\beta_j = 0 \forall j$, while under the alternative $\beta_j \neq 0$. As explained by Teräsvirta [2004], since $u_t^{*} = u_t$ under the null, the asymptotic distribution is not affected if an *LM-type* test is performed. Hence, the test statistic follows an asymptotic χ^2 distribution, but the corresponding *F-distribution* with $3m$ and $T - 4m - 1$ degrees of freedom is recommended instead in moderate samples. We then use the *F-version* of the test in this paper. If the null hypothesis is rejected (low *p-values*) for many transition variables, there are several transition candidates and thus the model is clearly non-linear.

When linearity has been rejected, we then need to choose the type of STR model. As explained below, the choices K=1 and K=2 lead to the LSTR1 and LSTR2 models respectively. The choice between these two kinds of model can be based on the previous auxiliary regression (3). Teräsvirta [2004] has shown that when $c_1 = 0$, $\beta_2 = 0$, the model is then an LSTR2 model. Finally, we only need to test the following sequence:

$$H_{04} : \beta_3 = 0$$
$$H_{03} : \beta_2 = 0 / \beta_3 = 0$$
$$H_{02} : \beta_1 = 0 / \beta_2 = \beta_3 = 0$$

If the H_{03} hypothesis yields the strongest rejection, then the LSTR2 model should be chosen. In all other cases, LSTR1 is the most appropriate.

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[23] See Hansen [1996] for a detailed discussion of this issue.

The results of the linearity test are shown in Tables 3 and 4. Note that, in order to save space, only the results of each specification (1) are reported. The associated p-values are clearly very small and suggest STR-type non-linearities when *lagged volume* and *spread* are used as transition variables. The previously described test strategy suggests estimating LSTR1 models.

Table 3. Linearity tests (p-values) for the Euro-Dollar currency pair

s_t	F	F4	F3	F2	Model
$Volume_{t-1}$	3.7553e-06	3.7414e-01	2.1168e-02	1.9248e-06	LSTR1
$Spread_{t-1}$	1.3245e-13	2.5983e-08	2.1944e-09	-	LSTR1

Note: The symbol - refers to a singularity matrix problem. We choose two lags for the volatility.

Table 4. Linearity tests (p-values) for the Euro-Yen currency pair

s_t	F	F4	F3	F2	Model
$Volume_{t-1}$	2.1601e-02	9.8827e-02	4.7568e-01	1.3434e-02	LSTR1
$Spread_{t-1}$	4.5186e-14	4.3303e-01	8.0755e-05	-	LSTR1

The symbol - refers to a singularity matrix problem. We choose one lag for volatility; with two lags, only the model with the lagged volume as a transition variable remains non-linear.

4.2.2 Euro/Dollar results

Given the previous linearity and specification tests, we estimate the corresponding LSTR1 models (p,q) models are estimated with p and q denote respectively the lag length of the endogenous and exogenous variables. Note that all variables are I(0)[24]. Under the assumption of exogenous covariates, the estimation method is nonlinear least squares or maximum likelihood under the assumption of normally distributed errors. As explained by Terävirsta [2004], the BFGS (Broyden-Fletcher-Goldfarb-Shanno) algorithm can be used with the numerical derivatives of the log-likelihood function[25]. It is important to choose good starting values for the transition parameters γ and c_1 in the case of a LSTR1 model. After

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[24] Results of the unit root tests are not reported but are available upon request.
[25] The Newton-Raphson algorithm can also be used.

constructing a grid, we can estimate the parameters β_1 and β_2 conditionally on the transition parameters and select the estimates minimizing the sum of squared residuals.

We first present the results concerning the EUR/DOL currency pair. Only the results from the specification with lagged trading volume as a transition variable are outlined, since the estimates with the *spread* as a transition variable obtain non-significant coefficients. For purposes of comparison, we estimate the specifications with both one and two lags in the volatility. However, results of the specification (2) in the table are our best and more robust estimates, since the information criteria (AIC, SC and HQ) are lower in this case. Furthermore, the adjusted R-squared coefficient is higher in specification (2): 0.17 as against 0.12.

Regarding Table 5, we found evidence of some non-linearity in the mixture distribution. Our results show that the MDH is stronger in periods of relatively high trading volume. More precisely, when the lagged trading volume (transition variable) exceeds an estimated threshold value of about 12.41, the non-linear part of the model comes into play and the semi-elasticity of the trading volume smoothly increases from 0.506 to 1.732 (0.506+1.226), indicating an increased role of the information on the volatility dynamics. The chart of the transition function is shown in Appendix A.

In STR models, the change between linear and non linear regimes is not instantly accomplished. Given the transition speed parameter ($\gamma = 2.44$ for the specification 1 and 1.37 for the specification 2, see table 5 below), such a change is not instantly accomplished. The transition starts when the transition variable surpasses its threshold (see chart 3) and once the transition totally accomplished, the non linear regime is fully at work (see chart 8 in appendix). In other words, when the transition variable goes under its threshold (see chart 3), the change is not accomplished instantly and so the reaction function smoothly goes back to its normal linear regime. To illustrate this property with our specification 2 (see table 5), let x the difference between the transition variable and the estimated threshold value $s_{t-1} - 12.41 = x$, then the smooth path from the linear to the nonlinear regime (model 2) can be described by the following formula : $\left(\beta_0 + \beta_{1,t}\right)\left(1 + \exp\left\{-1.37(x)/0.305\right\}\right)^{-1}$ where 1.37 is the value of the smoothness parameter γ and 0.305 is the standard deviation value of the transition variable.

