Intervention in the Foreign Exchange Market, Market Turnover and the Impact on Exchange and Interest Rate Dynamics in the Caribbean

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Abstract

Direct intervention in the foreign exchange market and interest rate policy seems to be inextricable linked, even when direct interventions are fully and immediately sterilized. The picture is further clouded when we introduce micro-structural element such as the effect of foreign exchange trading volumes which not only affect the dynamics of the relationship between these two policy variables and exchange rates but is itself driven by innovations in these variables. Looking at the impact of direct intervention and interest rate policy on exchange rates separately, and without taking account of micro-structural features that impact on the effectiveness of these policy instruments, may therefore give misleading results. Additionally, many studies only looked at the impact of these policy instruments on the level of the exchange rate but not on its variance, limiting its usefulness to policy makers in a situation where exchange rate volatility is increasingly the feature of exchange rate dynamics targeted by central banks. This study seeks to close this gap by investigating in a multivariate GARCH framework the links between direct intervention, interest rate policy, exchange rates and trading volumes in the foreign exchange market. In particular, it looks at whether direct intervention "signals" the future interest rate policy stance of the central bank and are designed to "lean against the wind" of exchange rate trends in select Caribbean countries. This framework not only allows one to look at how these policy instruments affects exchange rate dynamics in a joint framework but also shows how policy intervention affects the conditional covariance and correlation of important variable like interest and exchange rates over time. This can shed some light on the costs associated with unsynchronized implementation of related policy instruments in the foreign exchange market.

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1.0 Introduction

Most central bank operating flexible exchange rate regimes have intervened with direct intervention in the foreign exchange market. These interventions are usually executed together with offsetting operations in the domestic money market so that the money supply is not affected. In this sense they are *sterilized* interventions and therefore cannot be thought of as monetary policy initiatives. Over time there has been a growing pessimism about the effectiveness of intervention, especially in developed market economies (Schwartz, 2000). The results of empirical studies on the effectiveness of intervention in developed markets indicate that there is mixed evidence that intervention can affect the level and variance of exchange rate returns (Edison, 1993 and Sarno and Taylor, 2001).

In the case of developing and transition countries, there is less pessimism but the evidence is still mixed (Disyatat and Galati, 2007). Also, the issues are a little more complex in developing countries since direct interventions are often not immediately or fully sterilized and therefore there should be a closer connection between monetary/interest rate policy if the objectives for direct intervention and monetary policy are consistent. These two policy instruments could have strong links and feedback effects between each other in the context of the signaling channel, even if direct interventions are immediately sterilized. Also, monetary policy operating procedures may delay sterilization or render it incomplete which means there would be spillovers from direct intervention to monetary policy. Direct intervention, interest rate policy[1] and exchange rate dynamics should therefore ideally be examined in a *joint framework* but relatively few studies have adopted this approach (Lewis, 1995, Lewis and Kaminsky, 1996, Kim, 2003 and Kearns and Rigobon, 2005). Very importantly also, the market microstructure literature has stressed the importance of market volumes to asset price dynamics (Easley and O'Hara 1987, Evens and Lyons 2002 and Blume et. al. 1994) and as Kim and Sheen (2006) has shown for Japan prevailing condition in the foreign exchange market in terms of volume can significantly impact on the effectiveness of direct intervention in the foreign exchange market. Moreover, in some developing countries the central bank intervention can significantly affect foreign exchange market volumes relative to their developed market counterparts since the central bank is a relatively more important agent in the market because of smaller market size.

This suggests that exchange rate return dynamics, both in terms of mean and variance, are affected significantly by the prevailing condition with respect to market volume. The central bank policy reaction to emerging trends is also likely to be driven by trends in market volume, as well as exchange rate and interest rate dynamics. These features of the market and the central banks' policy decision making process highlight the endogenous nature of these policy measures, foreign exchange market volume and exchange rate dynamics. This suggests that these issues should be studied in a joint framework to account for the linkages and therefore the endogenous nature of these relationships. Also, the few studies that have indirectly evaluated the issue of the links between monetary policy, direct intervention and exchange rates in a joint framework (Lewis, 1995, Kim, 2003 and Kearns and Rigobon, 2005) have focused on the first moment of the exchange rate and not on the second moment which is a serious lacuna in the literature since central banks increasingly focus on controlling volatility rather than targeting a particular rate. These frameworks also did not allow one to look at how policy intervention affects the conditional covariance and correlation of important variable like interest and exchange rates over time. This can provide information on the inter-temporal dynamics of the way the correlation of important variables reacts to policy interventions and therefore shed some light on the costs and policy conflicts associated with unsynchronized implementation of related policy instruments over time.

[1] Interest rate policy and monetary policy will be used interchangeably in the rest of the paper.

