THE EFFECTIVENESS OF CENTRAL BANK INTERVENTIONS IN THE FOREIGN EXCHANGE MARKET

A thesis submitted for the degree of Doctor of Philosophy

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ABSTRACT

The Effectiveness of Central Bank Interventions in the Foreign Exchange Market

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The global foreign exchange market is the largest financial market with turnover in this market often outstripping the GDP of countries in which they are located. The dynamics in the foreign exchange market, especially price dynamics, have huge implications for financial asset values, financial returns and volatility in the international financial system. It is therefore an important area of study. Exchange rates have often departed significantly from the level implied by fundamentals and exhibit excessive volatility. This reality creates a role for central bank intervention in this market to keep the rate in line with economic fundamentals and the overall policy mix, to stabilize market expectations and to calm disorderly markets.

Studies that attempt to measure the effectiveness of intervention in the foreign exchange market in terms of exchange rate trends and volatility have had mixed results. This, in many cases, reflects the unavailability of data and the weaknesses in the empirical frameworks used to measure effectiveness. This thesis utilises the most recent data available and some of the latest methodological advances to measure the effectiveness of central bank intervention in the foreign exchange markets of a variety of countries. It therefore makes a contribution in the area of applied empirical methodologies for the measurement of the dynamics of intervention in the foreign exchange market. It demonstrates that by using high frequency data and more robust and appropriate empirical methodologies central bank intervention in the foreign exchange market can be effective. Moreover, a framework that takes account of the interactions between different central bank policy instruments and price dynamics, the reaction function of the central bank, different states of the market, liquidity in the market and the profitability of the central bank can improve the effectiveness of measuring the impact of central bank policy in the foreign exchange market and provide useful information to policy makers.

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THE THEORY AND RATIONALE FOR CENTRAL BANK INTERVENTION IN THE FOREIGN EXCHANGE MARKET

1.0 Introduction

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Studies that attempt to measure the effectiveness of intervention in the foreign exchange market in terms of exchange rate trends and volatility have had mixed results. This in many cases reflect the unavailability of data and the weaknesses in the empirical frameworks used to measure effectiveness. This thesis utilises the most recent data available and some of the latest methodological advances to measure the effectiveness of central bank intervention in the foreign exchange markets of a variety of countries. It therefore makes a contribution in the area of applied empirical methodologies for the measurement of the dynamics of intervention in the foreign exchange market. It demonstrates that central bank intervention in the foreign exchange market can be effective when high frequency data and more robust and appropriate empirical methodologies are used. Moreover, a framework that takes account of the interactions between different central bank policy instruments and price dynamics, the reaction function of the central bank, different states of the market, liquidity in the market and the profitability of the central bank can improve the effectiveness of measuring the impact of central bank policy in the foreign exchange market and provide useful information to policy makers.

1.1 The Global Foreign Exchange Market

The most recent Triennial Central Bank Survey of Foreign Exchange and Derivative Market Activity published by the Bank for International Settlements (BIS) estimates that the daily global foreign exchange market turnover had grown to USD 4.0 trillion by April 2010. This represents a 20% increase over the global turnover estimated in 2007 but much smaller than the 72% increase registered between 2004 and 2007. The most recent growth performance it must be noted took place during the period of the international financial crisis and the continuing turmoil in European sovereign bond markets. This continuing growth is therefore testament to the importance and resilience of this market.

The growth in foreign exchange turnover has been driven by the fact that it presents attractive returns relative to bonds and equities to leveraged short-term investors such as investors in the carry trade who exploits interest rate differentials across currencies, as well as to longer-term investors such as pension funds looking to diversify their portfolios. The growth of online trading platforms has also opened foreign exchange trading to retail investors by lowering transactions costs. The increasing international diversification of investors' portfolios combined with the availability of instruments to hedge foreign exchange risks meant that currency exposure had to be managed more actively which resulted in increased trading by more counterparties and therefore greater turnover in the market. The increasing importance of algorithmic trading driven by developments in electronic trading platforms which tried to exploit high frequency movements in exchange rates also led to increased turnover relative to the size of investors' positions.

Important trends in these markets which impact on price and liquidity dynamics include the increasing importance of the derivatives market, particularly foreign exchange swaps, increased trading between dealers and other financial institutions and the corresponding decline in inter-dealer trading, the increasing presence of emerging market currencies in global foreign exchange trading and the growth and subsequent reversal of the carry trade (Galati and Heath, 2007). The net effect of these changes is the growing heterogeneity of agents in foreign exchange markets in developed and emerging economies, the increasing need of central banks to take account of foreign interest rate when setting domestic rates and increasing volatility in foreign exchange markets driven by international shocks. All these trends have implications for the way in which central banks implement policy in the foreign exchange market generally making central banks' remit to promote financial stability more difficult.

The growth between 2007 and 2010 was driven by other financial institutions such as mutual funds, pension funds, insurance companies, hedge funds and central banks as these institutions accounted for 85% of the growth in the global foreign exchange market. This category of agents for the first time surpassed dealers and inter-dealers. This development reflects greater activity by high frequency traders, more trading by smaller banks and the increasing significance of retail investors to global turnover (King and Rime, 2010). There is therefore a growing heterogeniety of agents in the market but trading is still concentrated in the large dealers because they invest heavily in their trading systems which allow them to guarantee liquidity and smaller bid-ask spreads. In this context, smaller banks are becoming clients for these larger dealers in major currencies but contributing to the trade in domestic currencies by being the market maker. This strategy allows smaller banks to profit from their local expertise without having to compete in spot markets for major currencies, a role which they are not well resourced to perform.

Additionally, although global turnover in the foreign exchange market increased by 20% overall between 2007 and 2010, there is evidence[1] that liquidity in the market dropped sharply and hit a low point close to the end of the second quarter of 2009, only recovering to the 2008 levels in 2010. Daily average global turnover in the foreign exchange market may therefore have reached its peak in 2008 following the failure of Lehman Brothers. During the period of the crisis, many investors turned to the spot foreign exchange market to hedge risks which would have generated greater volatility in foreign exchange market turnover and increased the challenges central bank faced to promote stability in these markets. The increased volatility and risk aversion in foreign exchange markets led to a rapid reversal of carry trade positions and the accumulation of large losses by investors. These developments underlined the fact that volumes and price dynamics in foreign exchange markets are strongly correlated.

The financial crisis demonstrated once again that this market was an important channel through which financial crises can be propagated. These developments attracted

[1] From the Barclay Foreign Exchange Liquidity Index.

the increased attention of central banks which resulted in a tighter regulatory framework and increasing activism by central banks in this market through the provision of liquidity and more frequent policy interventions. At the same time, market makers in the foreign exchange market are now relying increasingly on central bank windows instead of swaps, seemingly accepting this greater role for central banks in the market. The study of the effectiveness of central bank policy initiatives in this market is therefore worthy of increased attention and study.

1.2 The Literature on Central Bank Interventions in the Foreign Exchange Market

Most central bank operating flexible exchange rate regimes have intervened in the markets but 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 the 1980s and 1990s, done almost exclusively on developed markets, indicated that there was mixed evidence that intervention can affect the level and variance of exchange rate returns (Edison, 1993; Sarno and Taylor, 2001). In the case of developing countries, there is less pessimism since in these markets the intervention volumes are larger relative to total turnover in the market. Additionally, a variety of regulations restricts the size of the market and helps to give the central bank leverage. The central bank also has an information advantage in the market due to reporting requirements. In spite of this, based on a review by Disyatat and Galati (2007), it is still unclear whether intervention in emerging and transition countries is more effective than in developed countries.

1.2.1 Intervention Channels

The literature on the effectiveness of central bank intervention in the foreign exchange market[2] generally focuses on the channels through which intervention impact on exchange rate dynamics and on the empirical methodologies used to measure the impact of intervention. Theoretically, interventions in the foreign exchange market (usually sterilized)[3] can affect the exchange rate through a variety of channels that are

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[2] See Edison (1993), Sarno and Taylor (2001), Neely (2005) and Vitale (2007) for useful reviews of the Literature focusing on intervention channels and estimation techniques.

[3] There is consensus that unsterilized intervention can affect exchange rate dynamics because it changes the money base and interest rates which reinforce the impact of the original intervention on exchange rates.

not mutually exclusive. These include the signaling, portfolio balance channel and market microstructure channels, all of which are based on their respective models of exchange rate determination[4].

The Signaling Channel

In terms of the literature on intervention channels, 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, 1993 a and b; Kaminsky and Lewis, 1995). In this framework the exchange rate is treated as an asset price which is determined by the money supply. The intervention of the central bank works by moving market participants' expectations of what future monetary conditions are likely to be closer to the central banks expectations, even if the intervention is sterilized. 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 be larger 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).

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

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 net effect of these structural factors on the effectiveness of the signaling channel can only be resolved by empirical measurement.

The Portfolio Balance Channel

Under the portfolio balance channel, intervention work by generating rebalancing in terms of the currency composition of market participants' portfolios which generates changes in the exchange rate. This is based on the portfolio balance model of exchange rate determination (Sarno and Taylor, 2001). 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; Dominquez and Frankel, 1993b). Agents therefore demand a higher return on the asset whose outstanding stocks has increased to equalize risk-adjusted returns. Foreign exchange market interventions alter agents' relative supply of foreign and local securities and force rebalancing which generates changes in the exchange rate. In the case of un-sterilized interventions, the corresponding contraction in the monetary base reinforces the impact of the intervention. The portfolio balance channel is thought to be more effective in developing countries where central bank credibility may be weak, where domestic and foreign currency debt are imperfect substitutes and where the central bank interventions are large relative to market turnover[5] (Canales-Kriljenko, Guimaraes and Karacadag, 2003; Galati and Melick, 2002).

The Microstructure Channel

The microstructure approach to foreign exchange markets focus on order flow[6], information asymmetries, trading mechanisms, liquidity and the price discovery process. Central bank intervention works in this framework by emitting information to

[5] The converse is of course true in developed market economies where the volume of market turnover has been growing rapidly restricting the scope for intervention on the scale that would have an impact on the rate.

[6] 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.

the market which modifies expectations and generates huge order flows which change exchange rate dynamics (Evens and Lyons, 2002). Intervention induced order flows may also increase volatility but this is dependent on whether the market is tranquil or volatile, which in turn depends on the amount of liquidity traders relative to informed traders in the market. Central bank intervention is a special form of order flow that causes agents to change their expectations on the future part of the exchange rate and net open positions which generates a cascade of order flows.

The relationship between volume and volatility in the microstructure setting is driven by agent heterogeneity and asymmetric information where informed traders gain at the expense of uninformed traders or customers who trade to eliminate exposure, especially when new information flows into the market. This is related to the mixture of distributions hypothesis (MDH) outlined by Easley and O'Hara (1992). In this framework, volume and volatility in prices are related because both aggregates are driven by common dynamics as new information comes into the market during normal (liquidity trading) periods (Frankel and Froot, 1990; Tauchen and Pitts, 1983), however, during periods of market turmoil liquidity traders withdraw from the market and there is a negative relationship (Galati, 2000).

This implies that there are two types of regimes or market conditions in which central bank can intervene, a liquidity trading regime where most liquidity traders are involved and where the mean and variance of the exchange rate returns are relatively small and, an informed trading regime where many liquidity traders leave the market and where the mean and variance of exchange rate returns are relatively large. If the market is in the former regime, central bank interventions would tend to increase volatility, as there is a positive relationship between volume and volatility in this regime. If the market is in the informed trading state, central bank interventions will tend to reduce volatility, since there is a negative relationship between volume and volatility in this regime.

Evidence on Intervention Channels

In terms of the actual evidence on the various channels through which intervention affects the exchange rate, empirical studies have found mixed evidence for the portfolio balance and signaling channels. Under the signaling channel, Dominguez and Frankel (1993a) estimated the impact of intervention on current and future exchange rate (using survey data) and found that intervention had a significant impact on expectations, especially if interventions were publicized. In terms of the portfolio balance effect, Obstfeld (1990) finds that the portfolio balance effects are significant but small. As a matter of fact, the evidence on the portfolio balance effect was until recently that this channel was of limited use in intervention (Edison, 1993). The exception to this was Dominguez and Frankel (1993b) who found a significant and large portfolio effect using survey data to measure exchange rate expectations and risk premiums.

Recent research that uses the framework of market microstructure and order flow (Evens and Lyons, 2002) found that intervention had a significant impact on exchange rates (US$/DM and US$/yen) through the portfolio balance channel, with a one billion US$ intervention having an immediate 0.44 percent impact on the exchange rate with a permanent impact at 0.35 percent. Dominguez (1999) utilizes an event study approach with intra-daily data to capture microstructure elements in a model of central bank intervention in the foreign exchange market. The results indicate that intervention has a significant impact on both the US$/DM and US$/yen rates. The results of this study also indicated that the effectiveness of central bank interventions depends on the state of the market at the time the central bank intervention becomes known in the market. The microstructure of the foreign exchange market could therefore play a significant role in determining the effectiveness of the central bank's intervention in this market.

1.2.2 The Empirical Methodology for Measuring of the Effectiveness of Central Bank Intervention

In terms of the literature on empirical approaches to measuring the impact of intervention, a range of methodological approaches has been used to evaluate the effectiveness of intervention in the foreign exchange market over the years. Excellent reviews are available in Edison (1993) for studies done in the 1980s, Sarno and Taylor (2001) for studies done in the 1990s and Cavusoglu (2010) for studies done in the 2000s.

The main methodological approaches include OLS regression of mean, risk premium and order flow equations (Dominguez and Frankel, 1993 a and b; Evans and

Lyons, 2002), event studies of intervention episodes (Fatum, 2000; Fatum and Hutchison, 2003; Hutchison, 2003), unified approaches to monetary policy and foreign exchange market intervention using structural vector autoregression (VAR) methodology (kim, 2003), a simulated general method of moments (GMM) approach using an exogenous shift in intervention policy as an identifying assumption (Kearns and Rigobon, 2005), the GARCH framework (Dominguez, 1998; Murray et al., 1997; Guimaraes and Karacadag, 2004) and multivariate GARCH approach (Kim and Sheen, 2006) for evaluating the impact of intervention on the level, as well as the volatility of the exchange rate. Most of these models implicitly assume a linear relationship between intervention and the mean and variance of exchange rate returns, which may not be relevant or appropriate in many cases. Indeed, many studies have argued that exchange rate behaviour generally evolve in a non-linear way (Sarno and Taylor, 2001).

Many non-linear exchange rate models have emerged geared to better capture the data generating process in exchange rates. These include smooth transition autoregressive models (Sarantis, 1999), non-parametric procedures (Diebold and Nason, 1990; Meese and Rose, 1990), chaos models (Hsieh, 1991) and Markov switching models (Engle and Hamilton, 1990; Filardo, 1994; Diebold et. al., 1994). These non-linear approaches generally fit the data well within the sample but do not always produce better out-of-sample forecasts relative to linear models. In particular, Diebold and Nason (1990) and Hsieh (1991) have used non-parametric models to estimate exchange rate returns and found that their out-of-sample forecasts were worst than the linear random walk model.

These studies with the exception of the VAR and the simulated GMM approaches all suffer from simultaneity problems, that is, the regression of exchange rate over intervention fails to separate the degree to which intervention responds to exchange rates rather than exchange rates responding to intervention. Attempts to overcome the simultaneity problem have included using lagged values of intervention, using the VAR framework (Neely, 2005; Kim, 2003) and simulated GMM (Kearns and Rigobon, 2005).

All approaches to dealing with this problem have their weaknesses. The problem with the VAR approach is the validity of the identifying restrictions used to identify structural shocks. In the case of the instrumental variables approach, finding appropriate instruments, that is, those that are correlated with intervention but uncorrelated with exchange rate returns, is very difficult. The use of lagged values of intervention is also problematic since one cannot estimate the impact of contemporaneous intervention (Neely, 2005). Finally, the simulated GMM approach is very promising but the validity of the assumption that the policy shift is exogenous and therefore a valid identifying assumption is also questionable and also very specific to particular markets where such policy shifts occurred.

In spite of potential simultaneity problems regime switching models such as, the Markov switching (MS) and smooth transition autoregressive (STAR) models have become very popular in studying exchange rate dynamics. In STAR models the transition between regimes is assumed to be smooth while MS models allow for the transition to be sharp. MS models are therefore better able to capture sharp and discrete changes in the data generating process, with the change in regime a random variable which has to be derived from the data. Countries that experience crises or abrupt changes in government policy can expect the speed of transition to be faster than that implied by the STAR model. In this sort of scenario the MS model would be better able to capture the dynamics of the data and produce more accurate forecasts (Caporale and Spagnolo, 2004).

In this regard, recent studies have adopted time varying Markov switching models to assess the impact of intervention on exchange rate dynamics. This model allows the probability of switching from one regime to the next to be dependent on an exogenous variable, with actual intervention or some proxy as the exogenous variable determining switches between regimes (Beine et al. 2003; Taylor 2004). These studies have been able to explain the general finding of most studies using the GARCH framework that volatility tended to increase after intervention. They did this by showing that intervention could increase volatility *if* it was done in *a low volatility* regime. However, intervention was also found to decrease volatility *if* the market was in *a high volatility state*[7]. The fact that single regime models found increased volatility was attributed to the fact that low volatility conditions (tranquil regime) usually predominates in markets and as such single regime estimates (which are really an

[7] Increased volatility in this case is defined a high probability of moving from the tranquil to the volatile regime, with decreased volatility defined as a high probability of moving from the volatile to the tranquil regime.

average of the low and high volatility regimes) would be biased in favour of the low regime outcome (increased volatility).

1.3 Summary

Developments in foreign exchange markets indicate that turnover in these markets is likely to continue growing not only in developed markets but also in emerging markets. These markets are also becoming more complicated with increasing heterogeneity among agents in these markets and with the greater integration of national and regional markets into the international economic and financial system. These developments have invariably increased the volatility of prices and volumes in foreign exchange markets and created greater challenges for central bank to maintain the stability of these markets. The recent 2008-2009 international financial crisis also highlighted that these markets are often the primary channels for financial contagion which motivated closer oversight of these markets by central banks in terms of tighter regulations to limit overly risky behaviour. The recent crisis has also shown that direct intervention in the foreign exchange market can limit the negative impact of shocks on exchange rate and liquidity dynamics and could therefore be a vital tool in the arsenal of the central bank when confronted with unstable market conditions and extreme risk aversion.

The review of the literature has also shown that there is room for improvement in terms of the empirical methodologies for measuring the effectiveness of central bank policy initiatives in the foreign exchange market. In many cases, the results of empirical studies on the effectiveness of central bank interventions in the foreign exchange market were either ambiguous or perverse because of the use of inappropriate or deficient empirical methodologies. Indeed, many recent studies (Kim and Sheen, 2006; Kearns and Rigobon, 2005) have shown that central bank interventions in the foreign exchange market were effective once an appropriate methodology was used. There is much scope therefore to improve our understanding of the impact of central bank policies in foreign exchange markets by using more appropriate and comprehensive empirical frameworks for studies in this area.

This is particularly relevant in the context of the recent crisis since improved knowledge in this area is critical to attempts by policy makers, who in all likelihood, will have to intervene more frequently both in developed and emerging market economies, to promote more stable dynamics in this very important market. The increasing availability of high frequency data on central bank interventions especially in emerging markets where central banks may have more leverage because of their size relative to the market also facilitates the use of these more appropriate empirical methodologies. The importance of accounting for different policy and market regimes, as well as the inherent inter-connectedness and endogeneity of policy instruments and market conditions to the effectiveness of central bank policy was also highlighted. The review of the literature also captured the need to use methodologies that accommodated the non-linear nature of exchange rates and volume in foreign exchange markets and to capture the impact of policies not only on levels but also at the levels of variances.

In this context, this thesis utilises the most recent data available and some of the latest empirical methodological advances such as fixed transition and time varying Markov switching models, as well as multivariate GARCH models to measure the effectiveness of central bank policy intervention in the foreign exchange markets of a variety of developed and emerging economies. It therefore makes a contribution in the area of applied empirical methodologies for the measurement of the dynamics of intervention in the foreign exchange market. It demonstrates that central bank policy interventions in the foreign exchange market can be effective if high frequency data broken down into different policy and market condition regimes are used together with more robust and appropriate empirical methodologies to better capture the complex dynamics in foreign exchange markets.

In particular, Chapter 2 investigated the impact of direct central bank intervention on the mean and variance of exchange rate returns in the foreign exchange markets for three developing markets, namely Croatia, Iceland and Jamaica and one developed market, Australia, for comparative purposes. Following Hamilton (1994) we assume exchange rate dynamics are captured by a first-order Markov switching fixed transition probability (FTP) model where there are two regimes, one in which the market is characterized by stable conditions (liquidity trading state) with a relatively small mean and variance and another characterized by volatility (informed trading state) with relatively higher mean and variance. We then extend this fixed transition model to a time varying transition (TVTP) model by making the probability of switching from one regime to the next depend on exogenous variables, in this case central bank interventions (Filardo, 1994; Diebold et al., 1994). We also innovate on previous studies using the Markov switching framework by including a policy interest rate as a control in the TVTP specification for monetary policy measures implemented around the same time as direct interventions and which can affect exchange rate dynamics. Additionally, we look at the impact of intervention sales and purchases separately in our analysis, since in many regards they are different policy instruments. We also compare the intervention dynamics in developing countries with that of a developed market.

The results show that there are two market conditions regimes, each characterized mainly by their variances. We find that direct intervention does have an impact on the probability of switching between regimes in the developed market but having little or no effect in the developing markets reviewed. Direct intervention in the developed market is generally found to be stabilizing when implemented in the volatile regime but de-stabilizing when implemented in the tranquil regime. We also find that intervention purchases and sales tend to have differential impacts since they are generally used to achieve different objectives. Monetary policy is also found to impact on the transition probabilities and this instrument tends to overshadow direct intervention in the developing countries under review. Contrary to the predominant view therefore, Australia, a developed market, had more success using direct intervention relative to the developing countries surveyed. The reason for this apparent anomaly seems to be that actual intervention practices such as having more frequent interventions and full and immediate sterilization of direct interventions to preserve its status as an independent policy instrument ensured its continued effectiveness in the foreign exchange market.

In Chapter 3 we examined the links between direct intervention, interest rate policy and exchange rate dynamics in Australia and Japan in a joint trivariate VAR-GARCH (1,1) framework using the BEKK parameterization. We study the Australian and Japanese foreign exchange markets to evaluate these issues since they are the largest developed markets in which central banks have intervened directly in the last decade. Their experiences with direct intervention and interest rate policy initiatives in the foreign exchange market are therefore among the few on which we can gauge how effective these policy instruments are likely to be in other developed markets.

The study confirmed that the relationship of intervention to policy interest rates could generally be characterized by the “signaling” framework, in that direct interventions and interest rate policy were coordinated and consistent so that intervention sales of foreign exchange were usually backed up by subsequent increases in interest rates to reinforce the impact of the initial direct intervention. The results also confirmed the results of many past studies that intervention is effective in Australia and Japan in the sense that it tends to move the level of exchange rate changes in the desired direction. The study also confirmed that central banks generally intervened to “lean against the wind”.

The results from the variance equations also showed that shocks to these policy instruments were not associated with increased exchange rate volatility in the short term. Indeed, quite to the contrary it showed that these policy instruments were generally successful in reducing exchange rate volatility in both countries, although Australia appeared to have greater success with direct intervention while Japan had more success with interest rate policy changes. Another noteworthy new insight from the results is that the lack of significant spillovers from exchange rate volatility to the volatility of direct intervention and interest rate changes also suggest that in both Australia and Japan the authorities was more concerned with countering undesirable trends in the exchange rate rather that dealing with excessive volatility. Finally, the evidence from the conditional correlations suggests that the links between the policy instruments were in large part due to the fact that both were driven by common factors. In particular, both generally responded to exchange rate changes in the context of leaning against undesirable exchange rate trends. Additionally, this relationship was most clearly defined when the market was highly unstable and therefore the objective of policy interventions was very clear to agents in the market.

Chapter 4 examined whether volume dynamics have a significant impact on the effectiveness of central bank policy instruments in the Icelandic foreign exchange market in a four variable (exchange rate returns, foreign exchange volume, direct intervention and policy interest rates) VAR GARCH framework. Moreover, given that there appears to be distinct policy and market conditions regimes over the full period of the study, the VAR-GARCH model is estimated for periods covered by a first period characterised by a crawling peg type exchange rate regime, an inflation targeting regime which was further divided into two sub-samples one characterised by exchange rate appreciation and the other in which exchange rate depreciation predominated and a last period characterised by capital controls and the dominance of the central bank as market maker and the primary provider of liquidity to the foreign exchange market.

The results validate the importance of trading volume, especially unexpected volumes, in both triggering policy responses and in terms of its role in the transmission of policy response to the market. The separating out of the full period into sub-samples characterised by distinct policy and market conditions regimes was also validated as the effectiveness of policy instruments, the relationship between important market parameters and the transmission of volatility were in many cases different in the various sub-samples, validating the regime dependent approach taken in chapter 2. The results indicate that unexpected volumes have a significant impact on the exchange rate, both at levels and variance. Furthermore, the central bank takes unexpected volumes into account in its decisions not only to intervene but in crafting the nature of the intervention as well. The central bank was also able to control the dynamics of unexpected volumes with its direct intervention activities, as well as with policy interest rate changes.

These results demonstrate that the volume dynamics was important in Iceland over the period being studied particularly in the lead up to the crisis in 2008 and in its aftermath. This adds to the evidence provided by Kim and Sheen (2006) of the importance of volume to the effectiveness of policy instruments in and the functioning of the foreign exchange market. This suggests that volume dynamics are important irrespective of the size and sophistication of the market and that studies that attempt to measure the impact of central bank policy interventions in the foreign exchange market without incorporating volume dynamics are fundamentally flawed.