To go further, we explored the historical trading volume data (Charts 1 to 3) and compared them to the threshold value of the transition variable (Chart 3). We find that the non-linear regime (strengthening of the volatility/volume relationship) occurred at the beginning of the sample corresponding to November and (to a lesser extent) December 2008, ensuing from the preceding Black October. The non-linear regime also applies the longer period in the last part of the sample (observations 380-516), from April to October 2010.

Our analysis detects three main periods.
- An initial period corresponding to autumn 2008, with very high Forex trading volume;
- A second period from the end of 2008 to the spring 2010 corresponding to slowing down of the foreign exchange market, with a smaller trading volume and a narrower volatility/volume correlation ;
- And a final period, from the end of April 2010 to the end of October 2010, in which the trading volume was repeatedly above its estimated threshold value. The dynamics of the trading volume was, however, not monotonic, since we see a takeoff in the trading volume around the 400th observation (period between the 5th and the end of May 2010), followed by a decrease until the middle of August and finally a recovery (from September 2010) triggering the non-linear part of the model.

Consequently, we do not corroborate the results obtained by Galati [2000], who showed from rolling regressions in the case of seven emerging markets that the correlation between trading volumes and volatility is positive during "normal" times but turns negative when volatility increases sharply, implying that the MDH holds under "normal" market conditions but not during periods of stress. By contrast, our results show the turbulent periods do not coincide with a negative mixture distribution, i.e. an absence of mixture distribution. On the contrary, we find evidence of increasing mixture distribution in the turbulent times, as in the autumn of 2008 during the peak of the financial crisis caused by the sub-prime crisis and intensified by the bankruptcy of Lehman Brothers. It is also plausible that the model would have detected a longer period of non-linearity, corresponding to a strengthening of mixture distribution, if we had obtained data for September and October 2008.

These findings need to be qualified. Although our results suggest a higher mixture distribution in periods of high volume trading, this does not mean that the mixture distribution increases only in crisis periods. Looking at the historical data, we see that the spreads and

volatility were particularly high in the beginning of our sample period, but are much lower in the last part. This implies that the first period of non-linearity detected by the model (autumn 2008), with simultaneously high volatility, spreads and volume trading, was really a period of pronounced crisis. In early November 2008, the economic situation was gloomy in the wake of Black October. Volatility in the financial markets and especially Forex was very high and was influenced by news about the depth of the European recession, the magnitude of the leading indicators in the US, the ECB decisions regarding the interest rate and rumors of recovery plans. During a financial crisis, there are increased intensity of a news-process leading to both increased volume and increased volatility. Moreover, each trader wants to get out its positions, leading to a large volume (especially in the initial phases of a financial crisis as in autumn 2008.

The second period of non-linearity seems to be of a different nature. At this stage, the trading volume was unnaturally high, but the level of *spreads* remained moderate, although the average level during this period (from 20 May 2010 to the end of October 2010) was higher than the previous calm period, where the "crisis" designation is inappropriate. From the historical data, we can see that the surge in trading volume in May 2010 to August 2010 was linked to a large depreciation of the euro exchange rate caused by the eruption of the sovereign debt crisis (mainly in Greece and in Portugal). This period led to a wave of speculation against the euro, during which investors sold euros and bought dollars and yen.

The final period of non-linearity (September 2010 to the end of October 2010) is characterized by a substantial appreciation in the euro-dollar exchange rate over the relevant period combined with good Wall Street indices and good statistics regarding the US economic cycle. Risk aversion increased and the traders took high-risk positions to the benefit of the Euro. This last part of the sample is somewhat different from the rest due to optimistic expectations about economic recovery.

Furthermore, our results are consistent with the theoretical work of Jeanne and Rose [2002]. Thus, if the proportion of noise traders in the aggregate volume is constant or increasing, then as the trading volume increases, so too does the number of noise traders and the relationship between volume and volatility becomes more highly correlated. This effect might be explained by the greater influence of noise traders when they are more numerous in the foreign exchange market, thus creating instability, as demonstrated by Jeanne and Rose [2002]. We suggest that the number of short-term operations also increases during this period. When volatility increases, then a vicious circle comes into operation: the number of

speculators will be higher, since they take advantage of the variability in order to speculate. Note that in the Jeanne and Rose model, the impact of noise traders in equilibrium is non-monotonic because noise traders have two counteracting roles: they both create and share risk at the same time. Excess variance is thus a function of the number of noise traders.

Table 5. Conditional ML estimates for LSTR model (2) concerning the Euro/Dollar currency pair with lagged volume as a transition variable

Model	(1)	(2)
	LSTR1	LSTR1
s_t	$Volume_{t-1}$	$Volume_{t-1}$
Linear part		
Constant	-5.427	-5.378**
	(-1.88)*	(-2.07)
Volume	0.503**	0.506**
	(2.08)	(2.34)
$Volatility_{t-1}$	0.153	0.251***
	(1.40)	(2.74)
$Volatility_{t-2}$	-	-0.214*
		(-1.66)
Non linear part		
Constant	-9.816	-16.581*
	(-1.58)	(-1.86)
Volume	0.736	1.226*
	(1.49)	(1.78)
$Volatility_{t-1}$	0.140	-0.160
	(0.95)	(-0.85)
$Volatility_{t-2}$	-	0.839***
		(2.66)
$\gamma / \hat{\sigma}_s$	2.44	1.37
	(1.72)	(2.32)
c_1	12.21	12.41
R2	0.12	0.17

Note: t-stats are in parentheses.