In spite of the volume of work that has been done on the effectiveness of intervention and interest rates on exchange rates and the impact of volume on exchange rate dynamics, not much work has been done in a joint framework on the links between direct intervention, monetary policy, particularly interest rate policy, foreign exchange market volume and exchange rates. This is a major gap in the literature on central bank intervention in the foreign exchange market with only Kim and Sheen (2006) trying to deal with this issue in a bivariate GARCH framework. That study however suffered from the weakness that it only looked at exchange rates and volumes in a joint framework, choosing to handle the central bank's direct intervention policy reaction separately and not including the central bank's interest rate policy reaction function. This framework did not therefore allow for the full set of linkages among the variables of interest to be explored and should in principle generate less efficient estimates than if a multivariate GARCH system where functions for all four variables were estimated simultaneously.

We also utilize daily data on intervention, policy interest rates, market volumes and exchange rates rather than the monthly and weekly data used in some studies (Lewis, 1995 and Kim, 2003). Daily data is more appropriate in today's policy environment given the ample evidence that exchange rates reacts to new information and policy interventions very quickly, even on an intra-daily frequency. Additionally, the paper utilizes the most recently data on intervention in the foreign exchange market in Trinidad and Tobago covering the period up to the end of September 2009. The paper therefore makes a contribution in terms of an explicit methodology for measuring the links between monetary policy, intervention, foreign exchange market volumes and exchange rates. It can also provide evidence on the "leaning against the wind" and signaling behavior of central banks. Moreover, it can help in the evaluation of how policy intervention affects the conditional covariance and correlation of exchange and interest rates.

In this study we extend Kim and Sheen (2006) approach by examining the links between direct intervention, interest rate policy, foreign exchange market volume and exchange rate dynamics jointly in a multivariate GARCH[2] framework. The paper is structured as follows. Section 2 details very briefly the literature on the links between intervention, policy interest rates, market volumes and exchange rates. Section 3 outlines the empirical methodology. Section 4 evaluates whether the empirical relationships between intervention, interest rate policy, market volumes and exchange rate dynamics in Trinidad and Tobago have important links and feedback effects not only on the first but the second moment of exchange rate returns which makes a joint empirical framework essential to the accurate assessment of the impact of policy on exchange rate dynamics. This section also attempts to determine whether the relationship between important policy variables and the exchange rate can best be described as signaling or leaning against the wind, as well as the importance of market microstructure effects in the implementation of policy in the foreign exchange markets in the Caribbean and section 5 concludes.

[2] To our knowledge no study has looked at this issue in a multivariate GARCH framework. The study closest in terms of empirical methodology to our work is (Beine, 2004) who looked at the impact of central bank interventions in three major foreign exchange markets and the spillovers in terms of correlations between the exchange rates in these markets. They did not, however, look explicitly at the issue of the interaction between interest rate policy and direct interventions.

2.0 Theory

Theoretically, *sterilized* interventions in the foreign exchange market can affect the exchange rate through a variety of channels that are not mutually exclusive. These include the portfolio balance, market microstructure and signaling channels, all of which are based on their respective models of exchange rate determination[3]. In terms of the literature on intervention channels, the portfolio balance channel works by generating rebalancing in terms of the currency composition of market participants' portfolios which generates changes in the exchange rate. The key assumptions of this framework are that domestic and foreign-currency denominated financial assets are imperfect substitutes and that investors are risk-averse (Edison, 1993 and Dominquez and Frankel, 1993b).

The microstructure approach to foreign exchange markets focus on order flow[4], information asymmetries, trading mechanisms, liquidity and the price discovery process. Central bank intervention works in this framework by emitting information to the market which modifies expectations and generates huge order flows which change exchange rate dynamics (Evens and Lyons, 2002). The main branches of market microstructure theory are the inventory and information approaches and both have direct implications for the effectiveness of direct intervention in the foreign exchange market. The inventory approach focuses on imbalances in order flow and how this drives the exchange rate through the portfolio balance approach when the central bank intervenes in the market. The information approach posits that information asymmetry among major agents in the market impacts on trading behavior and therefore on exchange rate dynamics. In this context, the central bank is viewed as an "informed trader" and volatility tends to increase when informed traders are in the market since their trades represent new information that the market has to incorporate into prices. Increased volumes, volatility and price changes are therefore likely to occur around central bank intervention operations. In both the inventory and information branches there is motivation for trading which drives exchange rate dynamics.

In the inventory framework trading is done to iron out imbalances in order flow and in the information framework trading is done to gather knowledge about dealers' motives and prices, the "learning by trading process". Specifically, Easley and O'Hara (1987) showed how informed traders will trade large volumes if they had superior information. The empirical literature on the mixture of distribution hypothesis has also shown that there is a strong link between volume and volatility. Epps and Epps (1976) suggest that there underlying latent variables that lead to the close correlation of volumes and returns. Central bank intervention has been seen as one such latent variable which drive both volumes and returns. Few studies have looked at the joint distribution of volumes and returns in the foreign exchange market because good data on foreign exchange volumes at a daily frequency has been hard to find. The few that did look at this issue in the foreign exchange market have found that unpredictable volume tend to push up bid-ask spreads and volatility (Hartmann, 1999, Kim and Sheen, 2006). These studies have also found

[3] See Mussa (1981), Taylor (1995) and Lyons (2001) for outlines of the signaling, portfolio balance and microstructure approaches to exchange rates respectively.