CHAPTER 2
CENTRAL BANK INTERVENTION AND FOREIGN EXCHANGE MARKETS[8]

2.0 Introduction

Foreign exchange market dynamics, especially pricing, are supposed to reflect underlying supply and demand conditions in flexible regimes with capital mobility or, put another way, they should reflect macroeconomic fundamentals in the long term (Rogoff, 1996). The evidence has been, however, that exchange rates, in developing countries and markets[9] in particular, can depart significantly from the level implied by fundamentals and exhibit excessive volatility in the short term (Sarno and Taylor, 2001). This reality creates a role for central bank intervention in foreign exchange markets to keep the rate in line with the economic environment and to stabilize market expectations. Exchange rate stability is still a major policy objective especially in developing markets given that the pass-through from exchange rate movements to inflation is higher in these markets compared to developed economies (Calvo and Reinhart 2002).

In spite of this, relatively few studies focused on developing markets. Disyatat and Galati (2007) provide a comprehensive review of studies on the effectiveness of intervention in developing and transition economies and find mixed evidence. Reviews of empirical studies, done almost exclusively on developed markets in the 1980s and 1990s, also produce mixed evidence that intervention affects exchange rate in mean and variance (Edison, 1993; Sarno and Taylor, 2001). To our knowledge no study has compared the intervention dynamics in developing and developed markets in an attempt to determine the factors that may affect the relative effectiveness of intervention in these two types of markets. Previous studies all suffer from a variety of methodological and

[8] A condensed version of this chapter has been published in Applied Financial Economics (See Seerattan and Spagnolo, 2009).

[9] Developing countries and developing markets may be used interchangeably in the paper in reference to foreign exchange markets. This is so even though some countries referred to as developing markets may actually be classified as developed countries but the fundamental characteristic in relation to this study is the level of development of their foreign exchange market. For instance, two countries considered in this study, namely Croatia and Iceland, are classified as upper middle income (or transition) and high income respectively by the World Bank. However, their foreign exchange markets are developing considering the small turnover in the market and the relatively low level of integration in the international currency markets.

data shortcomings which include insufficient high frequencies data, simultaneity bias and the dependence on linear empirical frameworks that were unsuited to capture the complexities of the causality dynamics. The use of linear frameworks, in particular, could not adequately measure the impact of intervention in different market conditions[10].

This chapter, using a Markov switching framework, proposes an alternative way of measuring the impact of direct central bank intervention on exchange rate dynamics. The exchange rate process is allowed to switch between two distributions, one corresponding to a relatively stable period and the other to a more volatile period. The advantage of such an approach is that it separates periods of low from periods of high volatility allowing the probabilistic structure of the transition from one regime to the next to be function of interventions. The causality effect we are interested in is not constrained to be symmetric in the parameterization (intervention affects the exchange rate differently in periods of low and high volatility) and in the temporal causality (intervention has a different impact on the exchange rate's future volatility in periods of low and high volatility).

The model therefore measures the impact of intervention for different states of the market. We extend on two recent studies (Beine *et al.*, 2003; Sager and Taylor, 2004) that have also adopted time varying transition probability Markov switching models. These studies showed that intervention could increase volatility if it was done in a low volatility state. Furthermore, intervention was also found to decrease volatility if the market was in a high volatility state[11]. The fact that single regime models found increased volatility was attributed to the fact that low volatility conditions (tranquil regime) usually predominates in markets and as such single regime estimates (which are an average of the low and high volatility regimes) would be biased in favour of the low regime outcome (low volatility). Similarly, Taylor (2004) and Reitz and Taylor (2008) using the Markov switching and Smooth Transition Regression-GARCH approach respectively, also find that intervention is effective in the sense that intervention is stabilizing when the exchange rate is heavily misaligned but less effective when the exchange rate is closer to its fundamental value (purchasing power parity value).

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[10] Intervention in this study refers to sales and purchases of foreign currency by the central bank designed to change the liquidity and pricing dynamics of the foreign exchange market.
[11] The market is classified as being in a high volatility state when prices are unstable, bid-ask prices are high and liquidity is tight as more risk adverse agents (as opposed to speculator) have withdrawn from the market while the opposite is true in the low volatile state .

The contribution of this study to the empirical literature is to have a better understanding of the intervention dynamics improving earlier contributions by: (i) considering and comparing countries with different intervention practices; (ii) including a policy interest rate to control for monetary policy measures which can affect exchange rate dynamics; (iii) looking at the impact of intervention sales and purchases separately, since in many regards they are different policy instruments. The analysis is conducted for three developing markets, namely Croatia, Iceland and Jamaica because although they are similar in the sense that most interventions are conducted in the spot market which is based on an interbank system but different in terms of intervention practices. They can therefore serve to highlight how intervention outcomes could differ for a group of relatively similar developing markets based on specific intervention practices.

We also include one developed market, Australia, for comparative purposes[12]because it is not a dominant international centre for foreign exchange trading and intervention in this market is relatively frequent as is the case in most developing markets where intervention is practiced. Also, as with developing markets, it is dominated by the spot transactions. The chapter is structured as follows; Section 2 briefly reviews the literature on intervention in the foreign exchange market. Section 3 describes the model specifications used. Section 4 introduces the data and the dynamics of intervention in the markets under review. Section 5 presents the empirical results and Section 6 concludes.

2.1 Literature Review

The relevant literature on the impact of intervention on exchange rate dynamics is reviewed only briefly as excellent reviews are provided by Edison (1993), Sarno and Taylor (2001), Akinci et al (2006) and Vitale (2007). The literature generally focuses on the channels through which intervention impacts on the exchange rate. Theoretically, interventions can affect the exchange rate through a variety of channels

[12] We are grateful to an anonymous referee who pointed out that the *de facto* exchange rate regime could be a significant determinant of the differential impact of intervention on the exchange rate across the group of countries reviewed in this paper. However, since all countries have *de jure* floating exchange rate regimes with varying degrees of management of the float (Iceland floated fully in March 2001 after operating a system where the exchange rate was managed within a 9% band), which includes the scale and frequency of intervention in the foreign exchange market, the exchange rate regime and intervention practice is not mutually exclusive and therefore we argue that intervention practice is still ultimately a valid factor in the differential intervention outcomes across markets observed in this study. See Gersl and Holub (2008) and Akinci et al (2006) for reviews of this issue.

that are not mutually exclusive. These include the signaling (Dominguez and Frankel, 1993a; Kaminsky and Lewis, 1995), portfolio balance (Edison, 1993; Dominquez and Frankel, 1993), and market microstructure channels (Evens and Lyons, 2002), all of which are based on their respective models of exchange rate determination. The portfolio balance channel is thought to be more effective in developing countries where central bank credibility may be weak, where domestic and foreign currency debts are imperfect substitutes and interventions are large relative to market turnover[13] (Canales-Kriljenko *et al.*, 2003). The signaling channel is thought to work more effectively in developed markets where central banks have greater credibility (Sarno and Taylor, 2001).

The most popular model specifications used to measure the effectiveness of intervention included OLS regression of risk premium and order flow on exchange rate (Dominguez and Frankel, 1993b; Evans and Lyons, 2002), event studies of intervention episodes (Fatum, 2000; Hutchison, 2003), unified approaches to monetary policy and foreign exchange market intervention using vector autoregression (VAR) methodology (Kim, 2003), simulated GMM (Kearns and Rigobon, 2005) and GARCH models (Guimaraes and Karacadag, 2004). These models implicitly assume a linear relationship between intervention and the mean and variance of exchange rate returns.

Many studies have argued, however, that exchange rate behaviour generally evolves in a non-linear way (Sarno and Taylor, 2001). A number of non-linear exchange rate models have emerged geared to better capture the exchange rates data generating process. These include, non-parametric procedures (Diebold and Nason, 1990), chaos models (Hsieh, 1991) and regime switching models such as smooth transition autoregressive (STAR) models (Sarantis, 1999) and Markov switching (MS) models (Engle and Hamilton, 1990; Hamilton, 1989).

These non-linear models tend to be superior to single regime type approaches in the sense that they can accommodate different outcomes to policy interventions depending on whether the market is in a volatile or tranquil initial state[14]. For example, intervention in a highly volatility market condition may lower volatility because most

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[13] The converse is of course true in developed market economies where the volume of market turnover has been growing rapidly restricting the scope for intervention on the scale that would have an impact on the rate.

[14] Initial state of the market refers to market conditions immediately preceding intervention activities.

agents in the market understand the rationale for intervention and are likely to act in concert with the central bank moving the market in the desired direction. If, on the other hand, the central bank intervenes when the market is relatively calm agents may be uncertain about the motives of the central bank and may act counter to central bank initiatives making them ineffective. In some respect, the argument is similar to one given in the target zone literature (Krugman, 1991) in which central banks normally intervenes only when the rates moves out of some predetermined band or zone. The movement of the exchange rate outside the target zone normally coincides with a period of increased volatility as agents in the market react to new developments. Agents in the market tend to understand and act in concert with the central bank if it intervenes when the rate moves outside the band (increased volatility) but not if the central bank intervenes when the exchange rate is inside the band (low volatility).

The notion of two regimes also fits well with the market microstructure approach to exchange rates. The market microstructure channel has also been increasingly seen as important in explaining the intervention dynamics in foreign exchange markets (Evens and Lyons, 2002). In particular, the Markov switching framework by allowing for two or more regimes can more adequately capture the micro-structural dynamics. That is, a liquidity trading regime where uninformed or liquidity traders dominate trading and the market is characterized by exchange rate returns with relatively low mean and variance. The more volatile informed trading state, where informed traders such as market makers or central banks are active in the market, is characterized by exchange rate returns that have relatively higher mean and variance. In this framework central bank intervention works by emitting information to the market which modifies expectations and generates large order flows. These orders may move the market trend in the desired direction if the central bank intervenes when the market conditions are volatile but may also increase short-term volatility if the central bank intervenes when the market is relatively calm (Guimaraes and Karacadag, 2004).

2.2 The Models

This section describes the models used. The exchange rate returns are defined as $y_t = 100 * \log(er_t / er_{t-1})$ where er_t denotes the number of units of the local currency per unit of foreign currency. We first consider the standard random walk (RW) model which normally provides the benchmark for empirical exchange rate models (Meese and Rogoff, 1983). The fixed transition Markov switching (FTP) model is then introduced and finally the extension to the time varying Markov switching (TVTP) model is presented.

2.2.1 The Linear Benchmark Models

Ever since the seminal paper by Meese and Rogoff (1983), it has become customary to compare exchange rate models to that of a random walk specification. In this spirit a simple linear stochastic model of the following form is used for comparative purposes:

$$y_t = \mu + \varepsilon_t \text{ where } \varepsilon_t \sim N\left(0, \sigma^2\right) \tag{1}$$

with $t \in T$. For the purpose of this study we extend (1) including lagged intervention. This model is of the following form:

$$y_t = \mu + \beta I_{t-1} + \varepsilon_t, \qquad \varepsilon_t \sim N\left(0, \sigma^2\right), \quad t \in T \tag{2}$$

2.2.2 Fixed Transition Markov Switching Model

The regime switching model considered in this section allows for shifts in mean and variance separating tranquil from volatile periods. y_t is modeled as being conditionally normal, where the mean and variance both depend on the operative regime, and is given by[15]:

$$y_t = \mu(s_t) + \sigma(s_t)\varepsilon_t, \qquad \varepsilon_t \sim i.i.d.N(0,1), \qquad t \in T. \tag{3}$$

[15] Although autoregressive dynamics are not accounted for explicitly in these analytical models we did experiment with different autoregressive structures in the empirical work but these proved not to be feasible specifications.

$$\mu(s_t) = \sum_{i=1}^{2} \mu^{(i)} 1\{s_t = 1\}, \qquad \sigma(s_t) = \sum_{i=1}^{2} \sigma^{(i)} 1\{s_t = 1\}. \tag{4}$$

where $\mu^{(i)}$ and $\sigma^{(i)}$ (i = 1, 2) are real constants and s_t are random variables in S = {1, 2} that indicates the state that the system is in at date t. A stable "liquidity trading" regime where μ_1 and σ_1^2 are relatively low (regime 1) and a volatile "informed trading" regime where μ_2 and σ_2^2 are relatively high (regime 2). Throughout, the regime indicator $\{s_t\}$ is assumed to form a homogeneous Markov chain on S with the fixed transition probabilities matrix defined as:

$$p^{ij} = \Pr(s_t = i / s_{t-1} = j), \qquad i, j \in S \tag{5}$$

where each column sums to unity and all elements are non-negative. p^{11} and p^{22} represent the probability of remaining in regime 1 and 2 respectively. It is also assumed that $\{\varepsilon_t\}$ and $\{s_t\}$ are independent. We shall refer to the two state order Markov switching model with fixed transition probabilities defined by (3)-(5) as FTP. The FTP generalizes the standard random walk (RW) model (1) by allowing the mean and variance of innovation $\{\varepsilon_t\}$ to vary between two states according to a hidden Markov chain $\{s_t\}$. The probability law that governs these regime changes is flexible enough to allow for a wide variety of different shifts, depending on the values of the transition probabilities. For instance, values of $p^{ij}\,(i = S)$, not close to unity, imply that structural parameters are subject to frequent changes, whereas values near unity suggest that regime transitions are not likely to occur. The density function has two components, one for each regime, and the log-likelihood function is constructed as a probability weighted sum of these two components. The parameter vector $v = (\mu_1, \mu_2, \sigma_1^2, \sigma_2^2, p^{11}, p^{22})$ is estimated by maximum likelihood (Hamilton, 1989).

2.2.3 Time Varying Markov Switching Model

Finally, to study the intervention dynamics we relax the assumption of fixed transition probabilities by allowing the transition probabilities to depend on lagged values (Filardo, 1994; Diebold *et al*., 1994) of intervention (I_{t-1}). Lagged values of intervention are used instead of contemporaneous intervention to deal with the simultaneity bias involved (Beine *et al*., 2003). We also include lagged policy interest rates (R_{t-1}) as a control for monetary policy measures which may be implemented around the same time as direct intervention. As with direct interventions, we use lagged policy interest rates rather than contemporaneous policy interest rates to deal with potential simultaneity bias[16]. The inclusion of lagged policy interest rates ensures we do not overstate the impact of the direct intervention by accounting explicitly for any additional base money/interest rate effect on the exchange rate. Therefore, the transition probabilities are defined as:

$$p_t^{11} = \Pr ob(s_t = 1 / s_{t-1} = 1, I_{t-1}, R_{t-1}), \tag{6}$$

$$p_t^{22} = \Pr ob(s_t = 2 / s_{t-1} = 2, I_{t-1}, R_{t-1}). \tag{7}$$

The probability to switch from the tranquil to the volatile regime is given by $p_t^{12} = (1 - p_t^{11}(I_{t-1}, R_{t-1}))$ whereas the probability to switch from the volatile to the tranquil regime is measured by $p_t^{21} = (1 - p_t^{22}(I_{t-1}, R_{t-1}))$. The functions of the transition probabilities are as follows:

$$p_t^{11} = \frac{\exp\{\alpha_1 + \beta_1 I_{t-1} + \delta_1 R_{t-1}\}}{1 + \exp\{\alpha_1 + \beta_1 I_{t-1} + \delta_1 R_{t-1}\}}, \tag{8}$$

[16] We experimented with different lag structures but the results were broadly similar in models with two lags while models with longer lags often failed to converge.

$$p_t^{22} = \frac{\exp\{\alpha_2 + \beta_2 I_{t-1} + \delta_2 R_{t-1}\}}{1 + \exp\{\alpha_2 + \beta_2 I_{t-1} + \delta_2 R_{t-1}\}}. \tag{9}$$

The time varying specification of course collapses to the fixed transition probability (FTP) model if $\beta_1 = \beta_2 = \delta_1 = \delta_2 = 0$. If intervention is stabilizing it will decrease the probability of remaining in the volatile regime (p_t^{22}) and/or increase the probability of remaining in the stable regime (p_t^{11}), that is, $\beta_2 < 0$ and/or $\beta_1 > 0$ respectively. If it is de-stabilizing then $\beta_2 > 0$ and/or $\beta_1 < 0$. Under the market microstructure framework, intervention is expected to be stabilizing if implemented in the volatile state and de-stabilizing if implemented in the tranquil state. This implies that $\beta_1 < 0$ and $\beta_2 < 0$. If intervention increases the probability of remaining in the volatile regime ($\beta_2 > 0$), as well as the tranquil regime ($\beta_1 > 0$), then intervention is only effective in the tranquil regime, paradoxically when it is generally not needed. In this case, it would have limited effectiveness as a policy instrument in the foreign exchange market. The two-state Markov switching framework is therefore open-ended and compatible with any view of the impact of intervention. In fact it is also compatible with the view that intervention has no impact in either regime $(\beta_1 = \beta_2 = 0)$.

2.3 Data and Intervention Dynamics

We use daily data on exchange rates for Croatia, Iceland, Jamaica and Australia. The data set on Croatia includes 1636 observations covering the period January 3, 2000 to April 10, 2006. Iceland's data set includes 1573 observations covering the period January 4, 2000 to April 28, 2006. Jamaica's data set includes 1161 observations covering the period February 7, 2002 to September 28, 2006. Finally, the data set on Australia covers 1434 observations over the period January 3, 2000 to June 30, 2005.

The exchange rate for Croatia, Iceland and Jamaica is defined as the midpoint between the weighted average bid and ask prices of the domestic currency per unit of the intervention currency. The exchange rate for Australia is defined as the midpoint between the weighted average bid and asks prices of the intervention currency per unit of the Australian dollar. The intervention currency for Iceland, Jamaica and Australia is the United Sates dollar while Croatia's intervention currency is the Euro. We use the actual daily sales and purchases of the intervention currency by the central bank against the domestic currency as our intervention variable. The policy interest rates utilized in this study are annualized rates and include the inter-bank rate for Croatia, the 3-month repurchase rate for Iceland, the 3-month reverse repurchase rate for Jamaica and the 3-month treasury bill rate for Australia.

All of the exchange rate and interest rate data for Croatia, Iceland and Australia were sourced from Datastream. Intervention data were sourced from the respective central banks. Interest rate and exchange rate data for Jamaica were sourced from the Bank of Jamaica. A briefly description of the intervention dynamics for the countries reviewed are outlined below.

The Croatian foreign exchange market is relatively small and under-developed. It is driven by links to the Euro rather than the US dollar, with approximately 67% of Croatian reserves denominated in Euros. The only market makers in the Croatian market are commercial banks. The Croatian central bank (Croatian National Bank, CNB) intervenes relatively infrequently (5%) in the spot market using partially sterilized interventions.

Table 2.1: The Dynamics of Intervention

Variable	*Australia*	*Croatia*	*Iceland*	*Jamaica*
Sales Days	371	23	29	222
Purchases Days	535	52	511	n/a
Total Interventions Days	906	75	540	222
Total Sample Days	1434	1636	1573	1161
% Intervention Days	0.63	0.05	0.34	0.19
% Intervention Sale Days	0.25	0.01	0.02	0.19
% Intervention Purchase Days	0.37	0.04	0.32	n/a
Average Inter. (US$M)	19.5	2.4	1.2	2.3
Average Inter. Sales	7.2	0.7	0.3	2.3
Average Inter. purchases	12.3	1.7	0.9	n/a
Max. Inter. Sales	176	148	42.2	26.1
Max. Inter. Purchases	458	179	82.5	n/a

Note: % intervention days are calculated as intervention days divided by total sample days.

The CNB used mostly buying interventions in this period because buying foreign exchange in the first years of Croatian independence was necessary to build up the stock of international reserves. The only year in the reviewed period where the CNB used selling operations to support the Kuna was 2003 when a banking crisis caused instability and capital outflows (see Table 2.1). Croatia has a managed floating exchange rate regime but the exchange rate exhibits relatively low flexibility. This is most likely due to the CNB's objective of managing the Kuna within a tight band against the Euro[17].

The Icelandic foreign exchange market is also a small, relatively underdeveloped market. The majority of trades are conducted in US dollars on the spot market. The Icelandic foreign exchange is built on an inter-bank market with the major commercial banks as market makers. In the period reviewed, the Icelandic Central Bank (ICB) interventions were relatively infrequent, occurring only on 34% of the days in the sample, with 32% of interventions being intervention purchases. The ICB intervened with predominantly selling operations in the 2000 and 2001, reflecting the fact that it was "leaning against the wind" in a period characterized by outflows of foreign currency and uncertainty leading to a weakening of the Krona. In the period 2002 to 2006 the ICB intervened mostly with frequent and relatively small buying operations, with the aim to build up foreign exchange reserves. The ICB does not fully and immediately sterilize its foreign exchange interventions as do central banks in some developed markets[18].

The Jamaican foreign exchange market is based on an inter-bank system, where commercial banks are the major market makers. Traders can directly observe trade volumes and prices on a real time basis through the electronic gateway for auctions trade and foreign exchange management (E-GATE). In the period under review the Bank of Jamaica (BOJ) intervened relatively infrequently on 19% of the sample days. They intervened selling only in the period under review, indicating that the BOJ was generally "leaning again the wind" in a period characterized by episodic instability in the market. The average intervention was relatively small. The BOJ sterilizes most of its foreign exchange interventions. There are instances, however, where full sterilization

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[17] See Egert (2007) and Chmelarove and Schnabl (2006) for more analytical reviews of intervention in the Croatian foreign exchange market.

[18] See Isberg and Petursson (2003) for a more comprehensive description of the intervention process in Iceland.

would move the money base away from the target set by the BOJ and in these cases the intervention would not be fully sterilized, leading to intervention reinforcing monetary policy measures (Robinson and Robinson, 1997).

The Australian foreign exchange market in April 2004 accounted for approximately 3.4% of average daily global foreign exchange turnover in traditional instruments. In terms of actual practice, the Reserve Bank of Australia (RBA) conducts all its interventions in the spot Australian dollar/US dollar market and immediately sterilizes these operations. A broad overview of the actual intervention operations of the RBA is outlined in Table 2.1. This shows that the RBA intervened on 906 days out of the 1434 sample days, with intervention purchases (535 days) being more frequent than intervention sales (371 days). This suggest that the RBA was "leaning against the wind" in this period in which the Australian dollar was appreciating[19].

The dynamics of intervention in these markets clearly reflect different intervention objectives and differences in the size and sophistication of the markets. There are some similarities across jurisdictions, such as, interventions were executed predominantly in the spot market and most central banks attempted to sterilize their interventions. There are important differences though which reflect the differences in the degree of development of the market and the intervention objectives, as well as differences in intervention frequency, surprisingly with Australia, the developed market, recording the highest intervention frequency (64%) relative to Iceland (34%), Jamaica (19%) and Croatia (5%). The fact that in some developing markets interventions are not immediately and/or fully sterilized might lead to monetary/interest rate policy dominating direct interventions.

2.4 Empirical Results

The parameter estimates with t-statistics and values of the likelihood function for each model considered for Croatia, Iceland, Jamaica and Australia are presented in Tables 2.3, 2.4, 2.5 and 2.6 respectively. The null hypothesis of linearity against the alternative of Markov regime switching cannot be tested directly using a standard likelihood ratio (LR) test[20]. The value of the standardized likelihood ratio statistics

[19] See Edison et al (2006) for a more recent review of the intervention activities of the RBA.

[20] Standard regularity conditions for likelihood-based inferences are violated under the null hypothesis of linearity, as the parameters of the transition probabilities are unidentified and scores with respect to

along with the associated *p*-values under the null hypothesis are reported in Table 2.2. We also test for the presence of a third state. The results provide strong evidence in favor of a two-state regime-switching specification for the four countries reviewed[21]. In order to test the adequacy of the models, Ljung–Box portmanteau tests were performed on standardized residuals and squared residuals. Overall the results indicate that the Markov regime switching specification captures satisfactorily the heteroskedasticity in the data.

The estimated results confirm that the regime switching models capture the exchange rate dynamics better than the linear random walk (RW) model and the simple linear model with lagged intervention (LWI). Figures 2.1, 2.2, 2.3 and 2.4 show that the filter probabilities for Australia, Croatia, Iceland and Jamaica successfully separate the tranquil from the volatile regime (where a volatile regime has been labeled as regime 2). The variances in the volatile regime are significantly higher than the variance in the tranquil regime in all countries. The volatile regime variance is as much as 3 times the size of the variance in the tranquil period in Croatia and Iceland and as much as 13 times the size of the variance of the tranquil regime in the case of Jamaica. It is also clear that for Croatia, Iceland and Jamaica the two-state process is driven by the variance. This is a fairly common finding in studies modeling exchange rate dynamics using regime switching models (Caporale and Spagnolo, 2004). Australia is the exception in this regard with the tranquil regime being characterized by significant positive exchange rate returns (appreciation) and lower variance and the volatile regime characterized by significant negative exchange rate returns (depreciation) and larger variance.

The probabilities for the FTP models indicate that generally the low volatility regime is more persistent, with the exception of Australia, where the probability of staying in the volatile regime is slightly higher. Nevertheless, both regimes show high persistency.

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parameters of interest are identically zero. Under such circumstances the information matrix is singular. An appropriate test procedure has been proposed by Hansen (1992). This procedure requires an evaluation of the likelihood function across a grid of different values for the transition probabilities and for each state-dependant parameter.

[21] Selection procedures based on the ARMA representation as well as procedures based on complexity-penalized likelihood criteria have also been considered. Psaradakis and Spagnolo (2003) show that model selection procedures based on the so-called three-pattern method (TPM) and the Akaike (AIC) are successful in choosing the correct state dimension.