Chart 1. EUR/DOL volatility dynamics
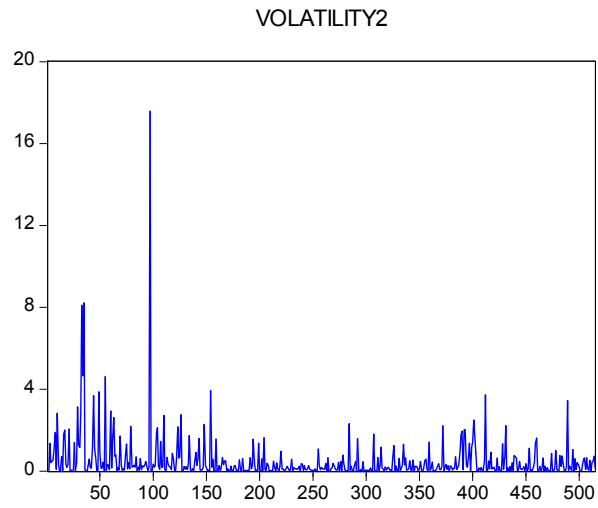
VOLATILITY2

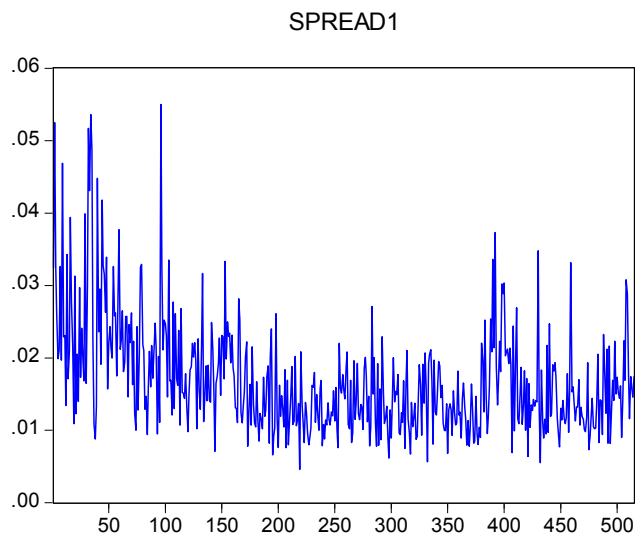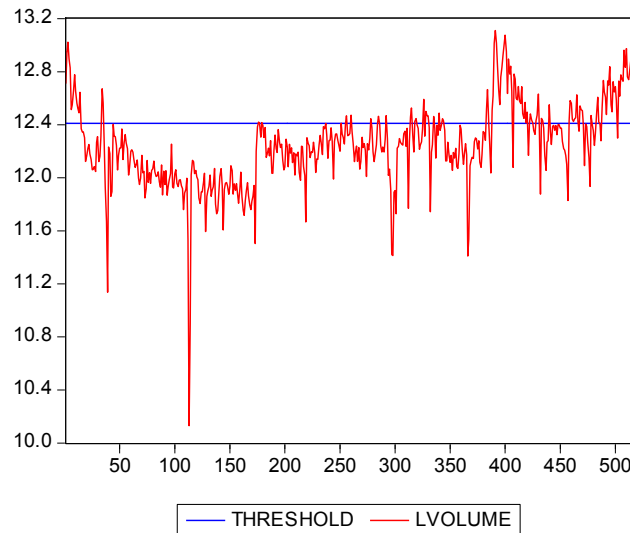
Chart 2. EUR/DOL spread dynamics

SPREAD1

Chart 3. EUR/DOL trading volume dynamics and threshold value

4.2.3 Euro/Yen results

We now check the robustness of the previous results by focusing on the Euro/Yen currency pair. The regressions on the Euro/Yen pair with lagged trading volume as a transition variable corroborate similar regressions estimated for the Euro/Dollar pair. The coefficient of the volume (0.439+2.496) is significantly higher in the non-linear part of the model than in the linear part (0.439) (see Table 6). Hence, when the trading volume exceeds its threshold estimated at 12.77, the model gradually moves from a linear to a non-linear regime, thus strengthening the MDH. Note, however, that the gamma coefficient is not significant at a 10% significance level, which puts the thrust of our results into perspective.

It is apparent from Chart 3 that the model detects very similar non-linear periods to the Euro/Dollar case previously analyzed, thereby providing evidence of a strong common and simultaneous dynamic between different foreign exchange markets, whatever the currency pairs traded. However, when we compare the Euro/Yen case with the Euro/Dollar, the trading volume is less frequently above its threshold value. Moreover, the frequency of observations in the non-linear regime is very low for the last 30 observations, i.e. when the trading volume drops, whereas in the Euro/Dollar case the trading volume was consistently above its threshold for this period.

Table 6. Conditional ML estimates for LSTR model (2) concerning the Euro/Yen currency pair with lagged volume and spread as a transition variable

Model	(1)[26]	(2)
	LSTR1	LSTR1
s_t	$Volume_{t-1}$	$Spread_{t-1}$
Linear part		
Constant	-4.805	-1.499
	(-1.82)*	(-0.68)
Volume	0.439**	0.162
	(2.06)	(0.91)
$Volatility_{t-1}$	0.101*	-0.049
	(1.74)	(-0.83)
$Volatility_{t-2}$	0.041	-
	(0.70)	
Non linear part		
Constant	-37.855	-15.427*
	(-3.74)	(-1.68)
Volume	2.946***	1.475**
	(3.76)	(2.04)
$Volatility_{t-1}$	-0.008	-0.103
	(-0.08)	(-0.87)
$Volatility_{t-2}$	-0.0126	-
	(-0.12)	
$\gamma / \hat{\sigma}_s$	1.07	3.08
c_1	12.77	3.61
R2	0.10	0.30

Note: t-stats are in parentheses.