[4] Order flow is transaction volumes that are *signed*. That is if you are the *active initiator* of a *sell* order this takes on a *negative sign* while the *active initiator* of a *buy* order takes on a *positive sign*. Markets with a negative sign and a positive sign indicate net selling and buying pressure respectively.

that the volume data exhibit significant conditional heteroskedasticity. Since it is widely demonstrated that exchange rate returns also exhibit this statistical property, a GARCH framework seems most suitable for any empirical work looking at the joint distribution of these two variables.

Additionally, the importance of volume information may derive from the possibility that market volumes may factor prominently in central banks' intervention decision. That is, high volumes in a situation where returns are relatively stable may be an important early warning of future volatility which warrants an intervention (Kim and Sheen 2006). For example, high demand for foreign exchange may be sufficient for the central bank to intervene selling foreign exchange to prevent the excessive perturbations in volumes leading to volatility in returns when fundamentals do not suggest a rationale for such volatility. These factors point to the importance of volume considerations not only in the determination of exchange rate returns but also in central banks' policy reaction function. This suggests the need to explicitly account for volume in empirical studies looking at central banks' policy interventions in the foreign exchange market, that is, how volumes drive exchange rate returns and policy actions and is in turn impacted by these variables, highlighting the endogenous nature of the relationship between these variables.

The signaling channel works by signaling to market participants the future stance of monetary policy, shifting their expectations about future monetary policy leading to a change in present exchange rate dynamics. This holds even if interventions are sterilized (Dominguez and Frankel, 1993a and Kaminsky and Lewis, 1996). In this framework the exchange rate is treated as an asset price which is determined by the money supply. This channel can only work effectively if the central bank has policy credibility since the lack of credibility may increase the likelihood of speculative attacks against the currency where market participants speculate against the defensive (usually) interventions of the central bank (Sarno and Taylor 2001). The fact that this channel works by changing perceptions means that it can only be effective if it is well publicized to strengthen the central bank's policy signal.

In developing countries where central banks' credibility may be weak, this channel may not be as effective as in developed market economies where the central bank has a long history of prudent macroeconomic management. As such, the magnitude of the interventions by central banks in these jurisdictions may have to use relatively larger intervention amounts to have an impact, in other words they would have to "buy credibility" for their signal of future monetary policy stance to be as effective as in a developed market context (Mussa 1981). On the other hand, central banks in developing countries enjoy certain benefits relative to their developed market counterparts such as information advantages over the market and the ability to intervene with larger amounts relative to the market given the size of turnover in these markets (Canales-Kriljenko, Guimaraes and Karacadag 2003). These factors may therefore give central banks in some developing countries an advantage over even some of their developed market counterparts in the use of the signaling channel, particularly where the size of the intervention amount is relative to the overall market is large given the small size of the market.

The signaling hypothesis requires that intervention leads to future changes in monetary policy in line with the initial intervention. That is if the signaling channel is dominant sales (purchases) of foreign exchange must be backed up by future contractionary (expansionary) monetary policy.

This is best explained by a simple model as outlined in Lewis (1995). This implies that intervention in the foreign exchange market and monetary policy targeting the exchange rate are inextricably linked, however, most studies studying the effectiveness of these policy instruments in changing exchange rate dynamics look at each instrument in isolation. This invariable leads to the misspecification of the relationship between exchange rates and these policy instruments, as well as biased empirical estimates of the parameters of these relationships.

To adequately capture the complex dynamics of the links between exchange rates, monetary policy, market microstructure features and intervention in the foreign exchange market a joint empirical framework is required. We turn to this in the next section.

3.0 The Empirical Methodology: Multivariate CARCH

The empirical methodologies which have been used in previous studies to capture the relationship between monetary policy, direct intervention in the foreign exchange market and exchange rates in a joint empirical framework include bivariate VAR (Lewis 1995), structural VAR (Kim 2003), simulated GMM (Kearns and Rigobon 2005) and bivariate GARCH (Kim and Sheen 2006). These studies however all suffer from a variety of weaknesses inherent in the empirical methodology used.

Lewis (1995) used two bivariate VARs one with monetary policy and exchange rate and another with intervention in the foreign exchange market and exchange rates using daily data to study these links. This is an imperfect arrangement because the full range of interactions cannot be studied without a higher order VAR.