Figure 2.1: Exchange Rate Changes and Filter Probabilities for Australia

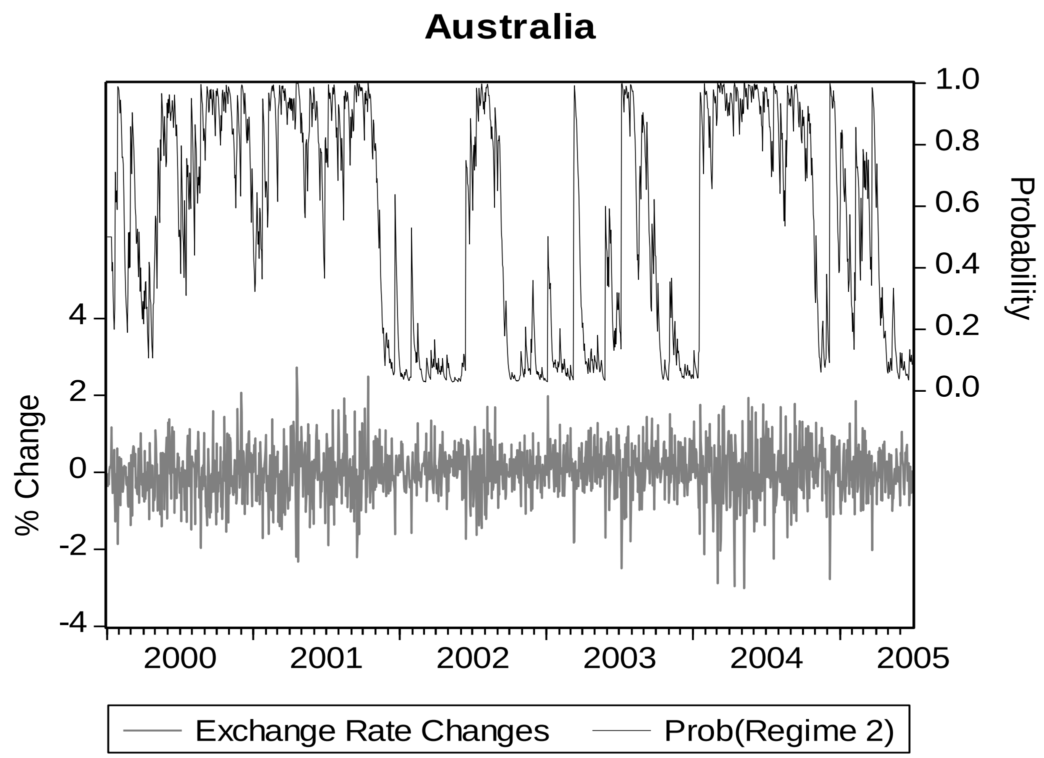

Figure 2.2: Exchange Rate Changes and Filter Probabilities for Croatia

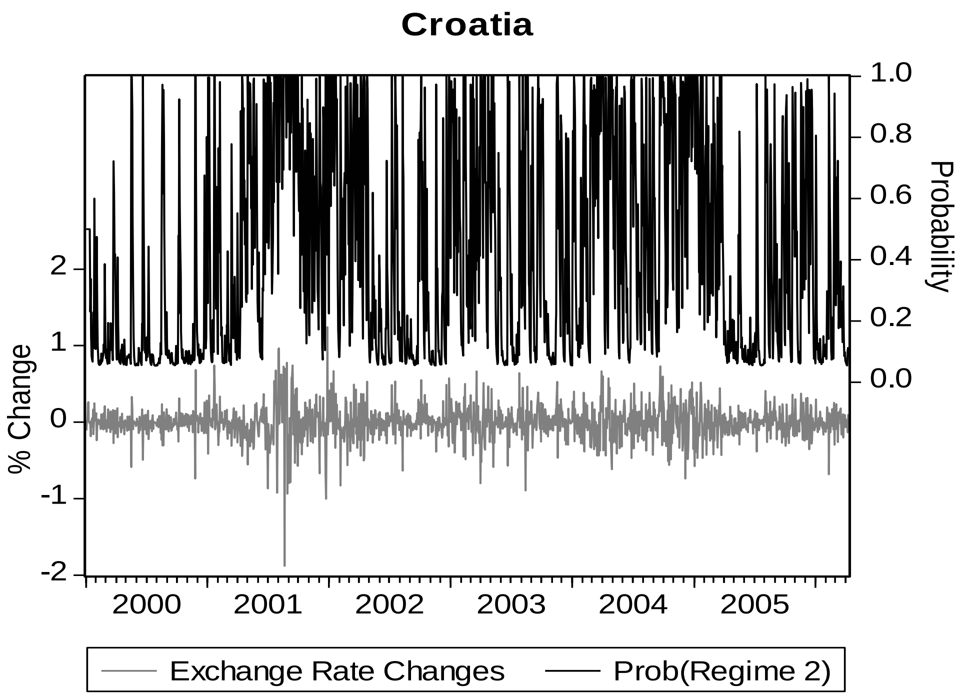

Figure 2.3: Exchange Rate Changes and Filter Probabilities for Iceland

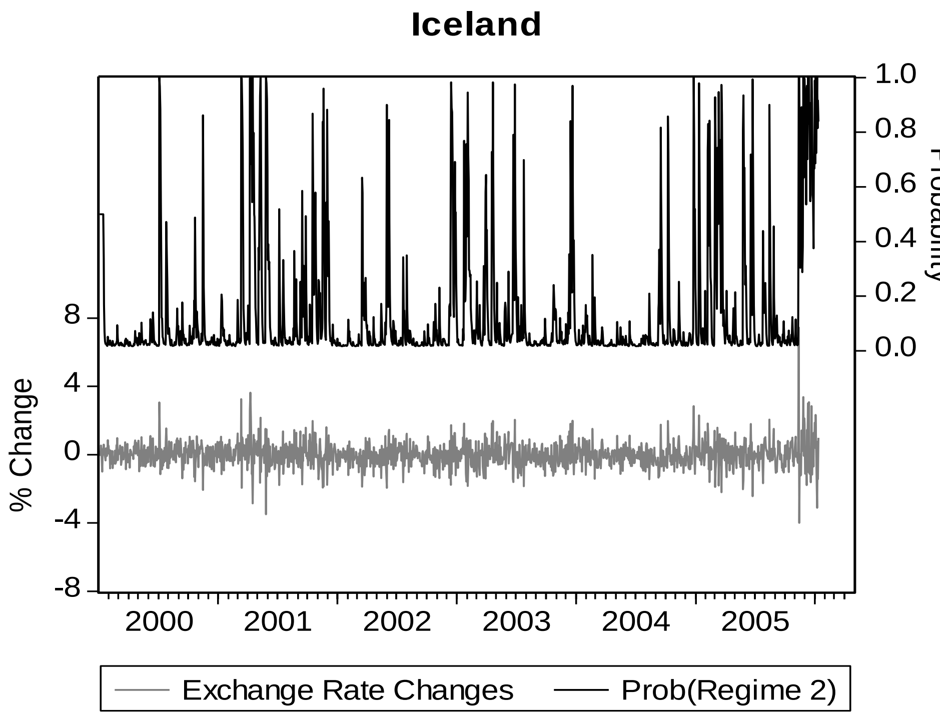

Figure 2.4: Exchange Rate Changes and Filter Probabilities for Jamaica

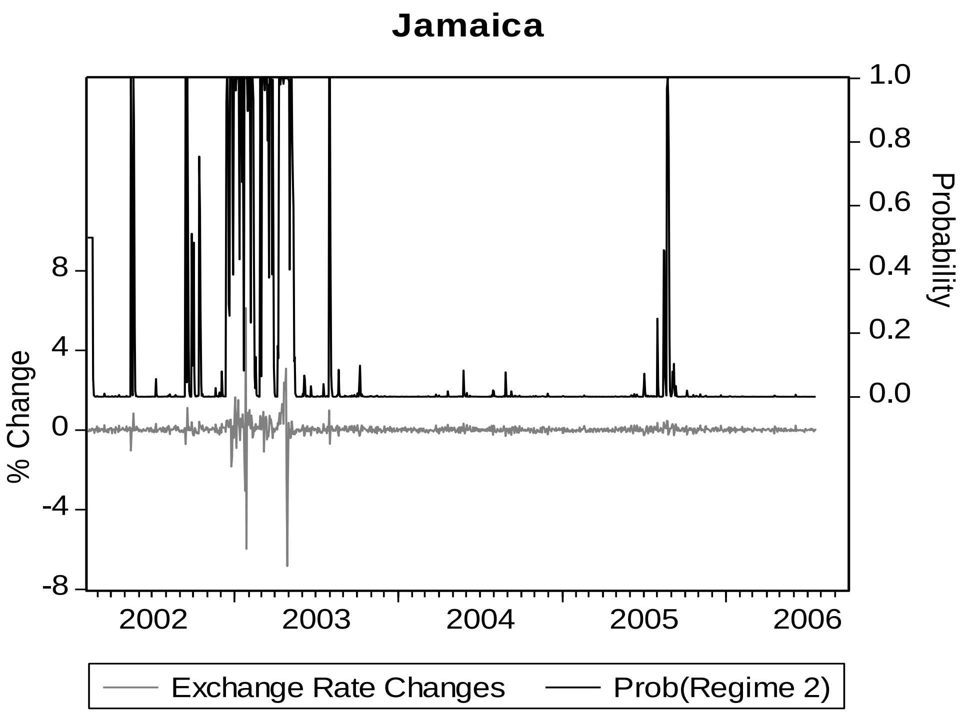

Table 2.2: States Dimension Test Results

	Australia	Croatia	Iceland	Jamaica
		Hansen Test		
		Linearity versus two-states Markov switching model		
Standardized LR Test				
LR	4.324	4.792	4.001	3.998
M = 0	(0.0020)	(0.0001)	(0.0001)	(0.0001)
M = 1	(0.0030)	(0.0001)	(0.0001)	(0.0002)
M = 2	(0.0070)	(0.0002)	(0.0002)	(0.0003)
M = 3	(0.0090)	(0.0090)	(0.0006)	(0.0005)
M = 4	(0.0120)	(0.0110)	(0.0021)	(0.0030)
		Two-states versus three-states Markov switching model		
LR	0.451	0.812	0.743	1.475
M = 0	(0.6216)	(0.3886)	(0.5524)	(0.4432)
M = 1	(0.6219)	(0.4191)	(0.5532)	(0.4521)
M = 2	(0.7005)	(0.4301)	(0.5541)	(0.4555)
M = 3	(0.7026)	(0.4500)	(0.5567)	(0.4601)
M = 4	(0.7102)	(0.4631)	(0.5581)	(0.4723)
Model Selection Criteria		Number of States		
TPM	2	2	2	2
AIC	2	2	2	2

Notes: The range [0.50, 0.99] in steps of 0.05 (10 grid points) is used as a grid for the transition probabilities; for the autoregressive coefficient and innovation variances, we use the range [0.1, 0.9] and [0.01, 0.17] respectively, in steps of 0.1 and 0.01 (9 grid points). The *P*-value is calculated according to the method described in Hansen (1996), using 1,000 random draws for the relevant limiting Gaussian processes and bandwidth parameter M = 0, 1, 2, 3, 4 (See Hansen, 1992 for further details).

The results from the TVTP models for Croatia (Table 2.3 columns 3 to 8) indicate that intervention did not have an impact on exchange rate dynamics either in the volatile or tranquil regimes. That is, intervention did not cause the transition probabilities in either regime. The results of the TVTP models with respect to direct intervention in Croatia are not surprising given the dynamics of intervention in Croatia occurring on only 5% of the sample days. The practice of using purchasing interventions to build up foreign currency reserves in periods when it would not affect exchange rate behavior also predisposed total intervention to have no impact. The fact that the CNB uses only partially sterilized interventions also meant that much of the impact of direct intervention may be channeled through the money base and interest rate changes to exchange rate returns. This seems to be the case as the policy interest rate significantly increased the probability of staying in both the volatile and tranquil regimes (parameters δ_1 and δ_2 in Table 2.3). It appears, therefore, that the direct intervention practices in Croatia were ineffective with interest rate policy being the dominant channel through which policy makers can impact exchange rate dynamics.

Table 2.3: Estimated Models for Croatia

Parameters	Models								
	RW	LWI	FTP	TVTP(T)		TVTP(B)		TVTP(S)	
	1	2	3	4	5	6	7	8	9
μ	-0.003	-0.0027							
	(-0.57)	(-0.50)							
μ_1			-0.008	-0.008	-0.008	-0.007	-0.008	-0.008	-0.008
			(-2.02)	(-1.92)	(-1.94)	(-1.76)	(-1.89)	(2.02)	(-1.96)
μ_2			0.002	0.002	0.003	0.003	0.004	0.002	0.003
			(0.25)	(0.28)	(0.26)	(0.28)	(0.31)	(0.25)	(0.27)
σ	0.218	0.217							
	(43.61)	(43.42)							
σ_1			0.099	0.099	0.102	0.101	0.106	0.99	0.101
			(28.51)	(28.43)	(28.92)	(28.64)	(29.78)	(28.33)	(28.68)
σ_2			0.311	0.311	0.320	0.314	0.329	0.310	0.318
			(49.22)	(49.51)	(45.93)	(47.88)	(42.95)	(49.62)	(46.57)
α_1			2.088	2.078	1.562	2.056	1.632	2.076	1.589
			(12.04)	(11.97)	(5.91)	(11.76)	(6.02)	(11.92)	(6.01)
α_2			1.772	1.777	0.860	1.656	0.825	1.758	0.907
			(10.19)	(10.13)	(2.96)	(9.21)	(2.88)	(9.93)	(3.21)
β		-0.003							
		(-0.94)							
β_1				1.369	1.568	0.025	0.057	-1.064	-1.199
				(0.61)	(0.73)	(0.22)	(0.27)	(-0.49)	(-0.55)
β_2				0.086	-0.029	4.373	4.374	1.855	2.741
				(0.04)	(-0.01)	(0.06)	(0.01)	(0.25)	(0.23)
δ_1					0.126		0.118		0.119
					(1.79)		(1.52)		(1.65)
δ_2					0.207		0.185		0.196
					(2.53)		(2.21)		(2.43)
p^{11}			0.89						
			(3.52)						
p^{22}			0.85						
			(5.61)						
L	12.7	11.0	11.3	12.2	8.4	7.3	9.5	6.0	7.6
LB^2	78.4	77.0	11.6	11.3	13.4	12.8	12.0	12.4	12.4
LogLik	-173.8	-174.3	-412.9	-413.1	-415.4	-409.9	-411.2	-413.2	-415.3

Notes: RW refers to the linear random walk model, $y_t = u + \varepsilon_t$ with mean μ and variance σ^2. LWI refers to the linear model with intervention, $y_t = u + \beta I_{t-1} + \varepsilon_t$ with mean μ and variance σ^2. FTP refers to the fixed transition probability model $y_t = u(s_t) + \sigma(s_t)\varepsilon_t$ with mean and variance μ_1 and σ_1^2 in regime 1 and μ_2 and σ_2^2 in regime 2, respectively. The fixed transition probabilities are $p^{11} = \frac{\exp\{\alpha_1\}}{1+\exp\{\alpha_1\}}$ and $p^{22} = \frac{\exp\{\alpha_2\}}{1+\exp\{\alpha_2\}}$. TVTP(T), TVTP(B) and TVTP(S) refer to the time varying transition probability (total interventions), time varying transition probability (purchasing interventions) and time varying transition probability (selling interventions) models respectively. The time varying transition probability functions with lagged intervention only are $p_t^{11}(I_{t-1}) = \frac{\exp\{\alpha_1+\beta_1\}}{1+\exp\{\alpha_1+\beta_1\}}$ and $p_t^{22}(I_{t-1}) = \frac{\exp\{\alpha_2+\beta_2\}}{1+\exp\{\alpha_2+\beta_2\}}$. The time varying transition probability functions with lagged intervention and lagged policy interest rate are $p_t^{11}(I_{t-1}, R_{t-1}) = \frac{\exp\{\alpha_1+\beta_1+\delta_1\}}{1+\exp\{\alpha_1+\beta_1+\delta_1\}}$ and $p_t^{22}(I_{t-1}, R_{t-1}) = \frac{\exp\{\alpha_2+\beta_2+\delta_2\}}{1+\exp\{\alpha_2+\beta_2+\delta_2\}}$. The t-statistics for the maximum likelihood estimates are in parentheses. LB and LB² are respectively the Ljung-Box test (1978) of significance of autocorrelations of twenty lags in the standardized and standardized squared residual. These tests should be interpreted with caution since they may not have a Chi-Squared distribution for Markov-Switching models.

Table 2.4: Estimated Models for Iceland

Parameters	Models								
	RW	LWI	FTP	TVTP(T)		TVTP(B)		TVTP(S)	
	1	2	3	4	5	6	7	8	9
μ	0.003								
	(0.146)								
μ_1			-0.024	-0.022	-0.022	-0.023	-0.021	-0.021	-0.021
			(-1.45)	(-1.32)	(-1.31)	(-1.47)	(-1.33)	(-1.37)	(-1.36)
μ_2			0.166	0.149	0.223	0.163	0.235	0.144	0.207
			(1.55)	(1.46)	(1.53)	(1.58)	(1.51)	(1.49)	(1.49)
σ	0.737								
	(38.81)								
σ_1			0.553	0.549	0.573	0.553	0.574	0.548	0.566
			(10.21)	(40.62)	(39.89)	(40.15)	(40.32)	(40.23)	(40.01)
σ_2			1.423	1.412	1.582	1.422	1.604	1.403	1.565
			(26.36)	(26.75)	(19.60)	(26.13)	(19.15)	(27.22)	(20.21)
α_1			3.507	3.440	1.801	3.476	2.305	3.537	1.902
			(12.96)	(12.42)	(1.67)	(10.21)	(1.77)	(12.36)	(1.98)
α_2			1.505	1.479	-	1.409	-	1.461	-
			(5.47)	(5.53)	11.314	(3.56)	13.811	(5.41)	10.600
					(-1.93)		(-2.01)		(-2.02)
β									
β_1				0.192	0.133	0.034	0.008	-0.244	-0.156
				(2.92)	(2.41)	(0.13)	(0.03)	(-2.94)	(-2.56)
β_2				0.011	0.052	0.131	0.594	-0.007	-0.039
				(0.22)	(1.15)	(0.28)	(0.77)	(-0.12)	(-0.93)
δ_1					0.162		0.111		0.154
					(1.32)		(0.82)		(1.34)
δ_2					1.022		1.433		1.150
					(2.21)		(2.23)		(2.23)
p^{11}			0.97						
			(3.23)						
p^{22}			0.82						
			(4.14)						
LB	24.0	31.5	9.7	9.2	6.6	9.7	5.5	9.3	5.8
LB^2	21.6	28.3	5.1	6.7	6.5	5.6	3.8	7.6	7.9
LogLik	-	-	-	-	-	-	-	-	-
	1750.1	1748.6	1596.7	1594.1	1576.1	1596.7	1592.7	1593.5	1591.6

Note: See notes Table 3.

Table 2.5: Estimated Models for Jamaica

Parameters	Models				
	RW	LWI	FTP	TVTP	
	1	2	3	4	5
μ	0.028	0.045			
	(2.21)	(3.26)			
μ_1			0.015	0.015	0.015
			(5.54)	(4.85)	(4.82)
μ_2			0.163	0.163	0.164
			(1.33)	(1.18)	(1.15)
σ	0.432	0.432			
	(33.23)	(30.87)			
σ_1			0.101	0.101	0.101
			(51.96)	(51.82)	(49.21)
σ_2			1.403	1.400	1.410
			(35.42)	(33.24)	(32.81)
α_1			4.722	4.700	6.048
			(14.66)	(12.29)	(6.27)
α_2			2.324	2.442	0.203
			(10.62)	(7.71)	(0.29)
β		0.007			
		(2.98)			
β_1				0.021	0.005
				(0.25)	(0.05)
β_2				-0.022	0.002
				(-0.35)	(0.02)
δ_1					-0.085
					(-2.05)
δ_2					0.079
					(1.94)
p^{11}			0.99		
			(5.27)		
p^{22}			0.90		
			(4.74)		
LB	32.3	30.6	14.9	14.7	14.6
LB^2	39.4	39.7	12.2	15.8	13.9
LogLik	-673.1	-668.6	-664.5	-664.6	-667.9

Note: See notes Table 3. There was almost no purchasing intervention observations in the sample period and the TVTP models are estimated using intervention sales only.

Table 2.6: Estimated Models for Australia

Parameters	Models								
	RW	LWI	FTP	TVTP(T)		TVTP(B)		TVTP(S)	
	1	2	3	4	5	6	7	8	9
μ	0.010	0.008							
	(0.54)	(0.41)							
μ_1			0.084	0.096	0.099	0.094	0.098	0.084	0.105
			(3.81)	(4.42)	(3.95)	(4.32)	(3.86)	(2.92)	(3.71)
μ_2			-0.051	-0.048	-0.096	-0.047	-0.102	-0.051	-0.072
			(-1.75)	(-1.62)	(-2.35)	(-1.66)	(-2.42)	(-1.45)	(-2.01)
σ	0.697	0.696							
	(38.72)	(38.62)							
σ_1			0.518	0.505	0.509	0.508	0.508	0.446	0.463
			(29.15)	(37.43)	(24.13)	(38.21)	(22.95)	(17.94)	(19.93)
σ_2			0.811	0.795	0.863	0.796	0.868	0.844	0.840
			(40.25)	(46.01)	(28.73)	(45.86)	(27.75)	(34.51)	(34.55)
α_1			4.216	6.837	22.010	7.584	21.722	0.986	23.174
			(12.63)	(4.57)	(4.32)	(3.71)	(4.55)	(2.27)	(2.79)
α_2			4.363	5.047	18.718	5.380	18.949	0.704	2.975
			(13.63)	(8.81)	(3.84)	(8.92)	(3.91)	(2.06)	(1.14)
β		0.0004							
		(1.43)							
β_1				-0.068	-0.013	-0.079	-0.011	-2.317	-0.284
				(-2.86)	(-1.64)	(-2.52)	(-1.34)	(-0.63)	(-2.32)
β_2				-0.044	-0.029	-0.050	-0.032	-1.078	-0.086
				(-3.81)	(-2.54)	(-3.94)	(-2.59)	(-1.94)	(-1.93)
δ_1					-3.787		-3.765		-4.398
					(-3.92)		(-4.09)		(-2.54)
δ_2					-3.111		-3.156		-0.369
					(-3.34)		(-3.53)		(-0.71)
p^{11}			0.98						
			(3.66)						
p^{22}			0.99						
			(3.19)						
LB	26.3	26.7	15.6	17.6	13.8	11.8	16.6	15.1	15.1
LB^2	48.1	46.2	12.1	13.8	14.5	12.1	12.4	10.6	16.3
LogLik	-	-	-	-	-	-	-	-	-
	1516.2	1515.1	1469.1	1469.3	1453.3	1469.2	1461.1	1477.7	1469.8

Note: See notes Table 3.

In the case of Iceland, the TVTP models indicate that total direct interventions increase the probability of staying in the tranquil regime (stabilization) but have no significant impact in the volatile regime, even when we account for monetary policy effects in the market (See Table 2.4 columns 3 and 4). When direct interventions were disaggregated into purchasing and selling operations the results show that intervention sales lowered the probability of staying in the tranquil regime (de-stabilizing)[22] but had no significant impact in the volatile regime. Intervention purchases had no significant impact on the transition probabilities in either regime. The policy interest rate was also

[22] Similar results were found by Beine *et al*. (2003).

significantly positively related to the probability of staying in the volatile regime. In the case of Jamaica, intervention had no significant impact on the probability of changing regimes. However, the coefficients of the policy interest rate indicate that interest rate policy may be the dominant policy instrument with respect to exchange rate dynamics. It also indicates a high interest rate policy may be destabilizing (See Columns 3 and 4 Table 2.5).

Finally, the case of Australia intervention reduces the probability of being in the tranquil as well as in the volatile regime, but does so more significantly in the case of the tranquil regime. This suggests an asymmetry in the impact with interventions in the tranquil regime being more destabilizing than the stabilizing interventions in the volatile regime (see Model 3 Table 2.6). Intervention, therefore, seems to be effective when the market is in the high volatility regime but counter-productive when it is in the calm regime, apparently validating the microstructure framework of intervention in the foreign exchange market. The Reserve Bank of Australia (RBA) also immediately fully sterilizes its interventions so there should be no additional money base/interest rate induced exchange rate changes arising from the original direct intervention in the market[23]. If this is so the monetary policy/interest rate measures will have an independent impact on the first and second moment of exchange rate returns and when included in the TVTP model it should not minimize or detract from the impact of direct interventions.

In the TVTP specification with the interest rate control included (model 4 Table 2.6) β_2 remains significantly negative but the size of the coefficient is smaller while β_1 is still negative but now insignificant. Direct intervention is therefore still an effective stabilization tool in the volatile regime. These results also suggest that even with full sterilization, these two policy instruments are not mutually exclusive with respect to exchange rate dynamics. This highlights the importance of explicitly accounting for monetary policy measures when investigating the effectiveness of direct interventions in this foreign exchange market[24]. It should be noted though that δ_1 and δ_2 are both significant and negative, implying that a high interest rate defense is stabilizing in the

[23] This is done because the RBA has different objectives for its normal monetary policy measures relative to direct interventions in the foreign exchange market which could be frustrated by un-sterilized interventions.
[24] These results corroborate the findings of Kim (2003) and Kearns and Rigobon (2005).

volatile regime but destabilizing in the tranquil regime, with a higher negative impact in the tranquil regime.

When direct intervention is separated out into purchasing and selling operations, purchasing operations (see columns 5 and 6 in Table 2.6), purchasing operations were the dominant mode of direct intervention in the period under review both in terms of the magnitude and frequency of interventions (see Table 2.1). Selling operations on the other hand only had a significant stabilizing impact in the volatile regime, reducing the persistency of this regime. However, when the monetary policy variable was included in the TVTP specification the results indicated that direct selling interventions reduced the probability of staying in both regimes (See Columns 7 and 8 Table 2.6). Moreover, in the intervention sales specification, the policy interest rate only had a significant impact in the tranquil regime. This may indicate that direct intervention, particularly selling intervention, is the dominant policy instrument[25] when the market is in the volatile regime. On the other hand, monetary policy seems to be the dominant instrument impacting on the foreign exchange market when it is in the low volatility regime.

Comparisons across countries reveal some interesting findings. Total intervention only had a significant impact in Australia (both regimes) and Iceland (tranquil regime only). This is reflected in Figures 2.5 to 2.8 where total intervention is plotted against the probability of transitioning from one regime to another. Figures 2.5 and 2.6 look at the probability of transitioning from the tranquil to the volatile regime for Australia and Iceland respectively. Figures 2.7 and 2.8 look at the probability of transitioning from the volatile to the tranquil regime for Australia and Iceland respectively. Figures 2.7 and 2.8 show that intervention increase the probability of switching from the volatile to the tranquil regime (stabilizing) in Australia but not in Iceland. On the other hand, Panels 5 and 6 show that intervention can also be de-stabilizing, generating high probabilities of transitioning from the tranquil to the volatile regime in Australia and Iceland, with only selling interventions driving the de-stabilizing effect in Iceland.