This time, the estimations with *spread* as a transition variable are significant (second column of Table 4). The coefficient of the volume is not significant in the linear regime, thus the MDH does not hold in this regime. By contrast, in the non-linear part of the model – when the spread exceeds its estimated threshold value – the coefficient linked to the MDH is

[26] The results with two lagged volatility are very similar and are available upon request.

significantly positive. In accordance with the results derived with the trading volume as a transition variable, the model detects a non-linear regime – that is, when the spreads surpass their threshold – for the beginning of the sample (110 first points corresponding to the period from the end of October 2008 to the end of March 2009). As a consequence, the MDH is strengthened in turbulent and crisis times. However, there is no longer evidence of the non-linear part corresponding to the end of the sample, except for a few observations (see Chart 5).

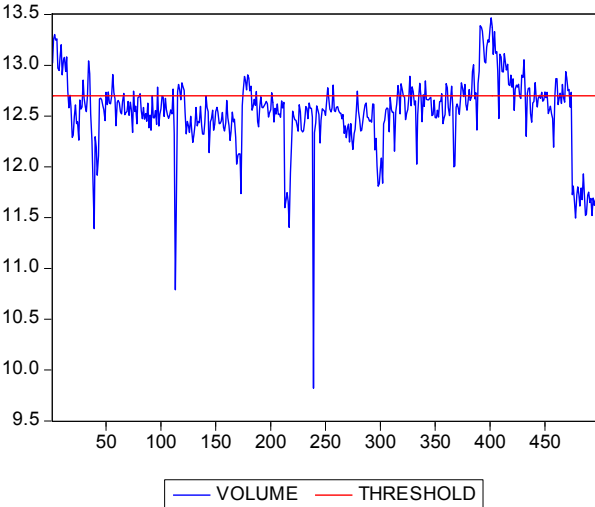**Chart 4. EUR/YEN trading volume dynamics and threshold value**

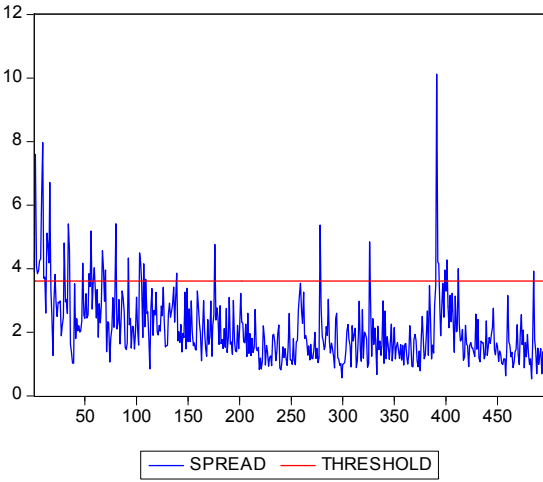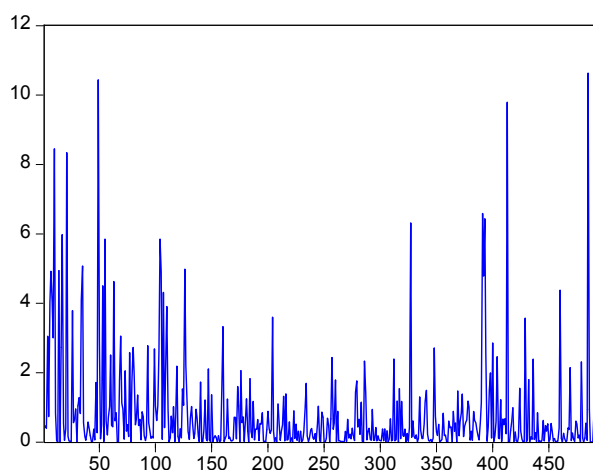**Chart 5. EUR/YEN spread dynamics and threshold value**

Chart 6. EUR/YEN volatility dynamics

4.2.4 Robustness checks: a GMM instrumental variables estimation

In order to check the robustness of our previous results, we estimate our STR model by instrumental variables using GMM (Generalized Methods of Moments). The idea behind is to take into account a possible endogeneity bias (especially due to correlation between volatility and volume) in line with the very recent papers of Areosa et al. [2011] and Bruggemann and Riedel [2011][27]. Lagged values of the regressors, of the spread and their squares are used as instrumental variables and the J-test is performed to check the efficiency of instruments. The table 7 reports these results. Although the magnitude of the coefficients is now more important than in the previous estimates, the results are qualitatively the same. We can see from the table 7 that the MDH is stronger in periods of relatively high trading volume. More precisely, when the lagged trading volume (transition variable) exceeds an estimated threshold value of about 12.39, the non-linear part of the model comes into play and the semi-elasticity of the trading volume smoothly increases from 0.211 to 1.12 (0.211+0.909), indicating an increased role of the information on the volatility dynamics.

To check the robustness of these results, we tried to change the set of instruments, the initial conditions and the specification of the model (especially the lagged of the endogeneous variable). The qualitative properties of our results have remained consistent throughout all estimates.