Kim (2003) solved this problem using the structural VAR approach but the use of monthly data and the validity of the identifying restrictions weaken the validity of his results. Kearns and Rigobon (2005) utilizes daily data and simulated GMM in a multi-equation framework to study the impact of intervention on exchange rates, whether the central bank reacts to exchange rate developments in the formulation of policy (and therefore the problem of endogeneity) and the how monetary policy initiatives affects these relationships. Their innovation was to use a change in intervention policy by the RBA and the BOJ to solve the problem of identification in a situation where the issue of endogeneity of the contemporaneous relationship between intervention and exchange rates was a serious problem. The weakness of this approach is that the identification scheme is very specific to the two markets studied and therefore its applicability to other markets is questionable. The study is also dependent on the assumption that the change in intervention policy is truly exogenous and not dependent on the exchange rate dynamics which is questionable given that intervention and therefore intervention policy has been shown to react to exchange rate dynamics. This approach also assumes that most parameters of the model is stable across the change in intervention policy which is also questionable given that the change was made to improve intervention's effectiveness, that is, to make the coefficient measuring the impact of intervention on exchange rates larger and/or statistically significant relative to what it was before the change in intervention policy.

Moreover, all these study focused on the first moment ignoring the variance and therefore the impact of policy on the volatility of the exchange the exchange rate. This is a major weakness of these approaches given that central bank policy is increasingly targeting volatility rather than a particular exchange rate. The empirical methodology must therefore be able to measure the impact of policy on the volatility of the exchange rate to be useful in a policy context.

Kim and Sheen (2006) employed a bivariate GARCH framework to study the links between exchange rate changes, volumes and the Bank of Japan's intervention in the foreign exchange market using daily data. This allowed them to look at these issues in a joint framework both at the level and variance of exchange rate returns and dealt with a number of weaknesses of previous studies. There were separate mean equations for exchange rate changes and volume with intervention treated as an exogenous variable. This approach represented a step forward because it was a joint framework which addressed the links and feedback effects between volumes and direct intervention on exchange rate dynmics both at the level of returns and variance. By not including seprate mean equations for the central bank's policy reaction functions for both direct intervention and interest rate policy in the multivariate GARCH framework, however, it represented these policy instruments as exogenous which is not really the case. kim and Sheen (2006) tried to address this weakness by modelling central bank interventions as driven by a number of variables including exchnge rate and volume dynamics in a separate friction model. By not treating with this issue explicitly in the multivariate GARCH framework meant that their estimates were not as efficient as they could be and, it did not allow them to explore the full set of links and feedback effects between exchange rate changes, volume, direct intervention and interest rate policy changes in the foreign exchange market.

To address these weaknesses we extend this approach by using a multivariate GARCH framework to study the links and feedback effects between monetary policy, intervention in the foreign exchange market, volume in the market and exchange rate dynamics. This framework allows us to look at the impact of intervention on exchange rate, the impact of monetary policy on exchange rates the links between the two policy instruments in particular whether central banks signal monetary policy with its intervention operations in the foreign exchange market and whether the central banks leans against the wind with respect to exchange rate dynamics. It also allows us to look at how volume dynamics impacts on the effectiveness of policy from a market microstructure perspective. Additionally, unlike previous studies, it can allow one to look at how policy intervention affects the conditional covariance and correlation of important variable like interest and exchange rates over time. This can provide information on the inter-temporal dynamics of the way the correlation of important variables reacts to policy interventions and therefore shed some light on the costs and policy conflicts associated with unsynchronized implementation of related policy instruments over time.

The following mean equation was estimated for each series being considered:

$$X_{i,t} = \mu_i + \alpha X_{i,t-1} + \varepsilon_{it} \qquad (1)$$

Where X_{it} is a vector of variables of interest (exchange rates, trading volumes in the foreign exchange market, direct intervention and policy interest rates) at time *t*, μ_i is a long term drift coefficient and ε_{it} is the error term for variable *i* at time *t*.

This mean equation formulation can be more explicitly represented in this study by the following three equations which outlines the mean equation for the variables of interest, that is, exchange rate (*ER*), intervention (*I*), the repo rate (*RR*) and market volume (*MV*):

$$ER_{1,t} = \delta_1 + \delta_{11}ER_{t-1} + \delta_{12}I_{t-1} + \delta_{13}RR_{t-1} + \delta_{14}MV_{t-1} + \varepsilon_{1,t} \quad (2)$$

$$I_{2,t} = \delta_2 + \delta_{21}ER_{t-1} + \delta_{22}I_{t-1} + \delta_{23}RR_{t-1} + \delta_{24}MV_{t-1} + \varepsilon_{2,t} \quad (3)$$

$$RR_{3,t} = \delta_3 + \delta_{31}ER_{t-1} + \delta_{32}I_{t-1} + \delta_{33}RR_{t-1} + \delta_{34}MV_{t-1} + \varepsilon_{3,t} \quad (4)$$

$$MV_{4,t} = \delta_4 + \delta_{41}ER_{t-1} + \delta_{42}I_{t-1} + \delta_{43}RR_{t-1} + \delta_{44}MV_{t-1} + \varepsilon_{4,t} \quad (5)$$

In this framework δ_{12} and δ_{13} measure the impact of intervention and monetary policy (interest rates) on exchange rates. Additionally, δ_{21} measure the tendency of central bank interventions to lean against the wind, δ_{32} indicates whether intervention signals monetary policy or not while δ_{42} indicates whether central bank intervention precipitates a cascade of trading and increased volumes.