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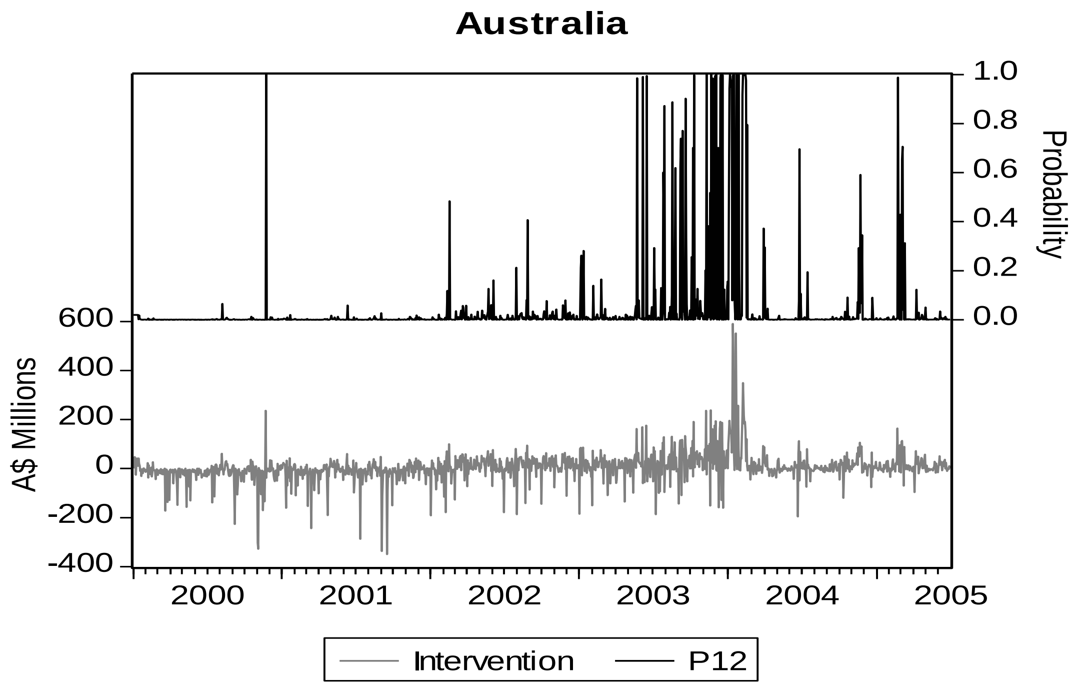
[25] The magnitude of the coefficient of selling interventions in the volatile regime is larger than in all other TVTP specifications.

When total interventions were disaggregated into purchasing and selling interventions, the results do not change much relative to the results for total intervention for Australia and Croatia. In the case of Iceland, however, contrary to the total intervention specification results which indicate that intervention increases the probability of staying in the tranquil regime (stabilizing), selling intervention decreases the probability of remaining in the tranquil regime (de-stabilizing). This result holds even when we account for monetary policy/interest rate effects. One explanation is that intervention purchases were used primarily to shore up foreign exchange reserves without affecting exchange rate dynamics while selling intervention reflects the "real" instrument in the sense that it was actually deployed to change exchange rate dynamics. The selling intervention did not succeed but instead increased volatility since it was implemented in the tranquil regime.

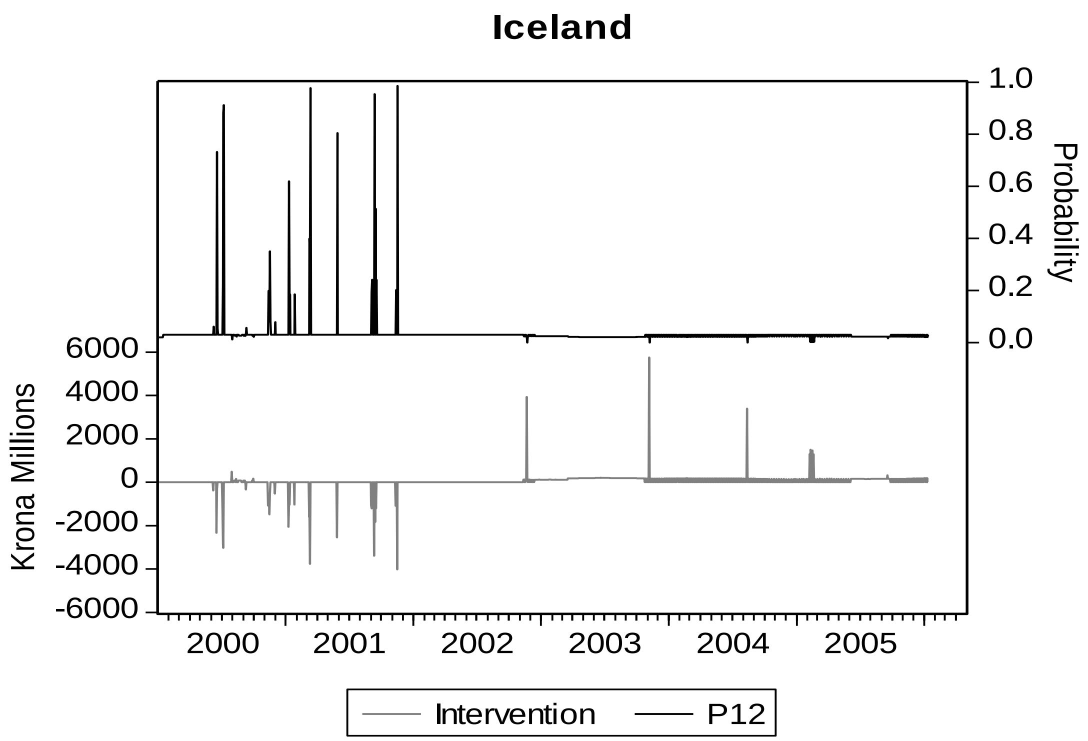
These results also suggest that in cases where direct intervention does not have a significant impact on the transition probability, as we find in both regimes in Croatia and Jamaica, as well as the volatile regime in Iceland, monetary policy/interest rates seems to play a significant role with respect to exchange rate dynamics. Another noteworthy point is that, contrary to conventional thinking, intervention appears to be more effective in the developed market (Australia) relative to the developing and transition markets (Croatia, Iceland and Jamaica). This does not appear to be due to the magnitude of intervention relative to market size. Rather, it seems to be caused by intervention practices such as the frequency of intervention and by the fact that direct intervention is implemented as a separate policy instrument to monetary policy by fully and immediately sterilizing intervention operations. By not fully sterilizing direct interventions the developing markets may find themselves in a situation where direct intervention became simply a complement to monetary policy measures and a relatively ineffective tool on its own.

Figure 2.5: Intervention and Transition Probabilities (Regime 1 to 2) for Australia



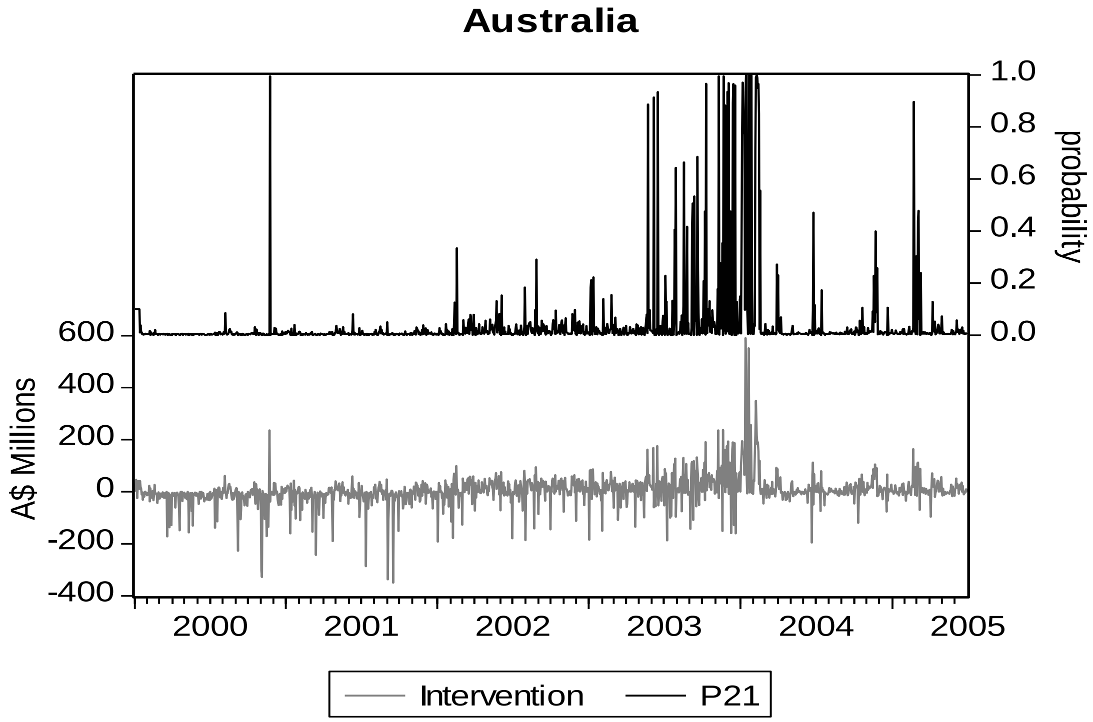
Note: P21 denotes the probability of moving from regime 2 (volatile) to regime 1 (tranquil) and P12 denotes the probability of moving from regime 1 (tranquil) to regime 2 (volatile). Intervention represents total intervention (sales and purchases).

Figure 2.6: Intervention and Transition Probabilities (Regime 1 to 2) for Iceland



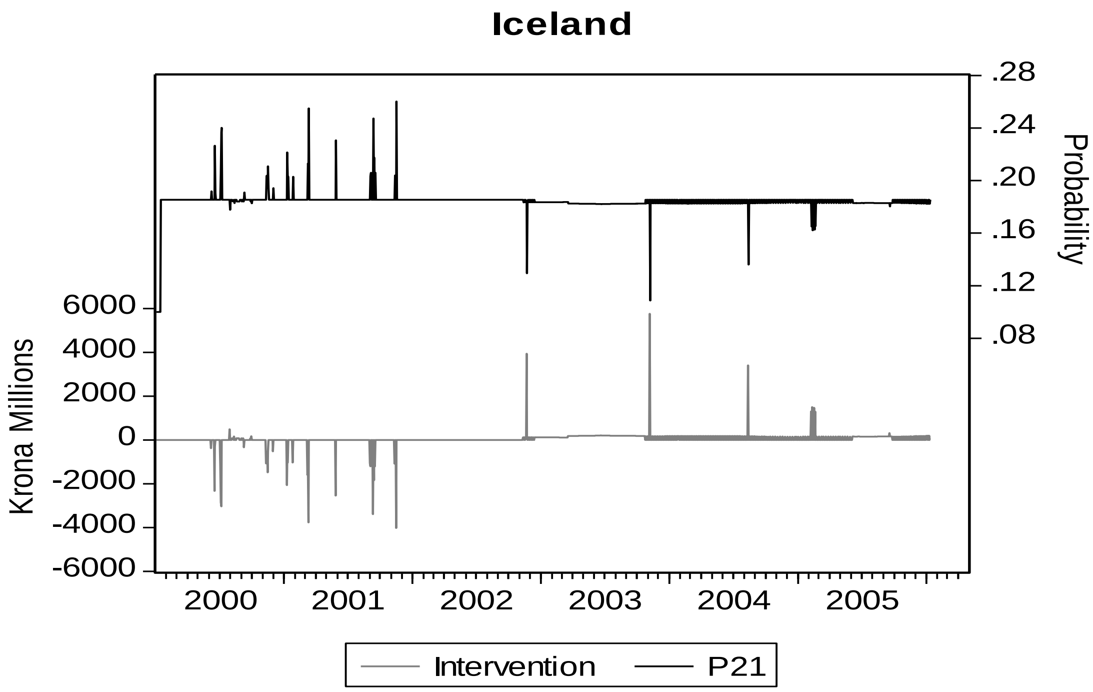
Note: Same as Figure 2.5.

Figure 2.7: Intervention and Transition Probabilities (Regime 2 to 1) for Australia



Note: Same as Figure 2.5.

Figure 2.8: Intervention and Transition Probabilities (Regime 2 to 1) for Iceland



Note: Same as Figure 2.5.

2.5 Summary

The results of recent studies on the effectiveness of direct intervention as a policy instrument have led to increasing skepticism about its usefulness in the foreign exchange market but the results of this study indicate that this skepticism may be misplaced. In this paper, we have provided some empirical evidence on the casual relationship between interventions and exchange rate volatility using a Markov switching model. We have contributed to this literature by augmenting the time varying transition probability models with a control for monetary policy and by investigating separately the impact of intervention sales and purchases. These extensions and the focus on the second moments differentiate this study from other contributions to this literature. Contrary to the predominant view, the empirical results show that direct intervention is effective in the case of Australia whereas it had little or no effect in the developing markets reviewed. Therefore, actual intervention practices, such as having more frequent interventions and full and immediate sterilization of direct interventions to preserve its status as an independent policy instrument, are important factors determining the effectiveness of this policy instrument. This implies that intervention practices rather than the level of market development may be the major determinant of effectiveness.

To summarize, there are important policy implications that our findings suggest: (i) the use of more frequent interventions rather than large one-off interventions tend to be more effective; (ii) if direct intervention aims to have an effect independent of monetary policy measures, these operations must be immediately and fully sterilized; (iii) even with full sterilization, there still seems to be feedback effects between these monetary/interest rate policy and direct intervention; (iv) selling and purchasing interventions lead to different effects. More care should therefore be taken in timing their deployment since intervening with both instruments at close intervals could lower the intervention effectiveness; (v) intervention should be used mostly in volatile market conditions when there are clear threats and policy objectives tends to be more clearly defined.

These issues are by no means exhaustive and many questions remain unanswered. The results of this study contribute to the empirical literature shedding some new light on the debate about the dynamic and effectiveness of direct intervention in the foreign exchange market. The issue of whether direct intervention might be able to stabilise the foreign exchange market more effectively is an issue which can only be addressed in the context of a structural model. This is beyond the scope of the present chapter and constitutes an interesting topic for future research.

CHAPTER 3
INTERVENTION IN THE FOREIGN EXCHANGE MARKET AND INTEREST RATE POLICY IN AUSTRALIA AND JAPAN: SIGNALING AND LEANING AGAINST THE WIND?

3.0 Introduction

Most central banks operating flexible exchange rate regimes have intervened with direct interventions in their 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. If central bank direct intervention in the market is not fully sterilised it can lead to changes in the interest rates as the central bank attempts to keep its liquidity targets. Also, monetary policy operating procedures may delay sterilization or render it incomplete which means there would be spillovers from direct intervention to monetary policy. Interest rate developments can also cause exchange rate changes which the central bank may see as counter to some of its other policy objectives which may lead to a response in the form of direct intervention. Of course, the signaling literature (Mussa, 1981) posits that direct intervention signals future changes in the policy interest rate.

In spite of these *a priori* strong links between direct intervention and policy interest rates, not much has been done on the links between direct intervention, monetary policy, particularly interest rate policy, and exchange rates. This is a major gap in the literature on central bank intervention in the foreign exchange market. This issue has assumed even greater importance since the recent global financial crisis as policy makers have grappled with a situation where "conventional" monetary policy measures such as interest rate policy have not been as effective given depressed demand conditions and weak consumer and business confidence. This has driven increased interest in unconventional policy measures such as direct intervention in the foreign exchange market and the possible trade-offs between this policy instrument and policy interest rates, even in developed market economies.

Direct intervention, interest rate policy[26] and exchange rate dynamics should therefore ideally be examined in a *joint framework* but relatively few studies have adopted this approach (Lewis, 1995; Kaminsky and Lewis, 1996; Kim, 2003; Kearns and Rigobon, 2005). These studies unfortunately tended to focus on the impact of policy on the level of exchange rate returns and not on its volatility which is increasingly of importance to policy makers. Kim and Sheen (2006) have come closest to treating with these issues in a joint framework by using a bivariate EGARCH model of exchange rate returns and market volumes. The main weakness of their approach, however, was it treated direct intervention and interest rate policy as exogenous variables and most studies on policy reaction functions have shown that these policy instruments are endogenous as they respond to developments in the market[27]. This approach therefore leads to less efficient estimates.

The multivariate GARCH framework we adopt corrects this specification problem by treating interest rate policy and direct intervention as endogenous variables. In this study we examine the links between direct intervention, interest rate policy and exchange rate dynamics in Australia and Japan in a joint trivariate VAR-GARCH(1,1)[28] framework. We study the Australian and Japanese foreign exchange markets to evaluate these issues since they are the largest developed markets[29] in which central banks have intervened directly in the last decade. Their experiences with direct intervention and interest rate policy initiatives in the foreign exchange market are therefore among the few on which we can gauge how effective these policy instruments are likely to be in other developed markets. This is increasingly going to occupy the attention of these markets as major currencies come under pressure from the ongoing fallout from the international financial crisis. In this environment, central banks in these jurisdictions will have to manage their exchange rates more actively but would be constrained by the

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

[27] See Lubika and Schorfheideb (2007) and Eichenbaum and Evans (1995) on interest rate policy reaction functions and Kim (2003) and Sarno and Taylor (2001) for policy reaction functions for direct intervention in the foreign exchange market.

[28] Our work also has some similarities to Beine (2004) who used a bivariate GARCH to look at the impact of central bank interventions in two major foreign exchange markets and the spillovers in terms of correlations between the exchange rates in these markets.

[29] In 2007 the Yen/US dollar and Australian dollar/US dollar currency pairs were the second and fourth most traded currency pairs globally at US$397 billion and US$175 billion respectively, together accounting for 19% of total global foreign exchange turnover which stood at US$3.2 trillion. The leading currency pair was the US dollar/Euro currency pair at 27% of total global foreign exchange turnover (See Bank for International Settlements, 2007).

degree to which they can raise interest rates. The dynamic of the links and feedback effects between direct intervention and interest rate changes in these markets is therefore a critical policy issue which requires renewed attention using more appropriate research methodologies.

The framework we adopt can also provide information on traditional issues such as whether direct intervention is used to “lean against the wind” of exchange rate trends and whether direct intervention “signals” future interest rates implying coordination between these policy instruments. Studies of these issues on Australia and Japan have found evidence supporting “leaning against the wind” and "signaling" behaviour (Kim, 2003; Kearns and Rigobon, 2005; Kim and Sheen, 2006). Very importantly also, the approach we adopt allows us to evaluate the relative impact of direct intervention and interest rate policy on the volatility of exchange rate returns. Additionally, this framework allows one to look at how policy intervention affects the conditional covariance and correlation of important variable like interest and exchange rates over time.

This information can provide insights into 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. This chapter therefore makes a contribution in terms of the appropriate empirical methodology for measuring the links between the implementation of direct intervention and interest rate policy in the foreign exchange market and the costs of the unsynchronized implementation of these policy instruments in Australia and Japan.

The chapter is structured as follows. Section 2 details very briefly the literature on the links between direct intervention and monetary/interest rate policy. Section 3 outlines the empirical methodology. Section 4 reviews the data used in this study and the intervention practices of the Reserve Bank of Australia (RBA) and the Bank of Japan (BoJ) especially as it relates to the coordination with monetary policy initiatives. Section 5 discusses the empirical results and section 6 concludes.

3.1 Theory

Many studies have examined the link between monetary/interest rate policy on exchange rates[30] while others looked at the impact of direct central bank intervention in the foreign exchange market on exchange rates[31]. These studies generally analysed the impact of these two policy instruments on exchange rates separately[32], ignoring the inherent endogenous nature of the relationship between direct central bank intervention, monetary/interest rate policy. In particular, research suggests that these policy instruments have policy reaction functions where the instruments not only impact on the exchange rate but the trends in the exchange rate can actually elicit changes in these policy instruments. Additionally, if central bank direct intervention in the market is not fully and immediately sterilised it can lead to changes in the interest rates as the central bank attempts to keep its liquidity targets. Interest rate changes can also cause exchange rate changes which the central bank may see as counter to some of its policy objectives which necessitate some response in the form of direct intervention. Of course the signaling literature posits that these two policy instruments are linked because direct intervention is followed by policy interest rate changes which is consistent or bolsters the effect of the direct intervention.

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[33]. Of these channels, the exchange rate, direct intervention and interest rate policy stance nexus is only a central theme in the signaling framework.

The signaling channel works by signaling to market participants the future stance of monetary policy which shifts 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; Kaminsky and Lewis, 1996). In this framework the exchange rate is treated as an asset price which is determined by the

[30] See Eichenbaum and Evans (1995), Clarida et. al. (1998) and Kim and Roubini (2000).

[31] See Cavusoglu (2010) for an updated review of studies in this area.

[32] Those studies (Lewis, 1995; Kim, 2003; Egert and Komarek, 2006; Kim and Sheen 2006) that did attempt to estimate the impact of these instruments on exchange rates in a joint empirical framework had a number of methodological problems.

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

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[34] against the currency (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.

The signaling hypothesis requires that intervention leads to future changes in monetary policy in line with the initial intervention. If the signaling channel is working sales (purchases) of foreign exchange must be backed up by future contractionary (expansionary) monetary policy. Lewis (1995) demonstrated these features using a standard asset pricing model. He showed that in this framework the exchange rate depends on lagged money supply, the discounted present value of changes in the money supply adjusted by lagged intervention and the expected discounted present value of all future interventions.

This is best explained by a simple model as outlined in Lewis (1995). Consider a standard asset pricing model:

$$s_t = (1-\theta)\sum_{J=0}^{\infty}\theta^j E_t f_{t+j} \tag{1}$$

where s_t is the log exchange rate, f is the log of fundamentals and θ is a discount factor. Furthermore

$$f_t = (m_t - m_t^*) + v_t \tag{2}$$

where m and m^* are the domestic and foreign monetary policy variables and v_t are fundaments which are not controlled by central banks. Following Lewis (1995) we assume that m^* and v are exogenous and uncorrelated which means that the exchange

[34] This occurs when market participants speculate against the defensive (usually) interventions of the central bank.

rate solution is dependent on current expectations of future domestic monetary policy, as well as current expectations of foreign monetary policy and other fundamentals out of central banks' control. We set the values of m^* and v to zero to focus on the role of domestic shocks so that $f_t = m_t$. This does not affect the inferences that can be drawn from this simple model regarding the impact of intervention and domestic monetary policy on exchange rates because by assumption future values of m^* and v are independent of m and direct intervention (I). Assuming that the process of fundamentals is autoregressive in 1st difference we have:

$$\Delta m_t = \rho_m \Delta m_{t-1} + \beta I_{t-k} + \mu_t \tag{3}$$

where Δ is the backward difference operator, ρ_m is the autoregressive coefficient of the first difference of fundamentals on their own lag, I_t is direct intervention at time t and β is a parameter relating intervention k periods in the past to a current change in the domestic monetary supply. If I is measured as sales of foreign currency and the central bank is effectively signaling with these interventions then β should be negative if m is a monetary aggregate.

The logic behind this is that an intervention sale is contractionary since it takes domestic liquidity out of the system. Therefore, for an intervention sale to be consistent with the signaling hypothesis future changes in monetary policy must be contractionary, that is, it must be correlated with a fall in m in the future. If a policy interest rate was used as a proxy for monetary policy then an intervention sale would have to be correlated with a rise in the interest rates, that is β must be positive. The process for intervention is assumed to be autoregressive and is defined as:

$$I_t = \rho_I I_{t-1} + e_t \quad \text{where} \quad E(e_t \mu_t) = 0 \tag{4}$$

For a given lag k then the exchange rate solution is:

$$s_t = m_{t-1} + \delta_m(\Delta m_t - \beta I_{t-k}) + \beta\delta_m \sum_{j=0}^{\infty} \theta^j E_t I_{t-k+j} \tag{5}$$

where $\delta_m \equiv (1-\theta\rho_m)^{-1}$. Equation 5 therefore shows that in this framework the exchange rate depends on lagged money supply, the discounted present value of changes in the money supply adjusted by lagged intervention and the expected discounted present value of all future interventions. In sum, current interventions affect the exchange rate by shifting the agents' expectations of future money supplies – that is signaling. When $\beta = 0$ interventions have no impact on the exchange rate but when $\beta < 0$ sales of foreign currency will signal future declines in money supplies and current and expected future interventions will lead to appreciation today.

If $k = 1$, that is, the lag between intervention and changes in the money supply is one period, the exchange rate solution is:

$$s_t = m_{t-1} + \delta_m \Delta m_t + \beta\theta\delta_m\delta_I I_t \tag{6}$$

where $\delta_I \equiv (1-\theta\rho_I)^{-1}$. From equation 6, once $\beta < 0$, current intervention will increase the expected money supply in the next period, changing the discount rate on money and therefore the exchange rate. The present value of the intervention effect on all future expected interventions and therefore money supplies is captured by $\delta_m\delta_I$, the product of the discount factor of money and the discount factor of intervention.

This implies that intervention in the foreign exchange market and monetary policy targeting the exchange rate are inextricably linked, with important feedback effects pointing to the inherent endogeneity of the relationship between direct intervention, interest rate (monetary policy) and exchange rates. Studies studying the effectiveness of these policy instruments on exchange rate dynamics separately, therefore, 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 and intervention, a joint empirical framework is required. We turn to this in the next section.

3.2 The Empirical Methodology: Multivariate GARCH

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 EGARCH (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 exploring the link between various monetary policy proxies and intervention and another looking at the relationship between various monetary policy proxies and the exchange rate. The first bivariate VAR was used to investigate whether the "signaling" channel was operating and the second VAR was used to see if monetary policy had any impact on exchange rates. This was an imperfect framework since it could not capture the full range of links and feedback effects between the three variables in a bivariate VAR. Kim (2003) solved the specification problem inherent in Lewis' method by using a structural VAR approach which included the exchange rate along with the two policy variables, as well as a host of other economic variables. However, the use of monthly data and the validity of the identifying restrictions weakened the validity of his results.