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[27] Our GMM code has been programmed on the basis of the Ox code from R. Bruggemann [2011].

Table 7. GMM estimates for LSTR model (2) concerning the Euro/Dollar currency pair with lagged volume as a transition variable

Model	(1)
	LSTR1
s_t	$Volume_{t-1}$
Constant	-2.289 (-1.56)
Volume	0.211* (1.77)
$Volatility_{t-1}$	0.086 (1.55)
$Volatility_{t-2}$	-0.044 (-0.92)
Constant	-10.008*** (-4.98)
Volume	0.909*** (37.9)
$Volatility_{t-1}$	-0.133*** (-3.28)
$Volatility_{t-2}$	0.498*** (1240)
$\gamma / \hat{\sigma}_s$	2.99
c_1	12.39
p (J-Stat)	0.27

Note: parentheses refer to t-stats for coefficients. Instruments used: constant, four first lagged of the explanatory variables, spread(-1) to spread(-4) and their squares.

5. Policy implications for a Tobin tax

We can now interpret these results in relation to the debate around the effects of a Tobin tax on volatility. Our conclusion is that a tax would, on average, be an effective instrument for reducing exchange rate volatility, since the volatility/volume relationship is always positive, while the trading volume to the currency transaction tax elasticity is always

negative over the sample. All other things being equal (and with a constant currency transaction tax elasticity), a Tobin tax would have a higher marginal effect for reducing volatility when the Forex trading volume is abnormally high. Indeed, the same x% decrease in the trading volume following the introduction of the Tobin tax would reduce volatility in the non-linear regime – i.e. when the trading volume is relatively high – more than in the linear regime characterized by a low trading volume. Regarding the positive relationship between volatility and trading volume, the introduction of a Tobin tax would be effective in reducing volatility in normal times (as in the middle period of the sample), but it would be even more effective in turbulent periods, as in autumn 2008 and spring 2010. The tax would be a very valuable tool in times of boom trading volume, especially in turbulent periods and extreme crisis periods with a surge in spreads (see Chart 2) and high volatility.

This result chimes with Tobin's writings [1974, 1978], which argue that the tax could reduce exchange rate volatility by discouraging destabilizing transactions, especially short-term transactions, more than long-term investments; indeed, the burden of taxation would be higher for short-term transactions. It may be supposed that if the tax proves to be more effective in reducing volatility in periods of turbulence, as indicated by our analysis, it is because it discourages transactions creating instability in times of crisis. With reference to the Frankel model [1996], the tax would reduce the sensitivity and responsiveness of speculators to exchange rate variation, i.e. it would either reduce the number of speculators or directly increase the proportion of long-term investors in the foreign exchange market. This result, moreover, is in line with the Jeanne and Rose [2002] model: the authors show that when the number of transactions from noise traders is sufficiently high and when the proportion of noise traders relative to informed traders increases, then so-called excessive volatility increases. This finding is thus in accordance with the right-hand part of the U-shape relationship derived by Jeanne and Rose [2002]: increasing trading volume is accompanied by an increase of the number of noise traders, who create volatility all the more so since they use volatility as a potential benefit[28]. A Tobin Tax could therefore be more effective in those periods where the number of noise traders is high, since they are more sensitive to taxation and therefore leave the market more easily than long-term investors.

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[28] Although we considered an increase of the aggregate trading volume in our analysis (not an increase of noise traders only), it seems to be rational to assume that the number of noise traders increases at least proportionally to aggregate volume.

One limitation to our analysis should, however, be addressed. It might be supposed that our findings – increasing mixture distribution in turbulent periods – could be biased if the trading volume is endogenous in times of crisis. In the theoretical analysis by Jeanne and Rose [2002], trading volume issuing from noise traders increasingly creates volatility as they progressively enter the market. But there is a feedback effect, since volatility acts as a benefit opportunity, which attracts all the more traders into the market. One can thus get a two-way causality between volume and volatility in turbulent times when the volume is high.

In the previous section, we test the robustness of our results by conducting GMM estimations of our LSTR model in order taking account endogeneity. To go further, we now implement Granger causality tests for the Euro/Dollar currency pair (Table 8 below) on different sub-samples referring to the linear and non-linear parts of the model respectively. We find evidence of unidirectional causality from trading volume to volatility (and not the inverse) in the second period of turbulence detected by the model (390-515 sample, from spring to autumn 2010), the increasing volume would lead to higher volatility. Conversely, it is not possible to empirically find a causality link in the intermediate period characterized by relative calm in the market (150-350 sample in Table 8). However, our tests show clearly a causality link from volatility to trading volume at the beginning of the sample (1-50 sample, end of the autumn 2008 crisis) – the increasing volatility would lead to lower trading volume. This finding (partially) puts into perspective the theoretical channels of the Jeanne and Rose [2002] model. In addition, our finding protects our STR results from potential endogeneity biases of the trading volume only for the second turbulent (and non linear) period.

Table 8. Granger causality tests (p-values)

Sample	Causality	$p=1$	$p=2$	$p=3$
1-50 (1st linear part)	$Volume \rightarrow Volatility$	0.6373	0.3537	0.4265
1-50	$Volatility \rightarrow Volume$	0.3937	0.1150	0.0089
150-350 (linear part)	$Volume \rightarrow Volatility$	0.3350	0.5798	0.7733
150-350	$Volatility \rightarrow Volume$	0.6750	0.7404	0.7894

390-515 (2d non linear part)	$Volume \rightarrow Volatility$	0.0021	0.0066	0.0209
390-515	$Volatility \rightarrow Volume$	0.9963	0.8052	0.9289

Note: $\rightarrow$ denotes **no causality** for order *p*.