The two most popular parameterization for multivariate GARCH models are the VECH (Bollerslev, Engle and Wooldridge, 1988) and BEKK (Engle and Kroner, 1995) and parameterization. The VECH parameterization is characterized as:

$$vech(H_t) = A_0 + \sum_{j=1}^{q} B_j vech(H_{t-j}) + \sum_{j=1}^{p} A_j vech(\varepsilon_{t-j}\varepsilon'_{t-j}) \quad (6)$$

where $\varepsilon_t = H_t^{1/2}\eta_t \quad \eta_t \sim iid$ N(0,1). The notation *vech* (.) in equation 6 is a matrix operator which stacks the lower part of the symmetric matrix into a column vector and H_t is the conditional variance-covariance matrix. A_0 is a vector of constants capturing the unconditional variances and covariances while B_j and A_j are matrices of parameters representing the GARCH process. The major weaknesses of the VECH model include the number of parameters[5] to be estimated and the fact that there is no guarantee that the covariance matrix will be positive semi-definite unless additional restrictions are imposed. The latter property is necessary for the estimated variance to be greater than or equal to zero. We therefore use the BEKK parameterization for the multivariate GARCH model estimated in this paper.

The general form of the BEKK model is:

$$H_{t+1} = C'C + A'\varepsilon_t\varepsilon'_t A + B'H_t B \quad (7)$$

[5] For example in a trivariate model the number of parameters to be estimated for the variance equation would be 78.

The BEKK model is more tractable since it utilizes quadratic forms in such a way to ensure that matrix H_t will be positive semi-definite, without additional restrictions having to be imposed. This multivariate GARCH parameterization can significantly reduce the number of elements to be estimated in the variance equations. The BEKK model still involves some heavy computations because of the number of matrix inversions which is required. Also, because the BEKK parameterization uses a higher order polynomial representation which increases the non-linearity of the parameters, obtaining convergence may be difficult and time consuming. The individual elements of matrices *A*, *B* and *C* in the case of a four-variable multivariate GARCH model are outlined below:

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} B = \begin{bmatrix} b_{11} & b_{12} & b_{13} & b_{14} \\ b_{21} & b_{22} & b_{23} & b_{24} \\ b_{31} & b_{32} & b_{33} & b_{34} \\ b_{41} & b_{42} & b_{43} & b_{44} \end{bmatrix} C = \begin{bmatrix} c_{11} & 0 & 0 & 0 \\ c_{21} & c_{22} & 0 & 0 \\ c_{31} & c_{32} & c_{33} & 0 \\ c_{41} & c_{42} & c_{43} & c_{44} \end{bmatrix} \qquad (8)$$

where *C* is a 4x4 lower triangular matrix of unconditional variances and covariance, *A* is a 4x4 square matrix of parameters that show the correlation of conditional variances with past squared errors and *B* is a 4x4 matrix of parameters that measure the impact of past levels on current levels of conditional variances. The parameters in *A* measure the impact of shocks in variables on the conditional variance of all variables while the parameters in *B* measure the volatility spillovers from variables under consideration.

As an example, the conditional variance equation for the first variable[6] which shows how shocks and volatility are transmitted over time in each sector can be expanded as follows:

$$\begin{aligned} h_{11,t+1} = {} & a_{11}^2\varepsilon_{1,t}^2 + 2a_{11}a_{12}\varepsilon_{1,t}\varepsilon_{2,t} + 2a_{11}a_{31}\varepsilon_{1,t}\varepsilon_{3,t}\varepsilon_{3,t}^2 + 2a_{11}a_{41}\varepsilon_{1,t}\varepsilon_{4,t}\varepsilon_{4,t}^2 \\ & + a_{21}^2\varepsilon_{2,t}^2 + 2a_{21}a_{31}\varepsilon_{2,t}\varepsilon_{3,t} + a_{31}^2\varepsilon_{3,t}^2 + a_{31}^2\varepsilon_{3,t}^2 + 2a_{31}a_{41}\varepsilon_{3,t}\varepsilon_{4,t} + a_{41}^2\varepsilon_{4,t}^2 \\ & + b_{11}^2 h_{11,t} + 2b_{11}b_{12}h_{12,t} + 2b_{11}b_{31}h_{13,t} + 2b_{11}b_{41}h_{14,t} \\ & + b_{21}^2 h_{22,t} + 2b_{21}b_{31}h_{23,t} + 2b_{31}b_{41}h_{34,t} \\ & + b_{31}^2 h_{33,t} + 2b_{31}b_{41}h_{34,t} + b_{41}^2 h_{44,t} \end{aligned} \qquad (9)$$