Kearns and Rigobon (2005) utilized 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 how monetary policy initiatives affected 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 also depended on the assumption that the change in intervention policy was truly exogenous and not dependent on 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 assumed that parameters of the model are 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 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 policies on the volatility of the exchange rate to be useful in a policy context. In this regard, Kim and Sheen (2006) used a bivariate EGARCH model to measure the impact of direct intervention on the exchange rate and also to explore the links of these two variables to transactions volumes in the Japanese foreign exchange market, not only at levels but also the level of variances.

Their focus was to examine how transaction volumes impacted on the relationship between intervention and exchange rates and therefore only included interest rates as an exogenous variable in the specification of the mean equations. This however represents a misspecification since it is generally accepted that direct intervention and interest rate policy are endogenous, depending on trends in exchange rates and other important variables. It also did not allow the full dynamic of the volatility spillovers between direct intervention, interest rates and exchange rates to be measured which would provide useful information for policymakers in terms of the volatility trade-offs from policy implementation.

To address these issues we use a tri-variate VAR-GARCH(1,1) framework using the BEKK parameterization (See Appendix). The mean equation formulation used in this study can be represented by the following where variables of interest include exchange rate returns (*ER*), intervention (*I*) and the policy interest rate changes (*RR*):

$$\begin{bmatrix} ER_t \\ I_t \\ RR_t \end{bmatrix} = \begin{bmatrix} \delta_1 \\ \delta_2 \\ \delta_3 \end{bmatrix} + \begin{bmatrix} \delta_{11} & \delta_{12} & \delta_{13} \\ \delta_{21} & \delta_{22} & \delta_{23} \\ \delta_{31} & \delta_{32} & \delta_{33} \end{bmatrix} \begin{bmatrix} ER_{t-1} \\ I_{t-1} \\ RR_{t-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \varepsilon_{3t} \end{bmatrix} \tag{7}$$

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 while δ_{32} indicates whether intervention "signals" monetary policy or not.

The conditional variance equation for each variable[35] which shows how shocks and volatility are transmitted over time in each sector can be expanded as follows:

$$\begin{aligned} h_{11,t+1} = {} & a_{11}^2\varepsilon_{1,t}^2 + 2a_{11}a_{12}\varepsilon_{1,t}\varepsilon_{2,t} + 2a_{11}a_{31}\varepsilon_{1,t}\varepsilon_{3,t} + a_{21}^2\varepsilon_{2,t}^2 + 2a_{21}a_{31}\varepsilon_{2,t}\varepsilon_{3,t} + a_{31}^2\varepsilon_{3,t}^2 \\ & + b_{11}^2 h_{11,t} + 2b_{11}b_{12}h_{12,t} + 2b_{11}b_{31}h_{13,t} + b_{21}^2 h_{22,t} + 2b_{21}b_{31}h_{23,t} + b_{31}^2 h_{33,t} \end{aligned} \tag{8}$$

$$\begin{aligned} h_{22,t+1} = {} & a_{12}^2\varepsilon_{1,t}^2 + 2a_{12}a_{22}\varepsilon_{1,t}\varepsilon_{2,t} + 2a_{12}a_{32}\varepsilon_{1,t}\varepsilon_{3,t} + a_{22}^2\varepsilon_{2,t}^2 + 2a_{22}a_{32}\varepsilon_{2,t}\varepsilon_{3,t} + a_{32}^2\varepsilon_{3,t}^2 \\ & + b_{12}^2 h_{11,t} + 2b_{12}b_{22}h_{12,t} + 2b_{12}b_{32}h_{13,t} + b_{22}^2 h_{22,t} + 2b_{22}b_{32}h_{23,t} + b_{32}^2 h_{33,t} \end{aligned} \tag{9}$$

$$\begin{aligned} h_{33,t+1} = {} & a_{13}^2\varepsilon_{1,t}^2 + 2a_{13}a_{23}\varepsilon_{1,t}\varepsilon_{2,t} + 2a_{13}a_{33}\varepsilon_{1,t}\varepsilon_{3,t} + a_{23}^2\varepsilon_{2,t}^2 + 2a_{23}a_{33}\varepsilon_{2,t}\varepsilon_{3,t} + a_{33}^2\varepsilon_{3,t}^2 \\ & + b_{13}^2 h_{11,t} + 2b_{13}b_{23}h_{12,t} + 2b_{13}b_{33}h_{13,t} + b_{23}^2 h_{22,t} + 2b_{23}b_{33}h_{23,t} + b_{33}^2 h_{33,t} \end{aligned} \tag{10}$$

[35] The constant terms are excluded.

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) and $h_{13,t}$ is the conditional covariance between the first (exchange rates) and third variables (interest rate). The error term $\varepsilon_{i,t}^2$ measures deviations from the mean due to some unanticipated event 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} therefore measure the impact of shocks in variables under consideration on conditional variances (volatility) while the b_{ii} measure volatility spillovers between sectors.

The BFGS algorithm is used to obtain final estimates of the parameters with the variance-covariance matrix and corresponding Bollerslev-Woodridge (1992) heteroskedasticity and serial correlation consistent standard errors. The Simplex method was used to obtain initial parameter for the BFGS algorithm.

3.3 Data and Intervention Practices in Australia and Japan

3.3.1 Data

We utilize daily data on intervention, policy interest rates and exchange rates rather than the monthly and weekly data used in some studies (Lewis, 1995; 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 basis. Additionally, the paper utilizes the most recently released data on intervention in the foreign exchange market by the Reserve Bank of Australia covering the period up to the end of 2006.

Intervention is defined as daily sales and purchases of foreign currency by the RBA and the BoJ. The exchange rates used for Australia and Japan are measured as units of the intervention currency, the US dollar, per Australian dollar and Japanese Yen respectively. Exchange rate returns are used in the estimated models as is standard practice in the literature and is defined as $ER_t = 100 * \log(er_t / er_{t-1})$ where er_t denotes the number of units of the US dollars per unit of domestic currency. The data set on Australia covers 1780 observations (after omitting holidays and other non-trading days) over the period January 3, 2000 to December 29, 2006 while the data set for Japan covers 1646 observations over the period January 5, 1998 to April 30, 2004.

Policy interest rate changes are as used as proxies for monetary policy initiatives instead of monetary aggregates in this study[36]. Policy interest rate changes are defined as $RR_t = 100 * \log(rr_t / rr_{t-1})$ where rr_t denotes the annualized policy interest rate. The annualized rates used are the Overnight Call Rate in the case of Japan and the 180-day Treasury Bill Rate for Australia. In Australia's case the policy interest rate is the Cash Rate but the 180-day Treasury Bill Rate is used since it better captured daily changes and is highly correlated with the Cash Rate.

Tables 3.1 and 3.2 present some summary statistics on exchange rate changes, intervention and interest rate changes for Australia and Japan. These series exhibit many of the usual properties of financial time series. They are generally non-normal, leptokurtic and serially correlated. In the case of Australia, there is bi-directional Granger causality between intervention and exchange rate changes, as well as between interest rate changes and exchange rate changes. There is, however, no Granger causality between interest rate changes and intervention in either direction. In the case of Japan, Granger causality runs only from exchange rate changes to intervention, while there is bi-directional causality between interest rate and exchange rate changes. Like Australia, there is no causality between interest rate changes and intervention.

[36] This is increasingly the practice in empirical studies since monetary aggregates contain elements which are positively correlated with interest rates (leeper et. al 1996). This would be an inappropriate proxy 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).

Table 3.1: Summary Statistics and Statistical Tests for Australia

Summary Statistics	*Australia*		
	Exchange rate	Intervention	Interest rate
Mean	0.013	0.046	0.003
Variance	0.48	0.31	0.45
Skewness	-0.26	0.87	-0.99
Excess kurtosis	4.57	26.15	17.64
JB normality	203.66	39981	16181
Unit root	-43.39	-11.12	-42.52
Q(20)	21.36 (0.37)	1222 (0.00)	50 (0.00)
Granger causality			
H0: Intervention does not cause Exchange rate	2.89	(0.08)	
H0: Exchange rate does not cause intervention	48.48	(0.00)	
H0: Interest rate does not cause Exchange rate	2.72	(0.09)	
H0: Exchange rate does not cause Interest rate	8.46	(0.00)	
Ho: Intervention does not cause Interest rate	0.92	(0.33)	
H0: Interest rate does not cause Intervention	0.04	(0.83)	

Notes: Unit roots test was the augmented Dickey-Fuller test with constant and lags chosen by the Schwarz Information Criterion. Q(20) is the Ljung-Box Q Statistic for serial correlation and JB normality is the Jaque-Bera test statistic for normality.

Table 3.2: Summary Statistics and Statistical Tests for Japan

Summary Statistics	*Japan*		
	Exchange rate	Intervention	Interest rate
Mean	0.011	0.029	-0.237
Variance	0.50	0.02	423.54
Skewness	0.52	1.68	0.33
Excess kurtosis	6.71	83.64	64.79
JB normality	1016	446773	262792
Unit root	-38.77	-12.28	-27.11
Q(20)	19.37 (0.49)	525 (0.00)	183.44 (0.00)
Granger causality			
H0: Intervention does not cause Exchange rate	0.41	(0.52)	
H0: Exchange rate does not cause intervention	2.74	(0.09)	
H0: Interest rate does not cause Exchange rate	3.55	(0.05)	
H0: Exchange rate does not cause Interest rate	3.97	(0.04)	
Ho: Intervention does not cause Interest rate	0.71	(0.39)	
H0: Interest rate does not cause Intervention	0.15	(0.69)	

Notes: Unit roots test was the augmented Dickey-Fuller test with constant and lags chosen by the Schwarz Information Criterion. Q(20) is the Ljung-Box Q Statistic for serial correlation and JB normality is the Jaque-Bera test statistic for normality.

3.3.2 Intervention Practices

In the case of Australia, the RBA's approach to intervention has changed over time. In particular, the RBA has moved from using frequent small interventions with many switches from intervention sales to purchases prior to June 1995 to infrequent and large intervention after that date (Kearns and Rigobon, 2005 and Kim and Sheen, 2006). This was driven by the RBA's initial concern with volatility and unsettled market conditions in the early years of the float[37] which then changed from June 1995 to focusing on episodes when the exchange rate moved to a level that did not seem consistent with macroeconomic fundamentals. The period covered by this study therefore coincides with the latter regime. Identifying when the exchange rate is not aligned with fundamentals is not a simple issue but in practice this means that the RBA generally intervenes when the exchange rate moves to long or medium term highs and lows (Becker and Sinclair, 2004).

The RBA's intervention purchases and sales of Australian dollars has been relatively frequent (See Table 2.3) and are predominantly against the US dollar in the spot market. The RBA not only has to decide when to intervene but also must determine the amount of the intervention. The RBA's intervention activities are sterilized by countervailing transactions in the Australian money market to keep the domestic policy interest rate close to target. The RBA has recently begun to make greater use of foreign exchange swaps to sterilize intervention activities. In Australia's case intervention policy generally seemed to be in sync with monetary policy objectives, with intervention generally attempting to move the exchange rate in a direction consistent with the current monetary policy stance (Mc Farlane, 1993).

In the case of Japan, the BoJ did not intervene nearly as frequently as the RBA (See Table 3.3) but when it did so it generally intervened on a much larger scale than the RBA. This is not surprising given the relative size of the two markets, although the turnover in the Australian market has been increasing relative to the Japanese market in recent years[38]. The stated objective of the BoJ's interventions in the foreign exchange market is to mitigate the negative impact of large fluctuations in the Yen, which is on a

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[37] The Australian dollar was floated on December 12, 1983.

[38] The average daily turnover in the Australian foreign exchange market over the period 1998-2007 was US$92.8 billion compared to US$180 billion In the Japanese market in the same period (BIS, 2007).

long term appreciating trend[39]. This implies that the BoJ not only responds to volatility but "leans against the wind" of Yen appreciation.

Table 3.3: The Dynamics of Intervention

Variable	*Australia*	*Japan*
Sales Days	443	3
Purchases Days	646	158
Total Interventions Days	1089	161
Total Sample Days	1782	1646
% Intervention Days	61.1	9.8
% Intervention Sale Days	24.9	0.2
% Intervention Purchase Days	36.3	9.6
Average Inter. Sales (US$M)	27.3	7805.1
Average Inter. Purchases (US$M)	31.3	2920.7
Max. Inter. Sales (US$M)	293.0	20306.1
Max. Inter. Purchases (US$M)	458.5	15568.0

Note: % intervention days are calculated as intervention days divided by total sample days.

The BoJ's intervention transactions were predominantly against the US dollar in the spot market but there were a few transactions against the Euro in the review period. The BoJ intervention transactions appear to be sterilized given that funds for US$ purchase/Yen sales were raised by issuing financing bills and US$ sales/Yen purchases are derived from the Foreign Exchange Fund Special Account of the Japanese government. The sterilization of intervention transactions and the link to monetary policy is complicated in the period covered by this study because interest rates were close to zero and the normal monetary policy transmission channels may not have been in play in many instances during this period. Moreover, from 2003 onwards the money supply has increased steadily along with intensive intervention purchases of foreign currency/sales of Yen. This implies that the BoJ did not sterilize all or part of the Yen sales from its intervention activity, that is, a significant amount of interventions may have been unsterilized (Spiegel, 2003). Even if the intervention transaction of the BoJ near the end of the period under review was unsterilized, the low interest rate/liquidity trap environment for this period may manifest itself in insignificant links between

[39] The objectives, modality and financing of intervention in the Japanese foreign exchange market are explained in a BoJ document at (www.boj.or.jp/en/about/basic/etc/faqkainy.htm).

intervention and interest rates but significant links between intervention and exchange rate implying that intervention is operating mostly through the portfolio channel.

3.4 Empirical Results

The mean and variance equations with BEKK parameterization are estimated simultaneously and the results for Australian and Japan are reported in Tables 3.4 and 3.5 respectively. The constant terms in the mean and variance equations are not reported for brevity[40]. The variables in the tri-variate VAR-GARCH(1,1), exchange rate returns, intervention and interest rate changes are indexed as 1, 2 and 3 respectively in Tables 3.4 and 3.5.

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) respectively on exchange rates. Additionally, δ_{21} measures the tendency of central bank interventions to lean against the wind while δ_{32} indicates whether intervention signals monetary policy or not.

In the case of Australia, the coefficient δ_{12} is -0.100 and significant, indicating that sales of foreign currency against the local currency lead to an appreciation of the Australia Dollar. This coefficient is relatively close but smaller than the coefficient obtained in Kearns and Rigobon (2005) but this is likely related to the fact that they used the period 1986 to 2002. The coefficient δ_{21} was 0.155 and significant indicating that the RBA intervened predominantly to "lean against the wind", that is, if the exchange rate was depreciating (appreciating) it intervened by selling (purchasing) foreign exchange to counter this trend. This is again in keeping with the findings of previous studies exploring this issue in Australia (Kearns and Rigobon, 2005).

[40] The constant terms were all highly significant indicating the models were well specified but were excluded because they had no bearing on the central themes being investigated. Also, including these terms would have made the tables difficult to format.

Table 3.4: Estimated Coefficients for the Trivariate GARCH for Australia

	Exchange Rate (i=1)		*Intervention (i=2)*		*Interest Rate (i=3)*	
δ_{1i}	0.005	(0.23)	-0.100	(-4.01)	0.040	(1.67)
δ_{2i}	0.155	(6.13)	0.162	(5.68)	0.003	(0.19)
δ_{3i}	0.037	(2.19)	-0.027	(-1.56)	0.030	(1.12)
a_{1i}	0.991	(343.43)	-0.032	(-4.68)	-0.004	(-1.60)
a_{2i}	0.067	(3.08)	0.808	(12.77)	-0.011	(-1.13)
a_{3i}	0.001	(0.32)	-0.001	(-0.12)	0.988	(212.27)
b_{1i}	0.084	(2.65)	0.217	(3.14)	0.038	(1.89)
b_{2i}	-0.063	(-2.94)	0.401	(6.03)	0.009	(0.65)
b_{3i}	0.006	(0.21)	-0.031	(-0.79)	0.146	(4.98)
$LB(10)$	9.9	[0.45]	10.2	[0.39]	8.9	[0.56]
$LBs(10)$	8.2	[0.61]	1.4	[0.99]	2.1	[0.99]
LLR	-3636					

Notes: $LB(10)$ and $LBs(10)$ are the Ljung-Box Q-statistics for standardized and squared standardized residuals at lag 10 respectively and LLR is the log likelihood. Standard errors are Bollerslev-Woodridge (1992) heteroskedasticity and serial correlation consistent. Values in round brackets are t-values and square brackets are the probabilities for the Ljung-Box Q-statistics. In terms of the estimated coefficients starting from left to right in the Table, the coefficient δ_{11} in the first row first column measures the impact of lagged exchange rate returns on current levels of exchange rate returns, the coefficient δ_{12} in the first row third column measures the impact of lagged intervention on current exchange rate returns and the coefficient δ_{13} in the first row sixth column measures the impact of lagged interest rate changes on current exchange rate returns. Similarly, in the ninth row first column, the coefficient b_{31} measures the volatility spillovers from lagged exchange rate returns to current volatility of interest rate changes, in the ninth row third column, the coefficient b_{32} measures volatility spillovers from lagged intervention to current interest rate changes and the coefficient b_{33} in the ninth row sixth column measures the volatility spillovers from lagged to current interest rate change changes.

The coefficient value for δ_{32} was -0.027, its sign suggested that a sale of foreign currency, which is contractionary, would lead to an increase in the interest rate (also contractionary) and therefore direct intervention appeared to "signal' future interest rate policy. This coefficient was however marginally insignificant. The impact of interest rate policy on exchange rates as measured by the coefficient δ_{13} is 0.040 indicating that increases (decreases) in interest rates leads to exchange rate appreciation (depreciation) as would be expected.

Other noteworthy results include the fact that interest rate and exchange rate changes appears to have a bi-directional relationship and seem to be driven by common factors since both coefficients δ_{13} and δ_{31} are positive and significant. These common factors are most likely due to the fact that the period under review is dominated by a trend of exchange rate appreciation and increased interest rates in the context of robust economic growth.

In the case of Japan, the mean equation results are broadly similar to Australia in the sense that intervention moves the exchange rate in the expected direction, the BoJ displays "leaning against the wind" behavior and direct intervention appears to "signal" future interest rate policy (Watanabe, 1994). That is, δ_{12}, δ_{21} and δ_{32} are -0.16, 0.01 and -2.18 respectively (See Table 3.5). These results are broadly in line with the results of previous studies in this area on Japan (Kearns and Rigobon, 2005; Kim and Sheen, 2006). The fact that δ_{12} is negative and significant means that when the BoJ intervenes selling US dollars (negative) the Yen appreciates (positive exchange rate returns). The estimated coefficient δ_{21} indicates that if the exchange rate is depreciating (negative exchange rate returns) the central banks tends to intervene selling foreign exchange to support the Yen and "lean against the wind" of the exchange rate trend. The BoJ also tends to intervene buying foreign exchange to slow down or stop an appreciating trend. In fact, for a significant part of this period the BoJ was engaged in intervention purchases of foreign currency to weaken the Yen against the US dollar in an attempt to promote export led growth.

Table 3.5: Estimated Coefficients for the Trivariate GARCH for Japan

	Exchange Rate (i=1)		*Intervention (i=2)*		*Interest Rate (i=3)*	
δ_{1i}	0.076	(2.57)	-0.156	(-1.83)	-0.001	(-2.07)
δ_{2i}	0.009	(12.01)	0.090	(5.00)	-0.001	(-5.89)
δ_{3i}	-0.122	(-0.17)	-2.180	(-2.38)	-0.525	(-4.79)
a_{1i}	0.995	(548.01)	-0.001	(-1.01)	-0.255	(-3.97)
a_{2i}	-0.032	(-0.21)	0.036	(1.83)	0.102	(0.09)
a_{3i}	0.001	(2.21)	0.001	(2.51)	0.967	(108.33)
b_{1i}	0.063	(2.51)	-0.075	(-7.78)	4.049	(3.52)
b_{2i}	0.087	(0.09)	6.179	(9.19)	-1.127	(-0.15)
b_{3i}	-0.001	(-1.62)	0.001	(0.37)	0.255	(7.07)
$LB(10)$	6.6	[0.75]	9.7	[0.61]	10.1	[0.53]
$LBs(10)$	1.2	[0.99]	1.9	[0.98]	1.1	[0.99]
LLR	-6662					

Notes: See notes to Table 4.

The negative and significant value of the coefficient δ_{32} indicates that intervention "signals" interest rate policy changes since direct intervention is normally followed by an interest rate policy change that bolsters the impact of the direct intervention. That is, intervention sales of foreign exchange (negative) which aims to curb monetary expansion would be followed by an increase in the policy interest rate (positive) which is also restrictive and intervention purchases of foreign exchange (positive) would tend to be followed by a decrease in the policy interest rate which are both expansionary. The negatively signed coefficient δ_{13} indicates that increases in the domestic policy interest rate leads to exchange rate depreciation. This is not what one would expect and may be due to extremely low interest rates during this period coupled with the mild average trend for the Yen to depreciate over this period. In any case the coefficient is extremely small (-0.0014). The coefficient δ_{23} is also negative and significant, albeit very small, indicating some level of bi-directional relation between interest rates and intervention, that is, if interest rates rise (contractionary) this is generally accompanied by the central bank intervention sales of foreign currency (contractionary). This implies that intervention activity and interest rate policy measures are geared to common goals and appear to be used interchangeably in Japan. These results, especially those from the mean equations, can be exploited for forecasting purposes. The strong relationship between direct intervention and exchange rate returns means that market participants can reliably estimate future exchange rate returns based on current central bank intervention activity. The ability to forecast exchange rate returns have huge implications for investment managers with Yen denominated financial assets and currency traders.

As noted above, the trivariate VAR-GARCH (1,1) framework through the variance/covariance equations also allows us to look at the volatility dynamics of exchange rates, intervention and interest rate policy in a joint framework. This is important since central banks are increasingly concerned about the volatility consequences of policy measures. The transmission of shocks across variables in the trivariate VAR-GARCH (1,1) is reflected in the a_{ii} coefficients 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 Australia, Table 3.4 shows that shocks to intervention, that is the coefficient a_{12}, is -0.032 and significant, which suggests that intervention activity reduces exchange rate volatility. The coefficient a_{13} is -0.004 but insignificant which suggests that interest rate changes do not have a significant effect on volatility. This implies that in Australia direct intervention could be deployed to control exchange rate volatility and undesirable trends but interest rate policy is only effective in moving the *level* of the exchange rate in the desired direction. More importantly, the implementation of these policy instruments were not associated with increased volatility and therefore reduced effectiveness as advanced by some studies. Additionally, shocks to the exchange rate increases the volatility of intervention since a_{21} is 0.068 and significant. This backs up the "leaning against the wind" results from the mean equation where intervention activity increases in response to exchange rate developments which the central bank views as undesirable.

The volatility spillovers between variables in the trivariate VAR-GARCH (1,1) are reflected in the b_{ii} coefficients. For Australia, volatility spillovers from intervention (b_{12}) and interest rates (b_{13}) to exchange rates are significant at 0.217 and 0.038

respectively, implying that inconsistent or erratic implementation of these policy instruments may contribute to greater exchange rate volatility. This may have informed the observed interest rate smoothing behavior on the part of central banks and the move to have fewer but larger direct interventions to project an unambiguous signal to the market.

In the case of Japan (Table 3.5), the coefficient a_{13} at -0.255 indicates that shocks to interest rates has a significant dampening effect on exchange rate volatility whereas the coefficient a_{12} at -0.001 but insignificant suggests that intervention activity have no significant impact on exchange rate volatility. This implies that direct intervention is not effective in controlling exchange rate volatility but interest rate policy charges are. Also, shocks to exchange rates have a small positive and significant impact on the volatility of interest rates as reflected in the coefficient a_{31}, implying a sort of trade off between exchange and interest rate volatility. Past shocks to intervention also generates a small but significant increase in the volatility of interest rates (a_{32}) implying that this policy instrument achieves its goals in terms of moving the exchange rate level in the desired direction, without increasing exchange rate volatility but at the expense of moderate increases in interest rate volatility.

The transmission of volatility spillovers between variables in the trivariate VAR-GARCH (1,1) for Japan indicates that volatility in intervention activity and interest rates have significant effects on the volatility in exchange rates. The coefficient b_{12} of -0.075 indicates that higher variances of intervention associated with the implementation of direct intervention leads to lower volatility in exchange rates and therefore the central bank do not have to worry about increased exchange rate volatility when using direct intervention. On the other hand, the significant coefficient b_{13} of 4.049 indicates that interest rate volatility increases the volatility of exchange rates and greater caution is needed when implementing policy interest rate changes. This suggests that policy interest rate changes should be done in consistent manner to avoid reversals and minimize volatility. It also suggests that interest rate smoothing would be a useful strategy in this market.

The multivariate GARCH framework also allows us to look at the conditional correlation of important variables over time. This allows us to see how these correlations evolve over time and could offer some insights into the substitutability of direct intervention and policy interest rates over time, as well important trade-offs between the costs of policy implementation such as increased volatility and the achievement of policy targets. In this regard, Charts 3.1 and 3.2 show the conditional correlation of the variables in the trivariate VAR-GARCH(1,1) model for Australia and Japan respectively.

In both Charts 3.1 and 3.2 the correlations over time between intervention and exchange rate, interest rate and exchange rate and intervention and interest rate are displayed in rows 1, 2 and 3 of these Charts respectively together with intervention, interest rate changes and exchange rate changes respectively. The most obvious fact flowing from Charts 3.1 and 3.2 is that while the correlations may be low for much of the periods under review in Australia and Japan, they are very high during periods when exchange rate volatility is high, as well as, during periods when there are very large changes in the two policy instruments.

For Australia, Chart 3.1 shows that generally the correlation of intervention and exchange rate is highest when intervention (panel A), interest rate changes (panel B) and exchange rate changes (panel C) respectively are high. Similarly, panels D, E and F of Chart 3.1 show that the correlation between interest rates and exchange rates are high when intervention, interest rate changes and exchange rate movement respectively are high. This is also the case of the correlation of intervention and interest rates when intervention (panel G), interest rate changes (panel H) and exchange rate movement (panel I) respectively are high.