To test the granger causality from volume to volatility, we consider the following model, for i=Euro/Dollar,

Euro/Yen: $Volatility_t = \phi_0 + \sum_{j=1}^{p} \phi_j Volatility\left(p_{i,t-j}\right) + \sum_{j=1}^{p} \alpha_j Volume\left(p_{i,t-j}\right) + u_t \quad p \geq 1$ for .

$$H_0 : \alpha_1 = ... = \alpha_p = 0$$

The null hypothesis is: .

Our results are also in accordance with the studies by Westerhoff [2003], Ehrenstein et al. [2005], Westerhoff and Dieci [2006] and even Bloomfield et al. [2009]. However, a number of critical points need to be made regarding our study. In our reasoning, we assume that the markets considered (Euro/Dollar and Euro/Yen) and then taxed represent the aggregate foreign exchange market, without taken into account any fiscal evasion. This assumption is open to objection, on similar grounds to the criticism made by Hanke et al. [2010] of the study by Bloomfield et al. [2009], who consider only one independent taxed market. A further study using panel data – with a large number of currency pairs from all the foreign exchange markets – would allow our results to be confirmed or disconfirmed once and for all. The statistical cost of such a study proves, however, to be high.

In any case, our results clearly differ from those of the two previous empirical studies (Aliber et al. [2003] and Lanne and Vesala [2010]), which question the usefulness of a Tobin tax for reducing exchange rate volatility. Our results are, moreover, in conflict with studies that claim that a Tobin tax would be ineffective for reducing high levels of volatility (see, for instance, Bird and Rajan [1999, 2001] and Davidson [1997]). Bird and Rajan put Frankel's [1996] model into general use and analyze the case of uncovered interest parity by introducing exchange rate expectations into Frankel's original model. They show that the inverse relationship between the burden of the tax and the maturity of the investment is valid only if the ratio between the expected exchange rate and the spot exchange rate is below 1.2 in the case of a high tax rate of 1%. In other words, to sufficiently discourage speculators and short-termist noise traders, the decrease in the exchange rate should not exceed 20%. However, in actual fact, during periods of speculative attacks, the decreases of the exchange

rate can be much greater than 20%, a situation that makes Bird and Rajan argue that a Tobin tax would not be an effective tool for reducing volatility in crisis periods. For instance, Spahn [2002] points out that the Italian lira lost 20% of its initial value during the EMS crisis (1992), the Indonesian rupiah lost 80% during the 1997 Asian crisis, the Mexican peso and the Brazilian real about 35-60% (1994 and 1999 respectively) and the Russian ruble 60% in 1998.

Like Bird and Rajan, but in the context of interest rate arbitrage, Davidson [1997] shows that a Tobin Tax is not a good instrument for warding off speculative attacks. He concludes, from a post-Keynesian analysis, that once the tax is unable to cover full amount of potential gains or losses, it is necessarily ineffective. Furthermore, the fact of reasoning in terms of annual yield rates is, in his opinion, misleading, for it allows one to imagine that the grains of sand of a low-rate tax can be transformed into massive paving stones when it is a matter of speculative flows. Jegourel and Kauffmann [2006] make a similar point: if the speculators do not annualize the cost of the tax, then the rate of taxation stays well below the depreciation levels normally expected in a crisis situation. For speculators, the depreciation therefore offers an opportunity for gain and to stay in the market and create volatility in spite of the tax.

Though we need to take into account these critical points, they are insufficient to invalidate our findings, since our reasoning is based on major currency pairs such as Euro/Dollar and not on emerging countries (as with Galati [2000]). Moreover, the argument developed in this paper refers to the Euro/Dollar and Euro/Yen currency pairs over the 2008-2010 sample period, during which there was no currency crisis. Furthermore, according to our computations, the Euro/Dollar currency appreciated by some 51% on the 86-282 sample, before falling by about 22% over the 282-399 sample.

Finally, our results are incompatible with the two-tier rate tax proposed by Spahn [2002]. This author proposed implementing an adjustable tax consisting of a low-rate financial transactions tax in "normal times", plus an exchange surcharge at prohibitive rates as a piggyback in turbulent times to significantly discourage speculation. Our results suggest that such a tax would be unnecessary, since the decreasing trading volume generated by the tax would have more effect on volatility in turbulent periods than in normal periods.

6. Conclusion

This paper examined the role of trading volume on exchange rate volatility that is the so-called Mixture Distribution Hypothesis, taking into account non-linearity for the Euro/Dollar and the Euro/Yen currency pairs. Using STR models, we find evidence that the relationship between trading volume and volatility tends to increase in turbulent periods when spread and/or trading volume are at high levels. This is the first paper evaluating the state dependency in the MDH literature.

Linking this result with the Tobin tax debate implies that a Tobin tax would be effective for reducing exchange rate volatility, even in turbulent periods. This paper provides the first empirical corroboration of this proposition and seems to confirm some previous theoretical papers in the vein of Tobin concerning the effectiveness of such a measure. A Tobin tax would have been stabilizing and effective in the 2008 crisis when spreads, volume and volatility were very high.