In this framework $h_{11,t}$ is the conditional variance for the first variable (exchange rates) at time t, $h_{12,t}$ is the conditional covariance between the first variable (exchange rates) and the second variable (intervention), $h_{13,t}$ is the conditional covariance between the first and third variables (interest rate) and $h_{14,t}$ is the conditional covariance between the first and forth variables (market volume). The error term $\varepsilon_{i,t}^2$ measures deviations from the mean due to some unanticipated event

[6] The constant terms are excluded.

in variable i and cross error terms such as $\varepsilon_{1,t}\varepsilon_{2,t}$ measure the impact of unanticipated events in one sector on another. The a_{ii} coefficients measure the impact of shocks in variables under consideration on conditional variances (volatility) while the b_{ii} coefficients measure volatility spillovers between sectors.

Assuming that the errors are normally distributed the following likelihood function is maximized:

$$L(\theta) = -\frac{TN}{2}\ln(2\pi) - \frac{1}{2}\sum_{t=1}^{T}(\ln|H_t| + \varepsilon_t' H_t^{-1}\varepsilon_t) \tag{10}$$

where T is the number of observations, N is the number of variables in the model and θ is the vector of parameters to be estimated. The BFGS algorithm is used to obtain final estimates of the parameter with the variance covariance matrix and corresponding standard errors. The Simplex method was used to obtain initial parameter for the BFGS algorithm.

4. Data and Estimation Results

4.1 Data

Intervention is defined as daily sales and purchases of foreign currency by the central bank. The exchange rate is measured as the domestic currency per intervention currency, the US dollars. The data set on Jamaica cover 1161 observations (after omitting holidays and other non-trading days) over the period February 7, 2002 to September 28, 2006. The data for Trinidad and Tobago include 2393 observations covering the period January 3, 2000 to September 30, 2009.

Policy interest rates are used as proxies for monetary policy initiatives instead of monetary aggregates in this study as this is increasingly the practice in empirical studies. This is so since monetary aggregates contain elements which are positively correlated with interest rates which over time make them inappropriate proxies for monetary policy analysis based on a monetary model since monetary models are driven by liquidity effects which predicts that monetary aggregates would be *negatively* related to interest rates (Christiano and Eichenbaum, 1992). Also, Bernanke and Blinder (1992) argue that policy interest rates are better predictors of economic trends since it is truly exogenous because they are targeted by the central bank. The annualized rates used are the upper bound of the Repo Rate in the case of Jamaica and the Interbank rate in the case of Trinidad and Tobago. In Trinidad and Tobago's case the policy interest rate is the Repo Rate but the Interbank rate is used since it better captured daily changes and is highly correlated with the Repo Rate.

4.2 Preliminary Results

The mean equation and the variance equations with BEKK parameterization are estimated simultaneously and the results for Jamaica and Trinidad and Tobago are outlined in Tables 1 and 2 respectively.

The estimation results from the mean equation are important because they speak to important issues concerning the practice of central bank intervention in the foreign exchange market. In particular, δ_{12} and δ_{13} measure the impact of intervention and monetary policy (interest rates) on exchange rates. Additionally, δ_{21} measure the tendency of central bank interventions to lean against the wind while δ_{32} indicates whether intervention signals monetary policy or not. In terms of the impact trade volume has on the market δ_{42} can let us know if intervention really elicits a cascade of trades as argued by the market microstructure school of thought and δ_{14} can indicate whether volumes matter for exchange rate trends.

In the case of Jamaica (see Table 1), the coefficient δ_{12} is positive and significant (0.019), indicating that sales of foreign currency against the local currency lead to an appreciation of the Jamaican dollar. The coefficient δ_{13} is -0.003 indicating that increases in interest rate leads to an appreciation of the Jamaican dollar. The way volume impacts on the market is captured by the coefficients δ_{14} and δ_{42} indicates that increased volume generally lead to a stronger currency and direct interventions lead to a cascade of trading volume as predicted by the microstructure literature. The coefficient δ_{21} is -0.13 and significant indicating that the BOJ intervened predominantly to "lean against the wind", that is if the exchange rate was depreciating they intervened selling foreign exchange to counter this trend. The coefficient δ_{32} of -0.017, although correctly signed to support the signaling framework is insignificant, indication the BOJ's intervention and interest rate policy is broadly but weakly consistent. This may suggest that interest rate and exchange rate policy may sometime be deployed to achieve different objectives which are not always congruent.