Figure 3.1: Conditional Correlations for Australia

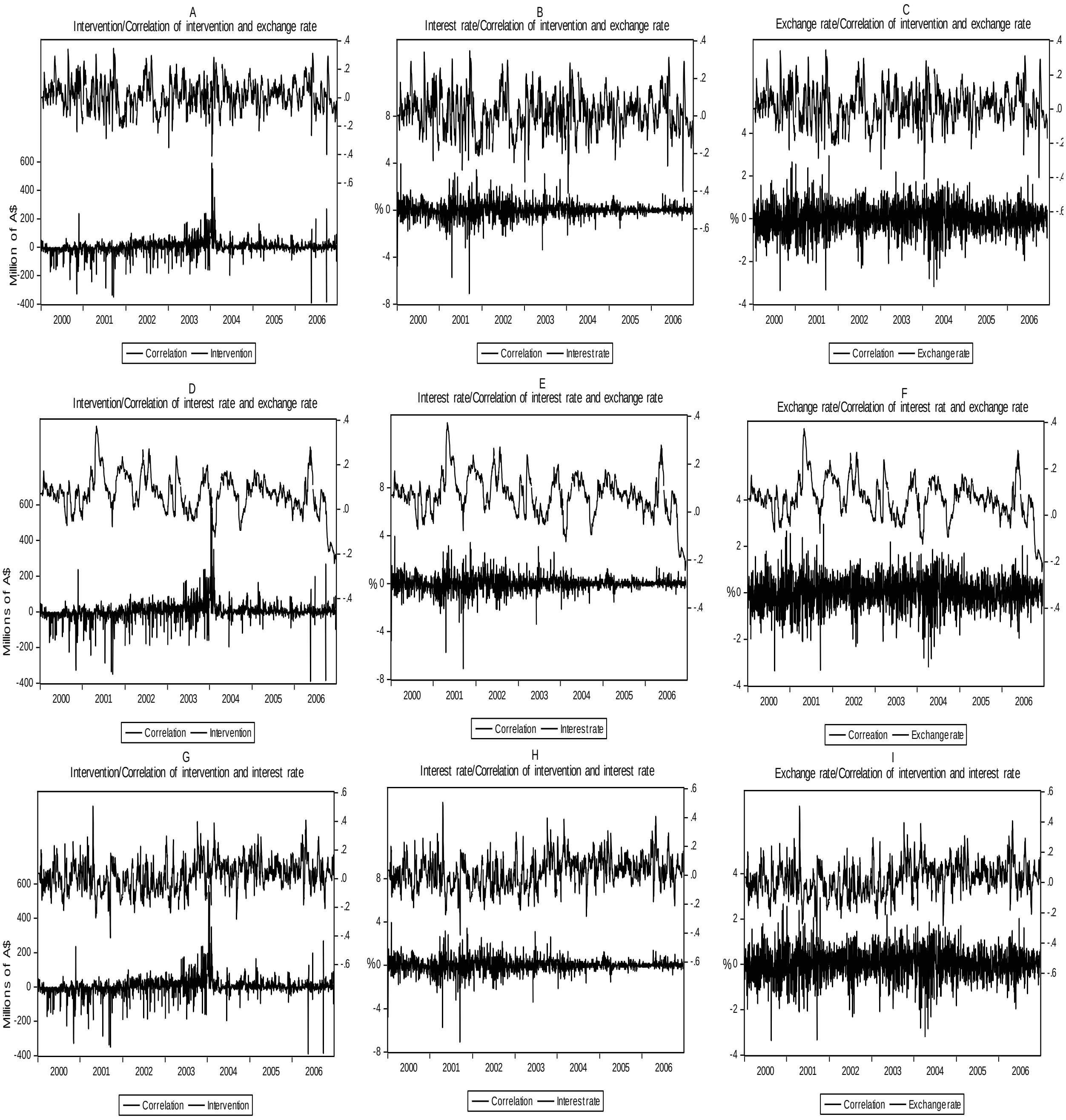
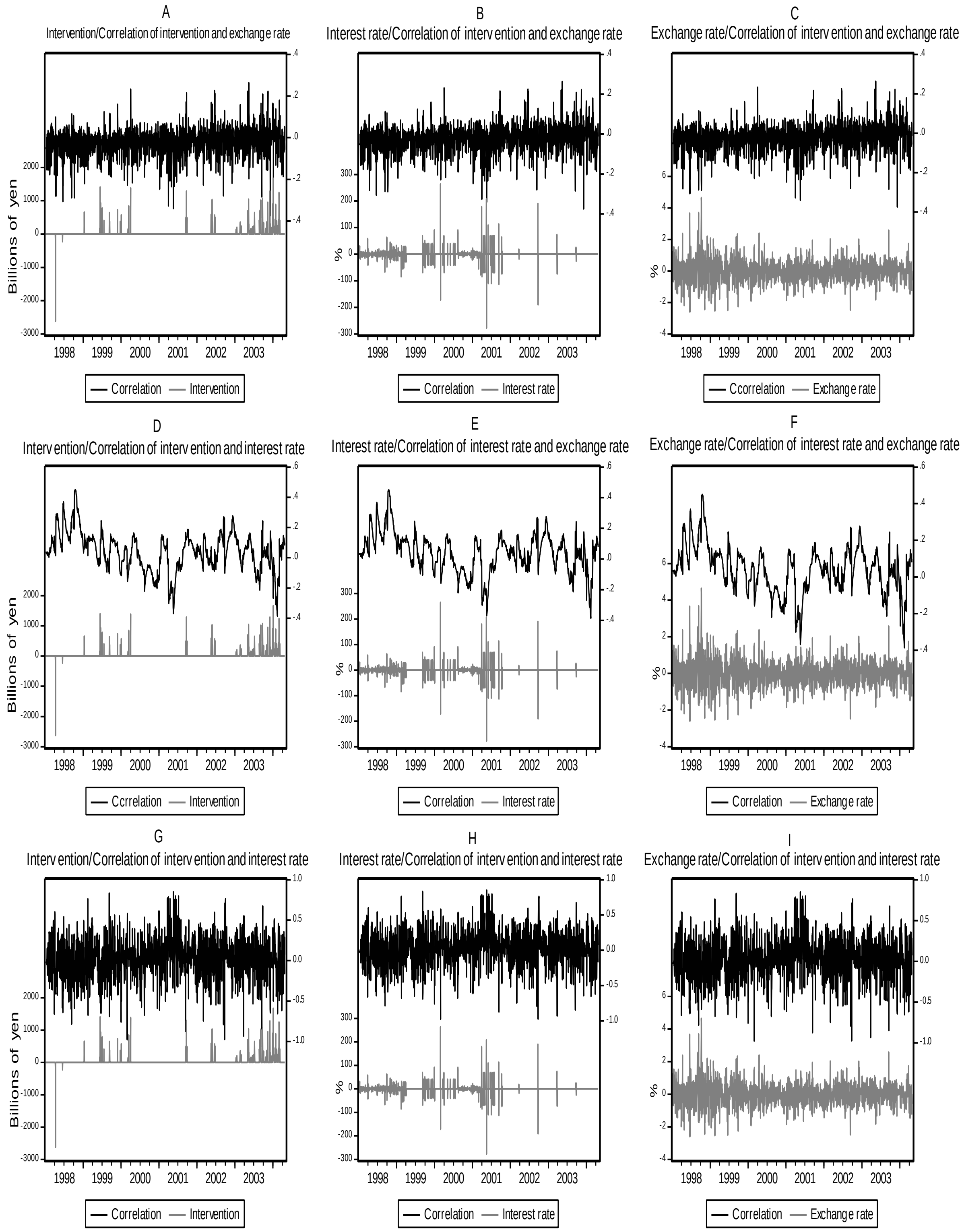


Figure 3.2: Conditional Correlations for Japan



In the case of Japan a similar pattern is observed when we look at Chart 3.2 panels A to I. The *average* correlation between these variables are low because of the low correlation between these policy instruments and exchange rates during the predominantly long periods of calm in the foreign exchange markets, suggesting the ineffectiveness of these policy instruments during these calm periods. During periods of high volatility, however, the correlations between exchange rates and policy instruments are high implying effectiveness.

The policy instruments therefore appear to be effective when they are most needed, that is, during periods of volatility and when the exchange rate may have moved too far from the level implied by fundamentals. The low and or insignificant impact of direct intervention found in many previous studies could be attributed to the fact that only in high volatility periods is changes to the policy instrument large enough and therefore the policy signal from the central bank clear enough to market participants to elicit a significant change in the exchange rate (Seerattan and Spagnolo, 2009).

It also appears that periods when the correlation of intervention and exchange rates was high coincided with periods when there were large changes in policy interest rates. For Australia, Chart 3.1 panel B bears this out while a similar pattern emerges for Japan from Chart 3.2 panel B. The correlation of interest rate changes and exchange rate returns seems also to be high when intervention activity is high in Australia (Chart 3.1 panel D) and Japan (Chart 3.2 panel D). This implies that there is some level of coordination between direct intervention and policy interest rate changes. This implication is borne out in the correlation of direct intervention and interest rate changes in panels G and H of Charts 3.1 and 3.2 for Australia and Japan respectively.

These charts show that the correlation between these two policy instruments tends to be high when the magnitude of policy interventions is high. Moreover, the correlation between these two policy instruments also tend to be high during periods when exchange rate movements are pronounced (panel I in Charts 3.1 and 3.2 for Australia and Japan), implying that unusually large exchange rate changes tend to elicit large policy changes in these two instruments which are coordinated.

The results imply that there are common factors driving direct intervention and policy interest rates initiatives. The results of the multivariate GARCH estimation in terms of the mean and variance equations, as well as the conditional correlations indicate that chief amongst these common factors is exchange rate developments. The sequence of events therefore appears to be that the central bank responds to unfavorable exchange rate developments, which normally relates to unusually large movement in the level and/or volatility of the rate. This elicits direct intervention by the central bank generally designed to “lean against the wind” which then “signals” the future interest rate policy stance.

3.5 Summary

The main conclusions of this chapter are broadly supportive of the results of previous studies looking at the issue of the effectiveness of and motivation for direct intervention in the foreign exchange markets in Australia and Japan. The results of the study also add new information on the links between exchange rate dynamics, direct intervention and interest rate policy in a joint framework that allow us to look at the results of policy both at the levels and volatility of exchange rates. The trivariate VAR-GARCH (1,1) framework also allowed us to look at the conditional correlation of important variables over time which highlighted the effectiveness of policy at key junctures in the periods under review and the fact that the policy instruments were linked because they were responding to common factors.

The results confirmed the results of many past studies that intervention is effective in Australia and Japan in the sense that it tends to move the level of exchange rate changes in the desired direction. The study also confirmed that central banks generally intervened to “lean against the wind” and the relationship of intervention to policy interest rates could generally be characterized by the “signaling” framework.

The results from the variance equations also added to our knowledge in the sense that it showed that the implementation of these policy measures was not associated with the cost of increased exchange rate volatility in the short term. Indeed, quite to the contrary it showed that these policy instruments were generally successful in reducing exchange rate volatility in both countries, although Australia appeared to have greater success with direct intervention while Japan had more success with interest rate policy changes. Additionally, in terms of the indirect cost of increased exchange rate volatility when intervention was used Japan paid no costs since the volatility spillovers were negative but Australia paid significant indirect costs in terms of greater exchange rate volatility. In the case of interest rate policy, indirect volatility spillovers from the policy instrument to exchange rate volatility was positive in both countries but Japan paid a much higher price relative to Australia. These differential impacts of policy instruments on the mean and variance of the exchange rate highlights the utility and logic of using a trivariate VAR-GARCH (1,1) framework for the simultaneous assessment of these issues.

Another noteworthy new insight from the results is that the lack of significant spillovers from exchange rate volatility to the volatility of direct intervention and interest rate changes also suggest that in both Australia and Japan the authorities was more concerned with countering undesirable trends in the exchange rate rather that dealing with excessive volatility.

Finally, the evidence from the conditional correlations suggests that the links between the policy instruments were in large part due to the fact that both were driven by common factors. In particular, both generally responded to exchange rate changes in the context of leaning against undesirable exchange rate trends. Additionally, this relationship was most clearly defined during periods of high exchange rate volatility when the policy interventions were large and the objective of policy interventions was very clear to agents in the market. The correlations also suggest a reason for previous studies results indicating intervention activities were ineffective, that is, the correlation of this policy variable with exchange rate changes were generally only high during volatile episode when there were large changes in the exchange rate. The coefficient generated by these studies were averages of the periods studied which were generally dominated by normal periods when there were small exchange rate changes and therefore would misleadingly generate coefficient that were either insignificant or wrongly signed. The time varying correlations allowed us to see clearly that the relationship between direct intervention and exchange rate was much stronger during unusual times and contrary to these previous studies this instrument was effective when it had to be.

CHAPTER 4
THE IMPACT OF CENTRAL BANK POLICY INTERVENTIONS ON THE VOLUME-ASSET PRICE DYNAMIC IN THE ICELANDIC FOREIGN EXCHANGE MARKET

4.0 Introduction

Trading volume in the foreign exchange market eclipses that in other financial markets by a considerable margin (Lyons, 1996; Jorion, 1996). The sheer size of trading volumes in these markets and the fact that trading also seems to be correlated with increases in price variability also suggests that trading volume may possess information that is central to the pricing dynamics in the foreign exchange markets (Tauchen and Pitts, 1983; Admati and Pfleiderer, 1988; Galati, 2000; Rime, Sarno and Sojli, 2010). The links between trading volumes and asset returns are usually analysed in the information flow and market microstructure frameworks (Copeland, 1976; Clarke, 1973; Tauchen and Pitt, 1983; Pfleiderer, 1984; Easley and O'Hara, 1987; Blume, Easley and O'Hara, 1994; Wang, 1994). This literature has focused on stock markets (Karpoff, 1987) but increasingly researchers have looked at this issue in foreign exchange markets (Jorion, 1996; Hartmann, 1999).

Studies on volume dynamics in foreign exchange markets have, however, suffered from the absence of comprehensive data on volume in these markets. These studies have used proxies such as foreign exchange futures (Jorion, 1996), the frequency of indicative quotes (Bollerslev and Domowitz, 1993) and brokered volume on the Tokyo market (Kim and Sheen, 2006). All of these volume measures suffer from weaknesses related to their suitability for capturing all the trades in the market. Galati (2000) is one of the few studies to examine comprehensive volume data in a number of countries and finds that unexpected volume is positively correlated to price volatility.

In this context, trading volume is likely to have a significant impact on the effectiveness of government policy instruments directed at changing the price dynamics in this market but only a few studies have focused on this issue (Chang, 2005; Kim and Sheen, 2006). Policy makers are also increasingly interested in the volatility dynamics in the market, as well as price at levels, so an empirical framework such as multivariate GARCH is needed which allows for the measurement of the impact of policy variables on both levels and variance for target variables. The suitability of this empirical methodology to analyse the links between volumes and prices in the foreign exchange market is reinforced when one considers that Hsier (1989), Baillie and Bollerslev (1989), Bollerslev (1990) and Anderson (1996) have all shown that exchange rate returns can best be modeled by a GARCH processes while Hartmann (1999) and Jorion (1996) have shown that foreign exchange volume can also be modeled as a GARCH process.

The few studies looking at the impact of policy on volume and prices in the foreign exchange market have correctly used the GARCH methodology but they have invariably focused on developed markets, have used trading volume information that did not capture the total volume generated in these markets and did not extend the empirical methodology to capture the full endogeneity between policy measures and volume and prices in the foreign exchange market (Chang, 2005; Kim and Sheen, 2006).

This study seeks to help fill the gap in the literature on the dynamic between volume and returns in the foreign exchange market in the context of central bank policy initiatives by building on and extending the work of Kim and Sheen (2006). It extends the work by looking at these issues in a developing market with a volume measure that captures virtually all the transactions in the spot foreign exchange market. It also extends the work by including both direct intervention and policy interest rates in a multivariate GARCH framework thereby capturing the major variable driving returns and volumes in the foreign exchange market and therefore the true endogeneity of the relationship between these variables. This therefore represents an improvement on the empirical specification used in Kim and Sheen (2006) to investigate these issues. It examines the links at levels and variance between volumes and returns in a developing market, the Icelandic foreign exchange market, and the effect that central bank policy such as direct intervention and interest rate policy has on this relationship in a four variable VAR GARCH (1,1) framework.

Very importantly, it also investigates the impact of policy on the level and volatility of trading volume. This is important since even in the absence of significant changes in exchange rate returns, unsettled market conditions in the form of huge swings in volume can be as damaging as price volatility. These episodes of volatility in trading volumes are often accompanied by volatile exchange rate returns and large changes in domestic interest rates, making economic management extremely difficult for policy makers.

The Icelandic foreign exchange market is chosen to investigate these issues because it suffered two episodes of crisis in its foreign exchange market recently in 2006 and 2008. Moreover, although the Icelandic foreign exchange market is small by international standards, experience has shown that volatility in this market has been transmitted to a number of emerging markets in 2006 because of the carry trade phenomenon. Additionally, the 2008 episode exposed the inherent vulnerability of small foreign exchange markets such as the Icelandic market driven by the risky portfolio strategy of their commercial banks which took on huge open positions in foreign currency liabilities to finance asset acquisition in domestic and foreign currency, way in excess of the Country's capacity to carry such liabilities or to bail out failed banks. In this context, as well as the context of the international financial and economic crisis in 2008, the problems in this market were transmitted to many developed markets. Indeed, a range of institutional investors were affected in developed market economies when Icelandic banks could not honor their foreign currency liabilities.

In both these episode of currency crisis in Iceland there were huge swings in trading volume. The links between volume and returns and the impact central bank policy interventions have had on this relationship and the market generally is therefore of increased importance given that the international financial crisis that began in 2007 has meant that this dynamic is likely to be played out in many countries. The recent global financial crisis in many cases was propagated through foreign exchange markets and direct intervention in the foreign markets was a tool used by many central banks in their efforts to control contagion from the financial crisis affecting their foreign exchange markets. Additionally, trading volume and market liquidity often dried up or became extremely volatile during the crisis exacerbating the economic problems being experienced. In this context, the importance of the relationship between trading volume and returns in the foreign exchange market, as well as how this relationship was affected by central bank intervention in this market has assumed great importance to policymakers. The release of data on the foreign exchange market by the central bank of Iceland has also made this analysis possible.

This study therefore investigates the link between trading volume and returns in the foreign exchange market at level and variance, as well as the effect that central bank policies (both in terms of interest rate policy and direct interventions) have on this relationship. This would allow policy makers to draw inferences about traditional challenges such as the effectiveness of central bank intervention in moving exchange rates in the desired direction and the ability to control exchange rate volatility. Very importantly, it will also investigate the impact of policy on the level and volatility of trading volume. This is important since even in the absence of significant changes in exchange rate returns, unsettled market conditions in the form of huge swings in volume can be as damaging as price volatility, especially in smaller markets where low market liquidity poses serious challenges to agents in the market. Also, large fluctuations in volume often signals that there is currently major differences of opinions amongst agents in the market about trends in prices which is also cause for concern because it could generate considerable price volatility in the future. Volatile volume can therefore serve as an important early warning of price volatility. It is therefore reasonable to expect central banks to be concerned about the behavior of trading volume in the foreign exchange market and to try and meliorate undesirable volume dynamics from developing in the foreign exchange market. In this context, trading volume is not only a target for policy but an explanatory variable in the policy reaction function of central banks, since developments with respect to volume can drive the policy response of central banks.

This study contributes to the literature on the link between volume and price dynamics in the foreign exchange market by examining these issues in a joint empirical framework, a four-variable VAR-GARCH (1,1), which allows us to capture the inherent endogenous relationships in the foreign exchange market between policy measures, price and volume. We can look at the impact of policy on the level and variance of target variables, we can look at the way in which market conditions drives the policy responses of the central bank and we can look at the interaction of different policy instrument to discern the interconnectedness of policy instruments.

This study is closest in orientation to the study by Kim and Sheen (2006). The structure of the chapter is as follows: Section 2 reviews the literature on the links between trading volumes and returns in the foreign exchange market and the impact central bank interventions have had on this relationship. Section 3 presents stylized facts on the Icelandic foreign exchange market and details of policy interventions by the Central Bank of Iceland. Section 4 outlines the empirical methodology and discusses the empirical results and, Section 5 concludes.

4.1 Literature Review: The Links Between Volume, Price Dynamics and Central Bank Policy Interventions in the Foreign Exchange Market

The relationship between volume and asset returns in financial markets has generally been couched in the information dynamics framework amongst agents in the market, as well as in the market microstructure framework. It should be noted that these are not mutually exclusive frameworks since information asymmetry plays an important role in both systems. The information flow framework is essentially driven by the sequential information arrival models and the mixture of distributions (MDH) models. The sequential information arrival models (Copeland 1976) starts off with agents in equilibrium, that is they are satisfied with their portfolio holdings, new information is then received by individual agents one at a time who then revise their beliefs and trades to arrive at a new temporary equilibrium. These actions lead to increased volumes and transaction price changes. This process continues until all agents have received the information and a new final equilibrium is reached. The fundamental insight of these models is that volume can forecast prices.

In contrast the MDH (Clarke, 1973; Tauchen and Pitt 1983) posits an underlying information flow that leads to the joint dependence of volumes and prices. They assume a random arrival of new information where information arrivals cause increased trading volume and price changes. Anderson (1996) modifies this basic model by including liquidity traders who do not trade in response to information arrivals and by assuming that information arrivals are serially correlated. The latter property leads to volatility persistence and therefore GARCH type models may be best at capturing the time series properties of the relationship between volume and prices in the MDH framework.

In terms of the market microstructure framework, private information is central to the analysis of the price-volume relationship. This relationship is, however, clouded by the fact that it is unclear what exact information volume provides to the market. The informational role of volume in the price process has been investigated by Pfleiderer (1984), Easley and O'Hara (1987), Blume, Easley and O'Hara (1994) and Wang (1994). These studies can be separated into two categories, one which used the rational expectations framework to look at how volume is generated in an environment where agents with different information trade and another which looks at the information inherent in volume and the learning that occurs from observing volume. The first set of studies (Wang, 1994) provides links between volume and agents characteristics which allows one to make a connection between price changes and volume. In particular, volume is positively correlated with the absolute value of excess returns and the greater the asymmetry between agents information sets the greater the trading volume.

The second approach (Blume, Easley and O'Hara, 1994) looks at the learning that occurs when agents can condition their behavior on information contained in volume as well as price information in forming demand. The role of volume in the price adjustment process is to help agents to clear up the uncertainty of the quality of information from the direction of information which is derived from observing prices. The signal from volume is different from prices because volume, unlike prices, is not normally distributed. Agents therefore get better information by observing both volumes and prices. In this learning by trading approach volume and price changes are positively correlated.

A review of the relationship between trading volumes and asset price dynamics by Karpoff (1987) also indicated that the vast majority of studies up to that period were devoted to examining this issue in the context of stock exchanges. This has since changed with a number of studies looking at these issues in the context of the foreign exchange markets (Bollerslev and and Domowitz, 1993; Jorion, 1996; Kim and Sheen, 2006; Galati, 2000; Melvin and Yin, 2000; Park, 2010). This trend has been caused by a number of factors. Some of the main reasons include the fact that foreign exchange markets are the largest in terms of daily turnover, the fact that exchange rate dynamics have such profound effects on economic conditions generally and on financial asset prices in particular and because more comprehensive information on the operations of foreign exchange markets are increasingly readily available.

Many studies have looked at the impact of direct central bank intervention in the foreign exchange market in terms of its impact on price dynamics (Beine, 2004; Kim and Rigobon, 2005; Kim and sheen, 2006). The direct intervention policy reaction function of the central bank have also been looked at by a number of authors (Almekinders and Eijffinger, 1996; Ito, 2002; Ito and Yabu; 2007) and some studies have looked at the substitutability and relationship between direct intervention and monetary policy, particularly interest rate policy (kaminsky and Lewis, 1996; Bosner-Neal, Roley and Sellon, 1998, Sellon, 2003; Vitale, 2003; Egert and Komarek, 2006). Moreover, many studies have looked at the impact of interest rate policy on exchange rate dynamics (Eichenbaum and Evens, 1995; Faust and Rogers, 2003; Chen 2006) and some have looked at the effect of central bank interventions on volume (Jorion, 1996; Chaboud and Lebron, 2001).

We do not know of any study, however, that have looked at the impact of central bank policy (both direct intervention and interest rate policy) on trading volume and exchange rate returns at both the level and variance in the foreign exchange market. The only study to our knowledge that have come closest to pulling these related strands of literature together in an integrated framework for the spot foreign exchange market is the Kim and Sheen (2006) study[41]. Kim and Sheen looked at the impact of central bank policy in the spot foreign exchange market in a multivariate GARCH framework that captured the many inherent links between volume, prices and policy variables in the foreign exchange market. However, Kim and Sheen (2006) by using a bivariate GARCH formulation with volume and returns together with a separate probit model for the policy reaction function of the central bank for direct intervention, was unable to capture the full dynamics of the linkages and endogeneity between volume, returns and direct intervention at levels and variances.

This is a significant weakness not only because one cannot trace the complete set of linkages and feedback effects but also because the estimated parameters would tend to be less efficient than if a more complete four-variable GARCH model was used to capture the relationship between volumes, returns, direct intervention and interest rates. Another weakness of the study by Kim and Sheen (2006) was that they only included policy interest rates as an exogenous variable in the separate policy reaction

[41] Chang (2005) have looked at the impact of central bank interventions on the relationship between volume and price volatility but only in the yen/US dollar *futures* market.

function of the central bank. Modeling the effect of policy interest rates this way did not capture the inherent linkages and endogeneity between direct intervention and policy interest rates and indeed between policy interest rates, exchange rate returns and foreign exchange volumes (Chen, 2005).

The failure to look at the role volume plays in central bank policy effectiveness in the foreign exchange market in a fully integrated empirical framework is a huge lucuna in the literature since volume dynamics is central to the functioning of the market in terms of price dynamics and confidence. We address this issue in the Icelandic foreign exchange market in the following sections.