APPENDIX

A.1 Euro/Dollar

Chart 7. Logisitic function of estimated LSTR1 with the lagged trading volume as a transition variable
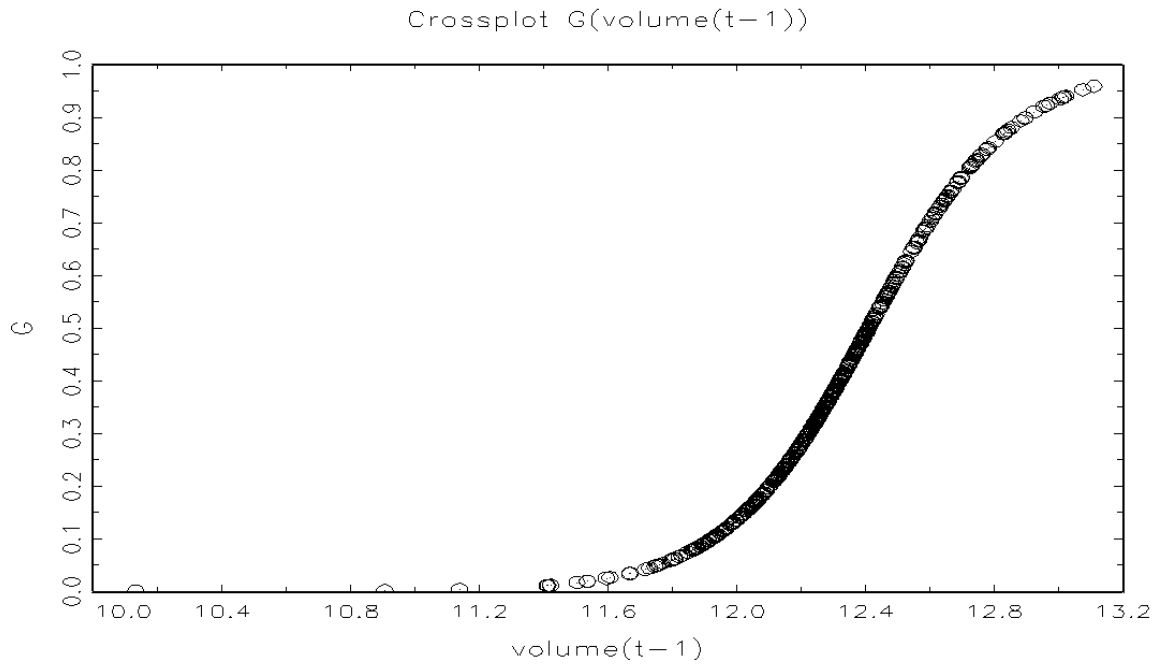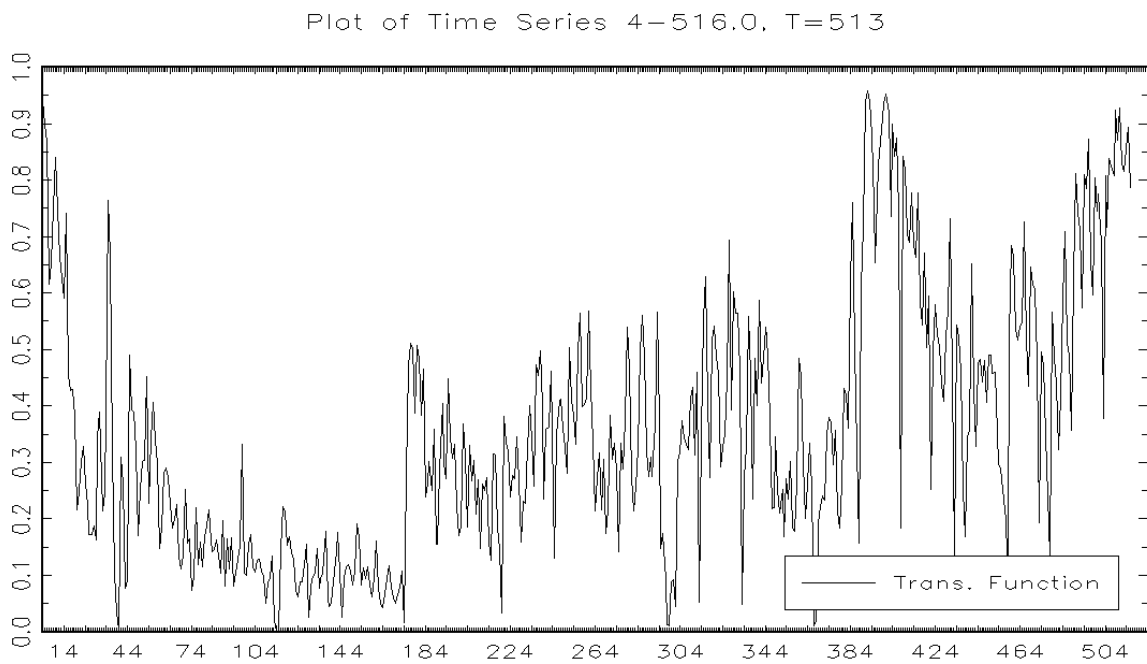

Crossplot G(volume(t−1))

Chart 8 : Transition function of estimated LSTR1 with the lagged trading volume as a transition variable

Plot of Time Series 4−516.0, T=513

Chart 9. Logistic function of estimated LSTR1 with the lagged spread as a transition variable