In the case of Trinidad and Tobago, the mean equation results were somewhat different to Jamaica. In one important area, the effectiveness of intervention, the result was similar in the sense that intervention moved the exchange rate in the expected direction. In contrast to Jamaica, however, the impact of interest rate changes is insignificant and, interestingly, the CBTT does not display "leaning against the wind" behavior since δ_{21} is positive and insignificant, suggesting that trend correction is not one of the CBTT objectives in the foreign exchange market. Surprisingly, δ_{32} is positive and significant, a result which strongly rejects the signaling framework. This suggests that direct intervention and interest rate policy are geared to different objectives and may be related to the peculiarities of the Trinidad and Tobago foreign exchange market where adjustments appears to effected through quantities rather than prices. Moreover, volume does not appear to impact on exchange rate returns (See Table 3).

As noted above the multivariate GARCH framework also allows us to look at the volatility dynamics of intervention and interest rate policy, as well as, trading volume dynamics, in a joint framework. This is important since central banks are increasingly concerned about the volatility consequences of policy measures. The variance/covariance equations results allow us to assess the volatility spillovers caused by the linkages between exchange rates, intervention, interest rates and trading volumes in the foreign exchange market.

The transmission of shocks across variables in the multivariate GARCH is reflected in matrix *A* with the diagonal elements measuring the impact of own past shocks while the off-diagonal elements measure the impact of shocks from other variables on volatility. In the case of Jamaica, Table 1 shows that shocks to intervention (a_{12}) significantly increase exchange rate volatility, while interest rate changes have no impact on volatility (a_{13}). This implies that there may be a cost of greater volatility even if the policy initiatives achieve their objective with respect to the level of the exchange rate, at least in the short-term. In this sense interest rate changes is less costly in terms of exchange rate volatility. Shocks to trading volumes also tend to reduce exchange rate volatility. Other interesting results in terms of the transmission of shocks for Jamaica include the fact that shocks to exchange rates spills over to intervention (a_{21}), lending further credence to the notion that the authorities often implement policy measures in response to exchange rate developments. Additionally, shocks to intervention seems to have a significant effect on the volatility of trading volumes (a_{42}) implying that interventions increase trading volumes but also increase the volatility of trading volumes probably as more speculative rather than liquidity traders enter the market.

The transmission of shocks in the case of Trinidad and Tobago again seems in sharp contrast to Jamaica in key areas. In particular, shocks to direct interventions lower exchange rate volatility implying there is virtually no cost in terms of volatility when using this instrument. On the other hand, shocks to trading volumes tend to lower exchange rate volatility and shocks to exchange rates increase the volatility of intervention as in Jamaica. Interest rate volatility is not affected by shocks in any of the variables again suggesting that interest rates have little traction in the market. Also, shocks to exchange rates increases volatility in volumes again lending credence to the microstructure links between exchange rate and foreign exchange market trading volumes.

Volatility spillovers across variables in the multivariate GARCH is reflected in matrix *B*. For Jamaica, increased volatility intervention (b_{12}) and interest rates to exchange rates (b_{13}) are negatively correlated with volatility in exchange rates, reinforcing the results in terms of the mean equations and the response to shocks. There are significant volatility spillovers from to trading volumes to exchange rates (b_{14}) again emphasizing the "mixture of distributions' notion in the microstructure framework where common information flows drive both trading volumes and exchange rates. The same dynamic seems to be in operation in terms of volatility spillovers from volumes to interest rates (b_{34}). Volatility spillovers in the case of Trinidad and Tobago mirror that of Jamaica in the case of volatility in intervention reducing exchange rate volatility. Volatility in volumes on the other hand reduces volatility in exchange rate which is not in congruence with the microstructure school which argues that common state variables drive common volatility dynamics in trading volumes and exchange rates.

5. Conclusions

The results of the study also add new information on the links between exchange rate dynamics, direct intervention, interest rate policy and trading volumes in the foreign exchange market in a joint framework that allow us to look at the results of policy both at the levels and volatility of exchange rates.

The results confirmed the effectiveness of direct intervention in the sense that in both Jamaica and Trinidad and Tobago this instrument moved the exchange rate in the desired direction. The BOJ paid a cost in terms of increased short term volatility in the exchange rate during intervention operation while the CBTT did not. This appears related to the fact that the Jamaican foreign exchange market seems to be affected by the microstructure features where a common state variable is driving innovations in both exchange rate volatility and trading volumes. The basis for this is that increased volumes signals that there are informed agents in the market (of which the central bank is one) which causes a cascade of trades with associated volatility in prices as new information is priced in.

The study also seems to show that the BOJ generally intervened to "lean against the wind" and the relationship of intervention to policy interest rates was best characterized by the "signaling" framework. This was not the case in Trinidad and Tobago where direct intervention did not seem to be tied closely to interest rate policy. Interest rate policy in Trinidad and Tobago appeared to have little impact in the foreign exchange market, in sharp contrast to Jamaica, and seem not to be an integral part of foreign exchange market activity. This may be due to the fact that flows into the foreign exchange market in Trinidad and Tobago are less tied to portfolio flows (which are more sensitive to the spread between domestic and foreign interest rates) as they are in Jamaica. The CBTT therefore has less of a binding constraint on the external side when implementing interest rate policy.