4.2 The Structure of the Icelandic Foreign Exchange Market and Central Bank Policy Interventions[42]

The current Icelandic foreign exchange market structure can trace its beginnings to May 28, 1993 when interbank trading in foreign currency began. Prior to this the exchange rate was set by the Central Bank. The main problem in the initial interbank market was that the market was only open for a short period during fixing meetings when market participants traded with each other and the exchange rate for that day was set. As the market developed and as volume increased, the short period for trading became a major constraint and on July 1, 1997 the fixing meetings were discontinued and an active interbank market in foreign currency came into being which operated during the banks' opening hours. This study covers the period after the beginning of this full time interbank foreign exchange market and covers the period January 7, 1999 to August 30, 2010.

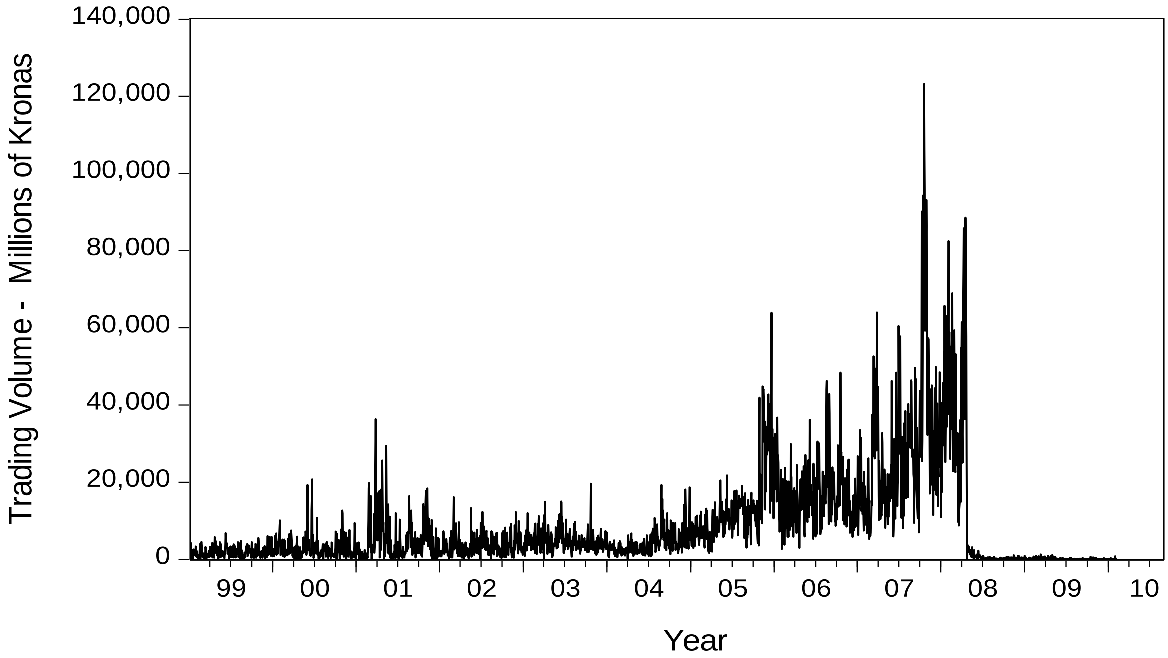
4.2.1 Volume and Exchange Rate Dynamics in the Icelandic Foreign Exchange Market

The development and evolution of the Icelandic foreign exchange market is reflected in the changing volume dynamics in the market (See Figure 4.1). As the market developed, market liquidity deepened and total traded volume increased consistently until the crash of the market in October 2008 when trading volume/liquidity declined drastically as agents' risk aversion increased sharply. Trading volume has

[42] This section is based largely on Isberg and Petursson 2003, Central Bank of Iceland, 2001 and various issues of the Central Bank of Iceland Monetary Bulletin.

remained relatively muted since then. The evolution of the market can also be evaluated in the context of the Central Banks' share of trading volume.

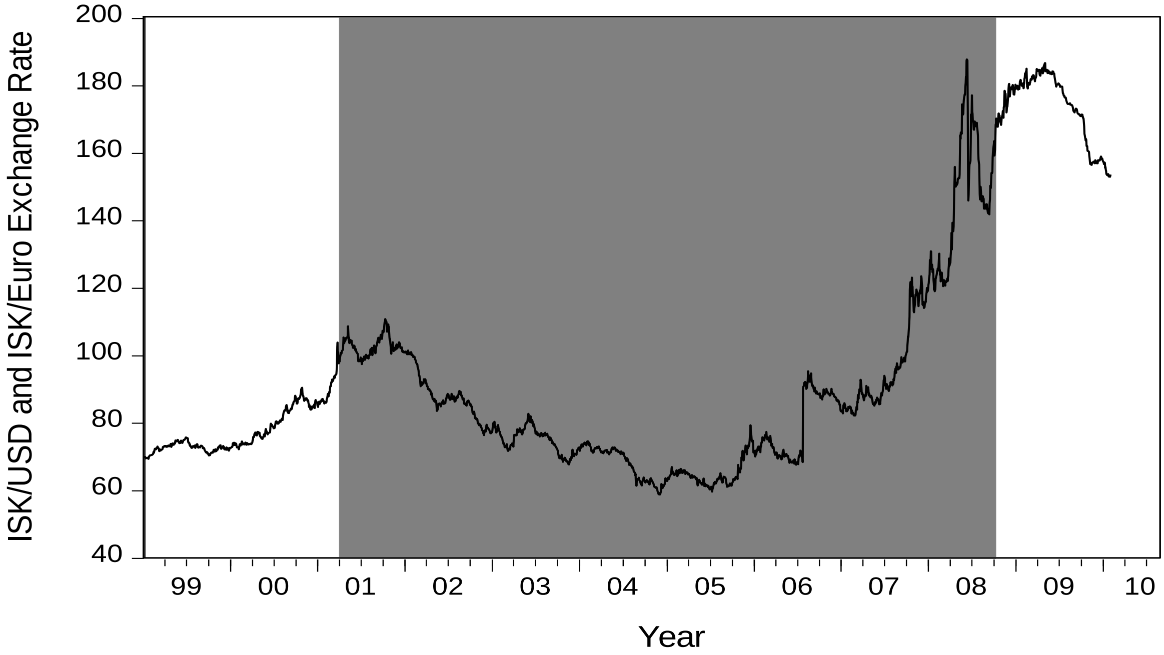
Figure 4.1: Trading Volume in the Spot Foreign Exchange Market



This declined from a high of 89.2% in 1995 at the early stages of market development to 2.2% in 2001 as the market deepened considerably. However, after the market turmoil in 2008, central bank volume rose to 66.4% of total volume as the bank again became the dominant player in the market as it sort to restore confidence and liquidity.

The evolution of the market was also reflected in exchange rate dynamics over the period under review. In the period January 7, 1999 to March 26, 2001, a full time interbank foreign exchange market operated under a crawling peg exchange rate regime and the market was characterised by the depreciation of the Krona. This trend continued after the adoption of an inflation targeting regime (see shaded area in Figure 4.2) and the floating of the Krona until the end of November 2001. From December 2001 the Krona entered a long period of gradual and consistent appreciation which came to an end in March 2006 when the credit rating of Iceland was downgraded. The exchange rate recovered somewhat towards the end of 2006 but by the summer of 2007 and the onset of the international financial crisis the depreciating trend accelerated again. There was some improvement in the rate beginning in January 2009 but by the end of March 2009 the rate started depreciating again until January 2010 when the rate started appreciating gradually (See Figure 4.2).

Figure 4.2: Exchange Rate Trends



4.2.2 Central Bank Policy Interventions and Trends in the Foreign Exchange Market

In the period 1993 to 2000, Central Bank policy was designed to allow the exchange rate to float with a band which was originally 2.25% which was later widened to 6% on September 6, 1995 and further to 9% on February 14, 2000. Subsequently on March 27, 2001, inflation targeting was adopted and the exchange rate was allowed to float without any specific constraints in terms of deviation bands. This led to a sharp increase in trading volume and greater volatility in the exchange rate. With the onset of the financial crisis, price volatility increased significantly and trading volume declined sharply in the last quarter of 2008. In this environment, the Central Bank had to intervene and provide liquidity to the market resulting in its share of market volume increased to levels not seen since the early 1990s. This episode of volatility was different to the crisis which occurred in 2006 since trading volume[43] and liquidity was not adversely affected then and price volatility was relatively short-lived. In the most recent episode, trading volume declined precipitously in late 2008 which amplified price volatility. Volume dynamics therefore made a difference to the severity and length of the most recent crisis.

[43] Trading had been executed in US dollars but this changed to Euros on December 1, 2006.

The factors affecting trading include expectations about exchange rate developments, market makers foreign currency balances (i.e whether they have short or long positions on their trading books), foreign exchange margin requirements, new economic information such as news of changes in economic policy and, central bank intervention. Interbank trading in foreign currency affects all traders' foreign currency holdings but changes in the exchange rate generated by this trading activity also affects the value of these holding and can result in further trading to get to their desired position. Trading volume and exchange rates therefore tend to exhibit bi-directional causality, reinforcing the importance of trading and trading volume to the functioning of the market. Based on transactions in the market, the exchange rate is fixed by the central bank between 10.45 and 11.00 am on each trading day. This feature of the market means that the daily trading volumes and price changes over the entire trading day is not synchronized which could cause problems if one was interested in analyzing the relationship between volumes and prices over the trading day.

The Icelandic foreign exchange market is still relatively illiquid and there are a few agents in the market. In these conditions a major player or trade can exert a disproportionate response in the market both in terms of price and volume. In particular, it is easy in such markets for a negative spiral to form where the market is short (that is, where most agents in the market foreign currency liabilities exceed their foreign currency assets), inflows of foreign currencies are weak and agents expect the domestic currency to weaken. In this environment, the purchase of foreign currency makes the market shorter and sets of a spate of buying as all agents try to close their positions and market makers raise their quotes sharply to reflect scarcity. This surge in turnover and increased price volatility is a more frequent event in these markets relative to more liquid markets where the large numbers of agents and huge volumes minimizes these episodic disturbances in the market. The ways in which these negative spirals can be stopped is by increased inflows into the market, usually easier if domestic interest rates are increasing relative to foreign rates. Central bank intervention can also reverse this trend and, of course, if market fundamentals change, then market makers would be willing to take a countervailing position by selling foreign exchange expecting the rate to recover and make profits.

In terms of the interaction of policy instruments such as direct intervention and interest rates in the foreign exchange market, the transition to an inflation targeting regime in March 2001 meant that the objectives for direct intervention had changed. With the new monetary framework the exchange rate was no longer an intermediate target for monetary policy since a formal inflation target was adopted as a nominal anchor for monetary policy. Intervention would not be used to target a particular rate but it was kept in reserve if exchange rate trends posed a threat to the inflation target or if exchange rate volatility threatened financial stability. In effect, however, the need to lean against exchange rate trends meant that intervention was used to target exchange rate trends and as such the central bank had to coordinate the timing of policy implementation to avoid policy conflicts that frustrated the achievement of the inflation target. In this context, intervention and policy interest rates were still inextricably linked. Once intervention operations were in tune with inflation expectations, intervention and monetary policy would have target consistency which would help bolster the credibility of the inflation target and increase the effectiveness of both policy instruments.

Over the period 2001 to 2010, there have been periods where direct intervention and policy interest rate appeared to be coordinated in the foreign exchange market, depending on conditions in the market such as exchange rate and trading volume dynamics, as well as general economic conditions such as economic growth and inflation. This period has also been witness to episodes when these policy instruments did not appear to be coordinated which usually coincided with periods when there was no target consistency and direct intervention was deployed to objectives that moved the country away from inflation targets. These policy instruments deployed in the foreign exchange market are coordinated if a tightening of monetary policy in the form of rising interest rates are accompanied by intervention sales of foreign currency (purchase of domestic currency instruments), which has a similar effect since it takes domestic liquidity out of the system. Conversely, purchases of foreign currency should be accompanied by falling interest rates.

The year 2001 was characterized by intervention sales of foreign currency to counter increased exchange rate volatility and a depreciating trend in the context of huge swings in trading volume in the wake of the move to an inflation targeting regime. Interest rates were also maintained at high levels and increased towards the end of the year in an attempt to bolster the exchange rate. This was followed by a period from January to August, 2002 when the exchange rate had stabilized and was on an appreciating trend and volume was stable. In this environment there was no direct Central Bank intervention in the market and the policy rate was lowered in line with inflation expectations. The period covering September 2002 to April 2004 was characterized by exchange rate stability and increasing volume as the market developed. The Central Bank generally purchased foreign exchange during this period to bolster reserves and policy rates were lowered as inflationary pressures were subdued.

From May 2004 to March 2006, the exchange rate was either stable or on an appreciating trend with increasing trading volumes and liquidity. In these market conditions the Central Bank continued its purchases of foreign exchange, however, due to rising inflationary pressures from an overheating economy policy interest rates were raised. The period April 2006 to March 2008 was characterized by increased exchange rate volatility and a depreciating trend[44] but the Central Bank continued its purchases of foreign exchange which seem to be predicated on the fact that market volumes were still very strong[45]. Interest rates were raised in this period not only to counter inflationary pressures but also to bolster the exchange rate.

For the period April 2008 to September 2008, the market was characterized by high exchange rate volatility and exchange rate depreciation driven by the unfolding international financial crisis and the unwinding of domestic imbalances. In spite of these problems, trading volume in the market remained relatively high on average but there was a noticeable increase in the volatility of volumes. In this environment, the Central Bank did not intervene directly in the market but kept policy interest rates high to bolster the exchange rate and counter inflationary pressures.

With the collapse of Lehman Brothers the international financial crisis worsened considerably. The following period from October 2008 to March 2009 was therefore characterized by the intensification of exchange rate volatility, the depreciation of the currency and the drying up of liquidity in the foreign exchange market. The collapse of

[44] In March 2006 a number of reports critical of the Icelandic banking system was published and the credit rating of Iceland was downgraded which resulted in a rapid depreciation of the Krona until July 2006. The exchange rate had recovered somewhat by mid 2007 but with the onset of the international financial crisis in the summer of 2007, the depreciation trend started again and the currency only started to recoup some of its value in December 2009.

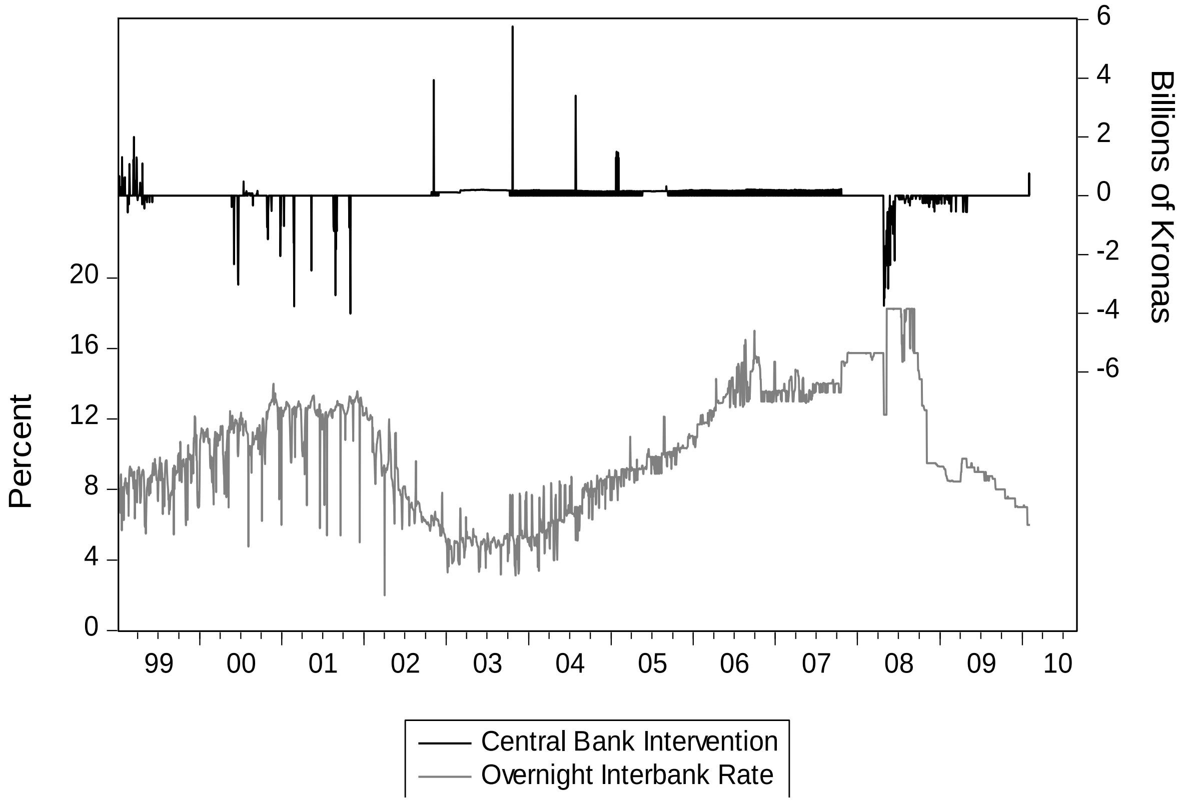
[45] This seems to be borne out by the fact that it only started intervention sales of foreign currency to bolster the exchange rate when foreign exchange volume dropped precipitously in October 2008. This gives credence to the view that trading volume trends were important as a target for policy and must be included in the Central Bank policy reaction function.

the banking system at the beginning of October 2008 resulted in the closure of the inter-bank foreign exchange market for the period October 4-14, 2008. When the market reopened on October 15, 2008 the Central Bank issued guideline that effectively restricted the trading of foreign exchange. The Central Bank subsequently issued capital controls to manage the crisis in the foreign exchange market. The Central Bank also responded with intervention sales of foreign currency to control volatility, counter depreciation and to increase trading volume and liquidity. This was accompanied by increases in Central Bank policy interest rates to back up its intervention operations.

During the period April to November 2009 these market conditions persisted but the Central Bank started to cut its policy interest rates in April 2009 as inflationary pressures eased. The period running from December 2009 to December 2010 was characterized by low trading volume with the exchange rate regaining some of its lost value and exchange rate volatility down. Policy interest rates also declined over this period as inflationary pressures eased. There was no Central Bank direct intervention operations in the market between December 2009 and July 2010 but intervention purchases began again in August 2010, ostensibly to start building up reserves again. The period from October 15, 2008 is therefore an entirely different regime characterized by restrictions on trading in the foreign exchange market.

The Central Bank interest rate policy and direct intervention strategy in the foreign exchange market was therefore mostly consistent. Nevertheless, between May 2004 and March 2008 the stance of these two policy instruments was somewhat contradictory with intervention purchases of foreign exchange (expansionary) used together with increased policy interest rate (contractionary) since direct intervention objectives in the foreign exchange markets was not consistent with policy interest rates' target for inflation. A similar situation occurred in the period April to November 2009 for the same reasons but on that occasion intervention sales were deployed together with cuts in the policy interest rate. Outside of these periods, however, there was target consistency between the two policy instruments (See Figure 4.3).

Figure 4.3: Central Bank Intervention and Policy Interest Rates



The experience also suggests that the Central Bank made policy decisions based on the volume dynamics in the market. In particular, if trading volume was buoyant and relatively stable they would tend to be unwilling to intervene even if there was an increase in price volatility. If volume volatility did not accompany price volatility the Central Bank would be more inclined to believe that it was a non-fundamental temporary factors driving development and therefore there was no need to intervene.

Very importantly, there appears to be three clear regimes that are included in the period under study. The first period running from 1999 to 2001 is essentially a crawling peg type arrangement where the Central Bank attempted to keep the exchange rate within some predetermined band. The period from 2001 to 2008 represented a period of floating exchange rates where the Central Bank used inflation targeting as its policy regime. A noteworthy fact though is that over this period there are two distinct exchange rate regimes, the first part of this period (March 29, 2001 to January 6, 2006) saw a regime where the exchange rate was appreciating while the latter part of the period (January 9, 2006 to October 3, 2008) the exchange rate was generally depreciating. The last period running from 2008 to 2010 represents a period where the

Central Bank had to take extraordinary policy measure - the imposition of capital controls to deal with the crisis in the foreign exchange market. In this context, the relationship between policy initiatives and price and volume dynamics in the foreign exchange market is therefore likely to change across policy regimes and this is one aspect that is investigated in the empirical analysis.

4.3 Data, Empirical Methodology and Estimation Results

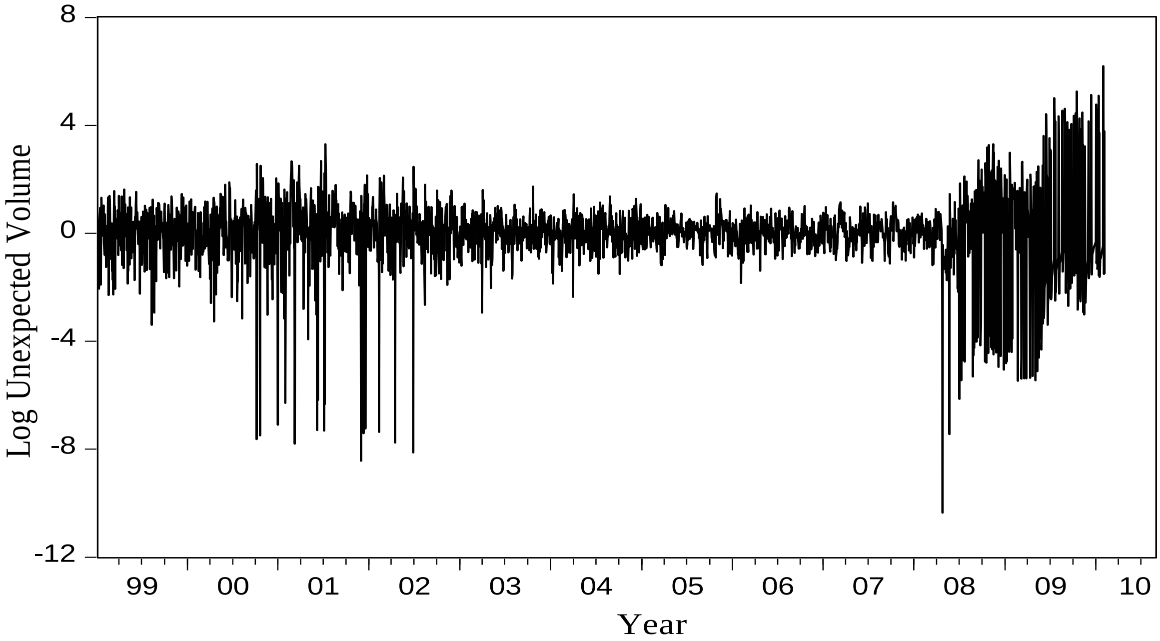
4.3.1 Data

We utilize daily data on trading volume in the Icelandic foreign exchange market, exchange rate returns, central bank intervention in the market and policy interest rates. 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 basis. Additionally, the paper utilizes the most recently released data on intervention in the foreign exchange market by the Central Bank of Iceland covering the period from January 7, 1999 to August 30, 2010. During this period the exchange rate system evolved from a crewing peg system to a floating exchange rate regime and finally to the period after the financial crisis in 2008 which was characterized by the imposition of capital controls and heavy central bank selling of foreign exchange to provide liquidity to the market. The data set covered by this study includes 2892 data points after holidays and other non-trading periods were eliminated. Moreover, since as outlined above the full sample includes three distinct exchange rate regimes, the sample is split into three sub-samples with the first spanning the period January 7, 1999 to March 26, 2001, the second from March 27, 2001 to October 3, 2008 and the final period running from October 15, 2008 to August 30, 2010. This is done to determine whether the relationships between the variables included in the model changes over time as market and policy regimes change.

Trading volume is taken as the total daily value of all spot trade on the Icelandic interbank foreign exchange market measured in millions of Kronas sourced from the Central Bank of Iceland. This is an improvement on previous studies (Kim and Sheen, 2006; Hartmann, 1999) which all used measure of trading volume which did not capture the full extent of trading volume in the market. The vast majority of foreign exchange spot trades took place in US dollars before December 1, 2006 but changed to Euros after that date. In the context of the mixture of distribution hypothesis, unexpected trading volume is the component of volume expected to impact significantly on future price dynamics since market agents have already factored in expected volume and this information is already embedded in current prices. Similarly, only unexpected volume is expected to impact on central banks' intervention decisions because again unexpected volumes represents in the MDH context, the arrival of new information and the presence of informed traders in the market which the central bank will have to respond to if it is to affect market dynamics. The general practice in the literature is to generate unexpected volumes using ARIMA modeling (Hartmann, 1999; Jorion, 1996; Bjonnes et. al., 2005) and we follow this approach in this study. The stationarity properties of the volume series was examined and then using standard Box Jenkins tests it was found that an ARIMA (3,1,1) specification performed best. The residual from this model was then used as the unexpected volume measure in the estimation of the empirical model (See Figure 4.4 below).

Intervention is defined as daily sales (negative) and purchases (positive) of foreign currency by the Central Bank of Iceland in millions of Kronas. Exchange rate returns are used in the estimated models as is standard practice in the literature and is defined as $ER_t = 100 * \log(er_t / er_{t-1})$ where er_t denotes the number of units of the local currency per unit of foreign currency. The exchange rate data available from the Central Bank of Iceland is flawed since the average rate is measured at 11am based on bid/ask prices up to that time. This is problematic since trading activity takes place the whole day while the market is open and not only up to 11am, leading to a situation where the average exchange rate does not adequately reflect trading volume dynamics for the entire day. To circumvent this problem we used the opening Reuters exchange rate instead.

Figure 4.4: Unexpected Trading Volume



To reflect that fact that most trades changed from US dollar to Euros on December 1, 2006, the exchange rate series used is the Reuters opening US/Krona dollar exchange rate up to this date and the opening Reuters Euro/Krona exchange rate thereafter. To avoid a similar large jump in exchange rate returns on this date we follow Bjonnes et. al. (2005) and adjust the exchange rate on December 1, 2006 by the USD/Euro rate on that day. The exchange rate return series used in the multivariate GARCH estimation is detailed below in Figure 4.5.