Crossplot G(spread2_yen(t−1))
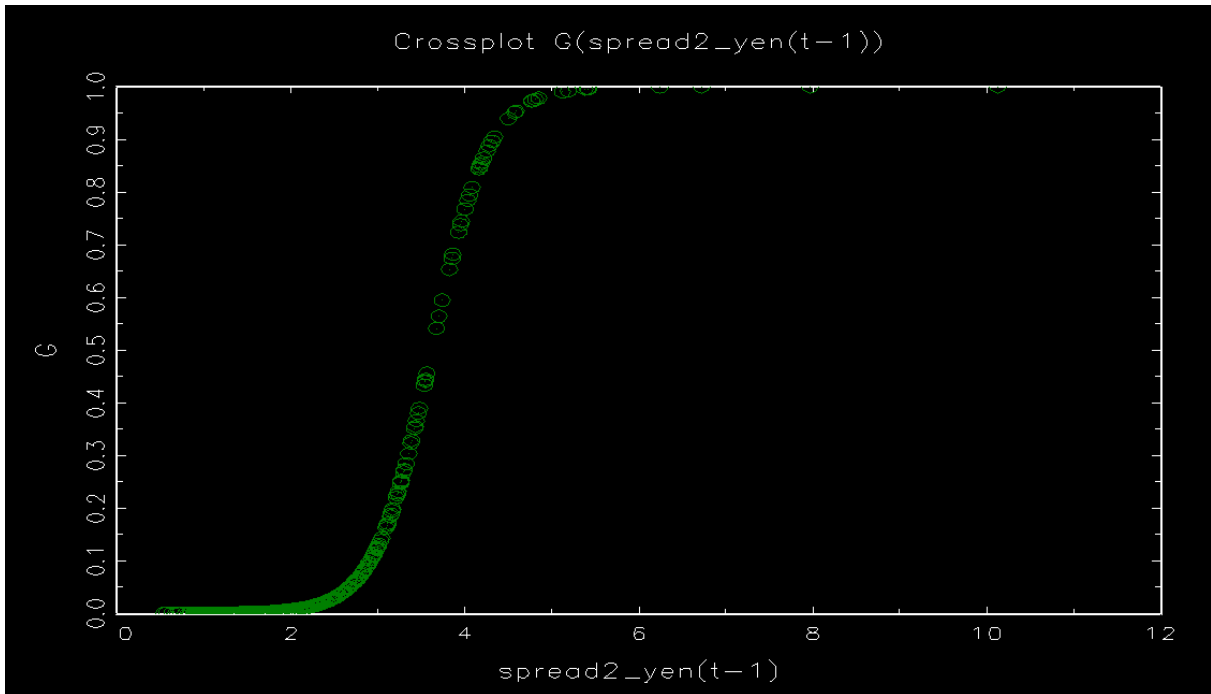
Chart 10. Transition function of estimated LSTR1 with the lagged trading volume as a transition variable

Crossplot G(volume_yen_log(t−1))
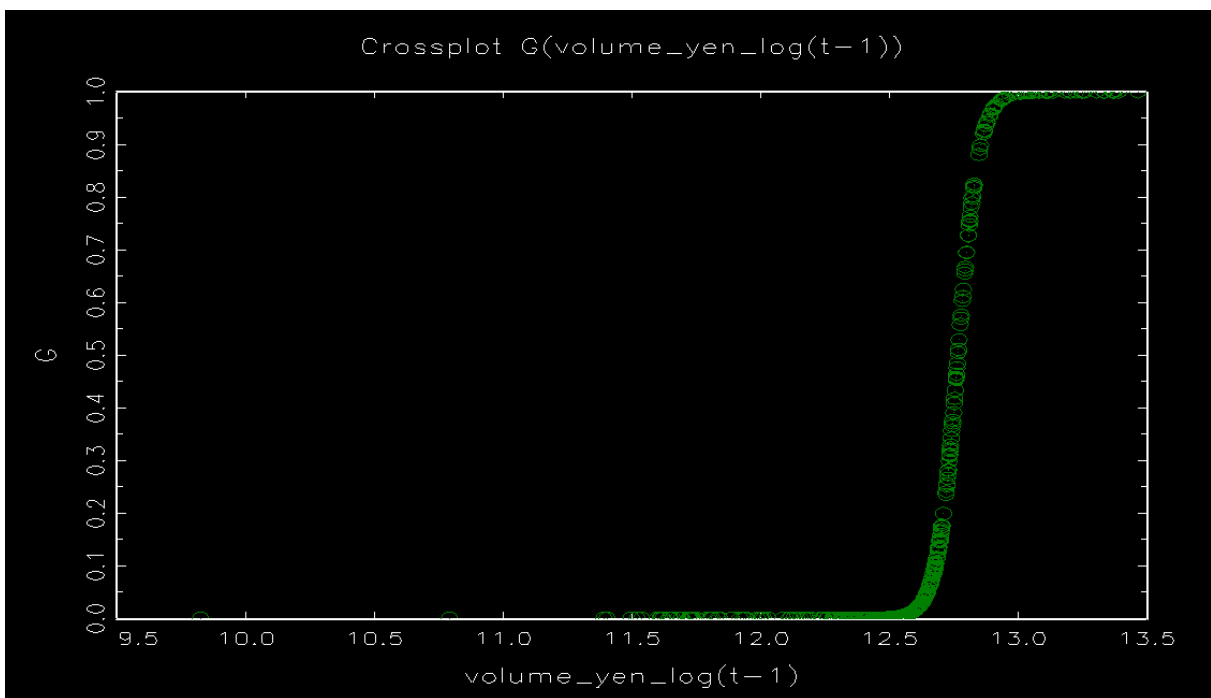
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