The main conclusion is that both direct intervention and policy interest rate policy have an impact in the foreign exchange market in Jamaica while only direct intervention is effective in Trinidad and Tobago. The fact that in Jamaica there are costs in terms of increased short term exchange rate volatility when using direct intervention which is not the case with policy interest rates means that policy interest rates are more effective for policy objectives in the foreign exchange market while in Trinidad and Tobago direct intervention is more effective. This reality is driven by the structure of the foreign exchange market in these countries and the constraints faced by the respective central banks when implementing policy in their foreign exchange market. Furthermore, these differential impacts in terms of the impact of policy instruments and trading volumes in the market on the mean and variance of the exchange rates highlights the utility and logic of using a multivariate GARCH framework for the simultaneous assessment of these issues.

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Table 1: Estimated coefficients for the multivariate GARCH model for Jamaica

	Exchange Rate (i=1)		*Intervention (i=2)*		*Interest Rate (i=3)*		*Volume (i=4)*	
δ_{1i}	-0.19	-0.43	0.019	2.70	-0.003	-2.15	-0.001	-5.19
δ_{2i}	-0.13	-2.90	0.46	16.13	-0.003	-1.22	-0.004	-6.84
δ_{3i}	1.47	2.79	-0.17	-1.42	-0.25	-4.42	-0.001	-0.59
δ_{4i}	11.57	3.20	8.82	6.48	0.13	1.01	-0.39	-13.0
a_{1i}	0.77	24.4	0.15	1.92	-0.56	-0.53	-10.3	-3.1
a_{2i}	0.08	7.64	0.004	0.03	0.29	1.70	0.75	0.31
a_{3i}	0.002	1.03	-0.004	-1.81	-0.93	-34.6	-0.31	-1.37
a_{4i}	0.0004	2.77	0.007	12.54	0.005	1.4	0.80	117.9
b_{1i}	0.65	9.34	-0.15	-1.99	-1.5	-2.44	8.78	2.92
b_{2i}	-0.03	-2.9	-0.09	-2.67	0.38	1.97	-1.64	-0.84
b_{3i}	-0.001	-1.0	0.002	0.97	0.42	3.71	0.62	3.2
b_{4i}	-0.001	-4.39	-0.006	-3.9	-0.006	-0.2	-0.05	-0.91
$LBQ(10)$	53.8	(0.00)	29.4	(0.00)	13.1	(0.21)	126.2	(0.00)
$LBQs(10)$	0.72	(0.99)	29.0	(0.00)	1.62	(0.99)	26.6	(0.00)
LLR	-7860							

Notes: $LBQ(10)$ and $LBQs(10)$ are the Ljung-Box Q-statistics for standardized and squared standardized residuals at lag 10 respectively and LLR is log likelihood ratio. Values underlined are t-values and those in brackets are the probabilities for the Ljung-Box Q-statistics.

Table 2: Estimated coefficients for the multivariate GARCH model for Trinidad and Tobago

	Exchange Rate (i=1)		*Intervention (i=2)*		*Interest Rate (i=3)*		*Volume (i=4)*	
δ_{1i}	-0.38	-19.5	0.001	2.53	0.002	0.82	-0.0005	-0.57
δ_{2i}	0.06	0.11	0.01	0.65	-0.05	-1.33	-0.003	-1.46
δ_{3i}	-0.11	-0.53	0.01	2.25	-0.12	-3.56	0.001	1.02
δ_{4i}	3.25	0.84	0.09	1.05	0.33	0.84	-0.41	-21.9
a_{1i}	-1.09	-109.1	-0.59	-1.67	-0.47	-0.75	-98.7	-10.9
a_{2i}	0.001	5.7	-0.98	-238.1	0.02	1.36	1.18	5.9
a_{3i}	-0.003	-0.81	-0.06	-1.53	0.99	160.5	-0.05	-0.09
a_{4i}	0.002	13.4	0.006	1.38	0.002	0.81	0.71	6.53
b_{1i}	0.11	6.25	-1.85	-2.62	-0.27	-0.77	-34.9	-3.1
b_{2i}	0.001	1.59	0.18	4.48	-0.007	-1.04	0.14	0.43
b_{3i}	-0.001	-0.76	0.01	0.88	0.13	4.23	-0.59	-0.61
b_{4i}	0.0002	2.96	0.003	1.7	0.002	0.80	0.37	11.5
$LBQ(10)$	219.5	0.00	78.5	0.00	36.2	0.00	274.4	0.00
$LBQs(10)$	18.3	0.05	13.7	0.19	4.4	0.93	38.0	0.00
LLR	-24862							

Notes: Same as Table 2.