Policy interest rate changes are as used as proxies for monetary policy initiatives instead of monetary aggregates in this study[46]. Policy interest rate changes are defined as $RR_t = log(rr_t / rr_{t-1})$ where rr_t denotes the annualized policy interest rate. The annualized rate used is the Overnight Interbank Rate. The primary policy interest rate in Iceland is the Collateral loan Rate but the Overnight Interbank Rate is used since it is available for the entire period and it is highly correlated with the Collateral loan Rate. The policy interest rate changes series is shown below in Figure 4.6.

[46] This is increasingly the practice in empirical studies since monetary aggregates contain elements which are positively correlated with interest rates. This would be an inappropriate proxy 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).

Figure 4.5: Exchange Rate Returns

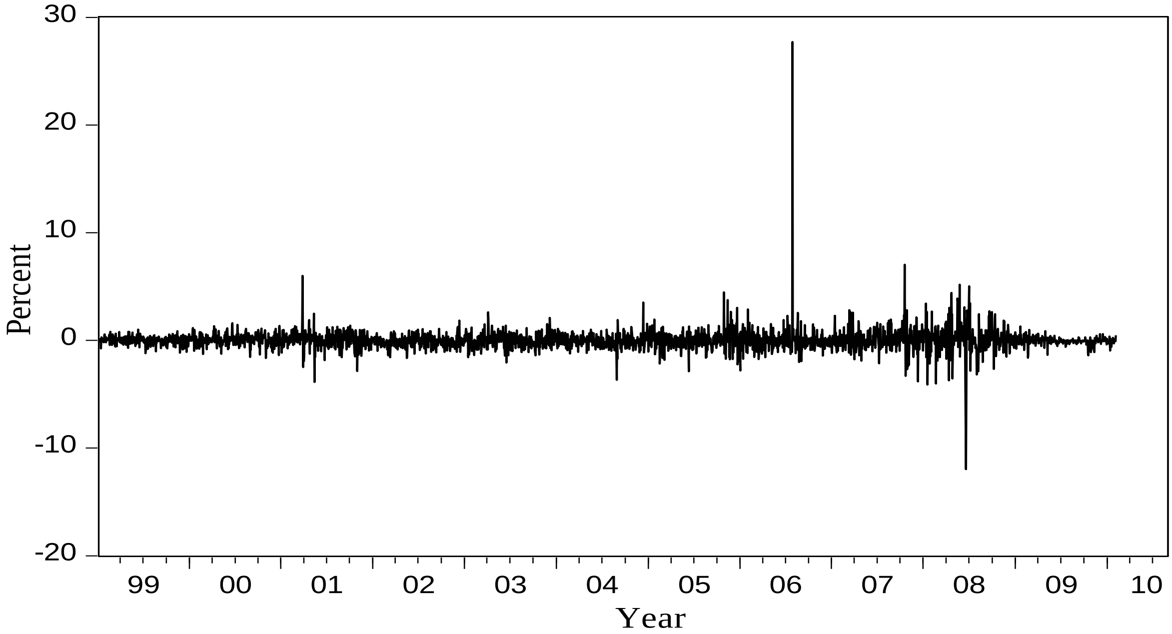


Figure 4.6: Policy interest Rate Changes

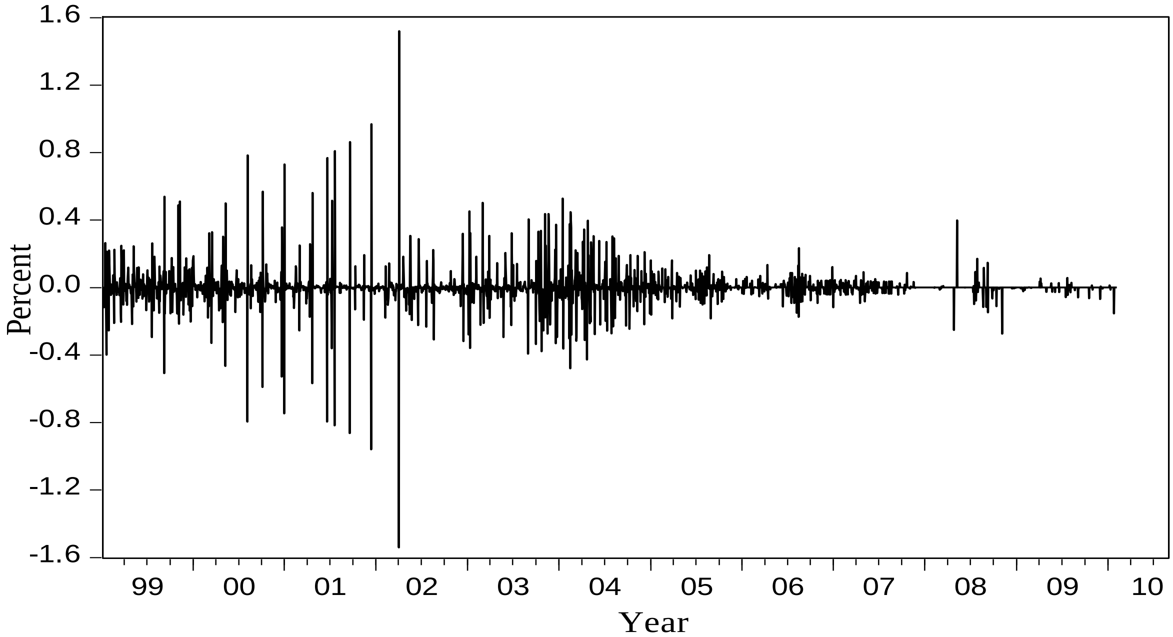


Table 4.1 presents some summary statistics on exchange rate changes, intervention and interest rate changes for Iceland. These series exhibit many of the usual properties of financial time series. They are generally non-normal, leptokurtic and serially correlated.

Table 4.1: Descriptive Statistics

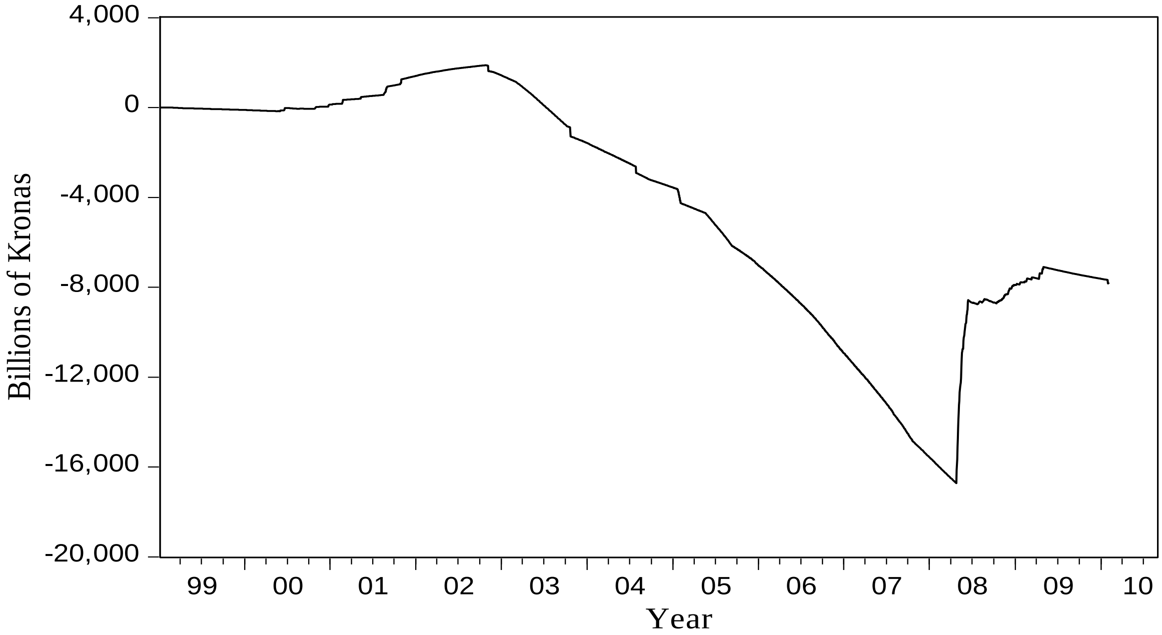
Statistic	Exchange Rate Returns	Intervention	Interest Rate Changes	Unexpected Volume
Mean	0.0273	12.8133	-0.0001	-0.0011
Median	0.0000	0.0000	0.0000	0.0983
Maximum	27.7178	5756.1000	1.5195	6.2031
Minimum	-11.9732	-4017.0900	-1.5412	-10.3515
Std. Dev.	0.9880	337.3516	0.1023	1.2932
Skewness	7.1495	-2.4685	0.2015	-1.5478
Kurtosis	227.6414	88.5092	59.9600	12.7823
Jarque-Bera	6099189.0000	883094.9000	390568.7000	12672.4900
Probability	0.0000	0.0000	0.0000	0.0000
Observations	2889.0000	2889.0000	2889.0000	2889.0000

Some of the other data elements used in the study include central banks profits, foreign interest rates and the variance of exchange rate returns. The variance of exchange rate returns is the series generated from the GARCH estimation below while the daily Federal Funds Rate was used as the representative foreign interest rate. In terms of central bank profits, it is virtually impossible to get information on central bank profitability, particularly at a high frequency. To compute a daily series on central bank profitability we exploit the information on actual daily central bank intervention as done in previous studies (Leahy, 1995; Neely, 1998; Kim and Sheen, 2002; Kim and Sheen, 2006). Profits from central bank intervention is made up of essentially two components, profit and losses from trading and net interest income from reserves obtained through trading (Edison, 1993). Profits from trading is determined by the difference between the value of intervention measured as the exchange rate at the end of the period and the exchange rate on the date the intervention was effected while net interest income is determined by additional interest earned from holding the intervention currency rather than domestic currency, that is the interest differential between the two currencies. Thus cumulative central bank intervention profits for Iceland can be measured by the following equation:

$$CP_t = \sum_{i=1}^{m} I_{t-1} \left[\prod_{j=1}^{i} (1 + i_{t-j}^{US}) ER_t / ER_{t-1} - \prod_{j=1}^{i} (1 + i_{t-j}^{ICE}) \right] \quad (1)$$

where CP is cumulative profits measured from m periods in the past, I is daily intervention, ER is the spot exchange rate, i^{US} is the foreign interest rate and i^{ICE} is the domestic interest rate[47]. The evolution of cumulative profits from central bank interventions is detailed in Figure 4.7 below.

Figure 4.7: Central Bank Cumulative Profits from Intervention



4.3.2 Empirical Methodology Multivariate VAR-GARCH

The empirical methodologies which have been used in previous studies to capture the relationship between central bank policy initiatives and dynamics in the foreign exchange market 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.

The VAR methodology used in Lewis (1995) and Kim (2003) is suitable for studying the interaction of variables that are endogenous. 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 by

[47] See Kim and Sheen (2002) for a detailed discussion on the pros and cons of this profitability measure.

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 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 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. They used 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 dynamics both at the level of returns and variance. However, by not including separate mean equations for the central bank's policy reaction functions for direct intervention and interest rate policy in the multivariate GARCH framework and instead modeling these policy instruments as exogenous, represented a significant flaw in the approach. This specification was not appropriate since the literature on policy reaction functions have found that policy makers respond to developments in the market and these policy instruments must therefore be specified as endogenous. Kim and Sheen (2006) tried to address this weakness by modeling central bank interventions as driven by a number of variables including exchange rate and volume dynamics but in a separate friction model. Very importantly also, they did not include a policy reaction function for interest rate policy. By not treating with this issue explicitly in the multivariate GARCH framework, 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 four variable 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, it can allow one to look at how policy instruments interact and therefore shed some light on the costs and policy conflicts associated with unsynchronized implementation of related policy instruments over time.

The mean equation formulation for the multivariate GARCH used in this chapter can be more explicitly represented by the following four equations which outline the relationship among the variables of interest, that is, exchange rate returns (*ER*), intervention (*I*), policy interest rate changes (*RR*) and unexpected volume (*UV*):

$$ER_{1,t} = \delta_1 + \delta_{11}ER_{t-1} + (\delta_{12S}.dums + \delta_{12C}.dumc + \delta_{12})I_{t-1} + \delta_{13}RR_{t-1} + \delta_{14}UV_{t-1} + \delta_{15}\Delta FFR_{t-1} + \varepsilon_{1,t} \tag{2}$$

$$I_{2,t} = \delta_2 + (\delta_{21S}.dumev + \delta_{21})ER_{t-1} + \delta_{22}I_{t-1} + \delta_{23}RR_{t-1} + (\delta_{24S}.dumert + \delta_{24})UV_{t-1} + (\delta_{25S}.dumert + \delta_{25})\Delta CP_{t-1} + \delta_{26}\Delta FFR_{t-1} + \varepsilon_{2,t} \tag{3}$$

$$RR_{3,t} = \delta_3 + \delta_{31}ER_{t-1} + \delta_{32}I_{t-1} + \delta_{33}RR_{t-1} + \delta_{34}\Delta FFR_{t-1} + \varepsilon_{3,t} \tag{4}$$

$$UV_{4,t} = \delta_4 + \delta_{41}ER_{t-1} + \delta_{42}I_{t-1} + \delta_{43}H11_{t-1} + \delta_{44}UV_{t-1} + \varepsilon_{4,t} \tag{5}$$

In this framework ΔFFR is the change in the Federal Funds Rate which is used as a proxy for foreign interest rate, ΔCP is the change in cumulative central bank profits and $H11$ is the variance of exchange rate returns. A number of dummy variables are also used to capture the possible impact of differential market conditions on variables of interest. In particular, $dumev$ is a dummy variable which takes on the value of positive (negative) 1 when exchange rate returns experience positive (negative) change by more than two standard deviation outside the mean and 0 otherwise. Also, $dumert$ is a dummy that takes on the value 1 when exchange return trends are positive (depreciation), -1 when exchange rate returns are negative (appreciation) and 0 otherwise. Finally, $dums$ is a dummy variable which takes on the value 1 for intervention purchases and -1 for intervention sales of foreign currency that are large (that is, more than 200 million Kronas) respectively and, 0 otherwise while $dumc$ is a dummy variable that takes on the value 1 if there are interventions in the same direction on two consecutive days and 0 otherwise.

Coefficients with important policy implications include δ_{12} and δ_{13} which measure the impact of intervention and monetary policy (interest rates) respectively on exchange rates. These two coefficients *a priori* are expected to be positive and negative respectively if they are effective as intervention sales (negative) of foreign exchange by the Central Bank of Iceland and increased domestic interest rates (positive) are expected to lead to an appreciation (negative) of the Krona. Additionally, δ_{21} measures the tendency of central bank interventions to lean against the wind and if this tendency is at play then the coefficient should be negative while a positive δ_{32} would indicate that intervention signals monetary policy.

Very importantly, δ_{42} if positive indicates that central bank intervention precipitates increased unexpected volume and therefore increases disorderly market conditions while a negative sign indicates that intervention calms the market by lowering unexpected volumes, possibly by driving more speculative traders out of the market. On the other hand, δ_{24} measures the way central bank intervention activity responds to unexpected volumes. If negative it indicates that the central bank reduces it intervention activities to stabilize trading volume but if it is positive it may indicate that the central bank has increased its intervention activity, possibly to counter informed traders in the market, whose presence is normally associated with an increase in unexpected volumes in the MDH framework and who may be driving an undesirable trend. These coefficients can lead to some important new policy insights since it will let us know if central banks are responding to volume, as well as price signals and, whether central bank policy initiatives can work to control volume dynamics in the market.

The coefficient on central bank profitability should be negative when profitability is rising since the central bank would feel it has the resources to practice "leaning against the wind". If it is positive when profitability is rising it indicates that the central bank is acting like a profit seeking dealer by riding the price trend. If profitability is falling the expected coefficient would still be negative since it may sell foreign exchange when the exchange rate is appreciating or buy foreign exchange when the exchange rate is depreciating to build profits and reserves.

As an example, the conditional variance equation for the first variable[48] which shows how shocks and volatility are transmitted over time in each sector can be expanded as follows:

[48] The constant terms are excluded.

$$
\begin{aligned}
h_{11,t+1} = {} & a_{11}^2\varepsilon_{1,t}^2 + 2a_{11}a_{12}\varepsilon_{1,t}\varepsilon_{2,t} + 2a_{11}a_{31}\varepsilon_{1,t}\varepsilon_{3,t}\varepsilon_{3,t}^2 + 2a_{11}a_{41}\varepsilon_{1,t}\varepsilon_{4,t}\varepsilon_{4,t}^2 \\
& + a_{21}^2\varepsilon_{2,t}^2 + 2a_{21}a_{31}\varepsilon_{2,t}\varepsilon_{3,t} + a_{31}^2\varepsilon_{3,t}^2 + a_{31}^2\varepsilon_{3,t}^2 + 2a_{31}a_{41}\varepsilon_{3,t}\varepsilon_{4,t} + a_{41}^2\varepsilon_{4,t}^2 \\
& + b_{11}^2 h_{11,t} + 2b_{11}b_{12}h_{12,t} + 2b_{11}b_{31}h_{13,t} + 2b_{11}b_{41}h_{14,t} \\
& + b_{21}^2 h_{22,t} + 2b_{21}b_{31}h_{23,t} + 2b_{31}b_{41}h_{34,t} \\
& + b_{31}^2 h_{33,t} + 2b_{31}b_{41}h_{34,t} + b_{41}^2 h_{44,t} \qquad (6)
\end{aligned}
$$

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 (interest rate) variables and $h_{14,t}$ is the conditional covariance between the first and the forth (unexpected volume) variables. The error term $\varepsilon_{1,t}^2$ measures deviations from the mean due to some unanticipated event in variable 1 (exchange rate returns) and cross error terms such as $\varepsilon_{1,t}\varepsilon_{2,t}$ measure the impact of shocks to variable 2 (intervention) on variable 1 (exchange rate returns). The a_{ii} coefficients measure the impact of shocks in variables under consideration on conditional variances (volatility) while the b_{ii} coefficients measure the impact of past variances on current variances, that is, volatility spillovers across time in the same variable, as well as volatility spillovers between variables.

The BFGS algorithm is used to obtain final estimates of the parameter with the variance-covariance matrix and corresponding Bollerslev-Woodridge (1992) standard errors which are heteroskedasticity and serial correlation consistent.

4.3.3 Empirical Results

As discussed in section 4.2.1 there are in principle three distinct policy regimes over the period reviewed by this study. Moreover, the second policy regime, that is, the inflation targeting regime can be divided further into a first sub-period when the exchange rate generally appreciated and a second sub-period when the exchange rate generally depreciated. Since the central banks and other agents in the market tend to respond differently depending on market conditions, the relationship between the policy variables and price and volume dynamics may be fundamentally different in these two periods and therefore these two sub-periods could be considered as two separate regimes. In this context, there could be three to four separate regimes over the full period covered by the study and this was examined empirically by estimating the model for the periods covered by the three major policy regimes and also for the two distinct market environment periods under the inflation targeting policy regime.

The fact that the results from the multivariate GARCH model for the full sample and the inflation targeting policy regime represent averages of the sub-periods contained in these samples means that coefficients estimated from these periods may not provide consistent or sensible results. In fact, coefficients in different sub-samples may have opposite signs which make the relationship between the variables ambiguous when estimated over the longer periods. Indeed, this was the case for the full sample, as well as the inflation targeting period as the coefficients estimated over the sub-samples often had different signs. In this context, I only discuss in detail the results for the four sub-samples although the results for the full sample and the full inflation targeting regime are also presented.

The First Period

The first period running from January 7, 1999 to March 27, 2001 was a period characterized by trading volume increasing from relatively low levels as private agents came to dominate the market and the central bank percentage of trading volume fell off. It was also a period where the exchange rate regime was based on a crawling peg system and the exchange rate was on a depreciating trend generally in the context of relatively low volumes where the central bank often intervened selling foreign exchange to boost liquidity and counter the depreciating trend in the rate.

The VAR-GARCH estimation results are detailed in Table 4.2 below. For direct intervention in the market to be effective the coefficient δ_{12} must be positive indicating that intervention sales of foreign exchange leads to appreciation in the exchange rate. The estimated coefficient was -0.033 and insignificant but as argued in many studies this may be due to simultaneity bias and the fact that small or isolated interventions may not be effective. When we consider dummy variables for large and consistent interventions the picture changes as the coefficients for large interventions (interventions over 200 million Kronas) δ_{12S}, as well as that for consistent interventions (those that are in the same direction for two or more days) δ_{12C} are both positive and significant and therefore effective on those occasions when interventions were large and/or consistent. Unexpected volume as captured by coefficient δ_{14} also had a significant negative impact on exchange rate returns indicating that increased unexpected volume led to an appreciation in the rate. This is to be expected in this period when much of the increases in unexpected volume were related to central bank intervention activity which from the results above appeared to have been successful. This appears to be corroborated by the fact that coefficient δ_{41} was significantly positive indicating that a depreciating exchange rate (increasing rate) usually led to increased unexpected volume which again is most likely driven by central bank intervention sales to bolster the exchange rate. Very interesting, neither the domestic policy interest rate nor the foreign interest rate had an effect on the exchange rate. In all likelihood this result was due to the fact that during this period the interbank system in the foreign exchange and money markets were relatively under-developed and had little exposure to the international financial markets.

In terms of the policy reaction function for direct intervention in the foreign exchange market, it appears that the central bank was "leaning against the wind" of exchange rate trends during this period as evidenced by the fact that the coefficient δ_{21} was significantly negative (-0.008). Paradoxically, the coefficient on the dummy for large changes in the exchange rate (δ_{21S}) was positive and significant suggesting that when exchange rate changes were very large the central bank "leaned with the wind" possibly because it felt that these changes were in the right direction and wanted to reinforce the trend.

Table 4.2: First Period Estimated Coefficients for the VAR-GARCH Model for Iceland

	ER(i=1)	*I(i=2)*	*RR(i=3)*	*UV(i=4)*	ΔFFR	ΔCP	*H11*
				Mean Equations			
δ_{1i}	0.064	-0.033	0.009	-0.036[c]	0.002		
δ_{12s}		0.323[a]					
δ_{12c}		0.424[b]					
δ_{2i}	-0.008[a]	-0.349[a]	0.002	-0.009[a]	-0.003	-0.00002[a]	
δ_{21s}	0.135[a]						
δ_{24s}				-0.008[a]			
δ_{25s}						-0.000005[a]	
δ_{3i}	0.011	-0.009	-0.342		0.048		
δ_{4i}	0.277[a]	-0.180		0.018			-0.009
				Variance Equations			
a_{1i}	-0.633[b]	0.005	-0.079	-1.568[a]			
a_{2i}	-0.146	0.233[a]	-0.046	-0.746[a]			
a_{3i}	-0.345	-0.002	0.218	1.736			
a_{4i}	0.261	0.003[c]	-0.067	-0.085			
b_{1i}	-0.054	0.048[a]	0.011	-0.407[a]			
b_{2i}	-2.051[b]	6.136[a]	0.075	-2.130[c]			
b_{3i}	-0.305	0.139[a]	0.200	-2.498			
b_{4i}	-0.049	0.054[a]	-0.005	-0.006			
$LB(10)$	7.991 (0.62)	8.051 (0.62)	8.921 (0.60)	8.604 (0.57)			
$LBs(10)$	6.008 (0.81)	1.682 (0.99)	11.880 (0.29)	13.185 (0.21)			
LLR	-304.96						

Notes: $LB(10)$ and $LBs(10)$ are the Ljung-Box Q-statistics for standardized and squared standardized residuals at lag 10 respectively and LLR is the log likelihood. Values in square brackets are the probabilities for the Ljung-Box Q-statistics while a, b and c denotes significance at the 1, 5 and 10 percent levels respectively. The standard errors estimated are heteroskedasticity and serial correlation consistent (Bollerslev-Woodridge, 1992).

Also, significant and negative was the coefficient δ_{24} which measures the impact of unexpected volumes on direct intervention activity, indicating that an increase in unexpected volumes generally led to a decline in intervention activity. This result is reinforced by the fact that the coefficient of the dummy for exchange rate trends (δ_{24S}) was also significantly negative, indicating this result held irrespective of whether the exchange rate was depreciating or appreciating. Unexpectedly high volumes in this context may signal episodic volatility and problems in the market and the central bank therefore scales back its trades which will tend to lower the unexpected component of volume. This result may also indicate that the central bank may believe that interventions on days of especially high traded volume is less likely to be effective compared to days when traded volume is low because central bank volume is a more significant component of total volume on those days and its signal is therefore much stronger. This means that the central bank is responding to volume in addition to price signals and vindicates the inclusion of the volume measure in the direct intervention policy reaction function of the central bank. This is a fairly new result as only Kim and Sheen (2006) have looked at this issue for Japan and found similar results so this adds support to this relatively new finding of the importance of volume in the foreign exchange market generally and to central banks' decision to intervene in the market in particular.

The impact of the profitability of central bank interventions on the willingness to support the currency is a key challenge in developing markets where foreign exchange liquidity is generally on the low side and the central bank does not have large reserves. As indicated below, if δ_{25} is negative it suggests that the central bank will be comfortable with practicing "leaning against the wind" behaviour but if positive it would suggest that the central bank is behaving like any other profit seeking dealer by riding on the exchange rate trend by buying the domestic currency (selling foreign currency) when its value is rising (appreciating) and selling the domestic currency (buying foreign exchange) when its value is falling (depreciating). The coefficient δ_{25} is negative and significant indicating that the central bank was comfortable with selling foreign exchange to support the exchange rate in a period when the rate was generally on a depreciating trend since intervention profits were generally increasing in this period. Taken together these results from the mean equations present a cogent picture of the logical framework in which the central bank operated, the signals it responded to and the constraints it faced in its intervention activity in the Icelandic foreign exchange market.

This empirical framework also allows one to discern the impact of the market conditions and policy changes on volatility which is increasingly important to policy makers today since the results from the variance equations shed light on these issues. As described above the a parameters measure the impact of shocks in variables on the conditional variance of all variables while the b parameters measure the impact of past variances on current variances of all variables. Shocks to unexpected volumes significantly reduced the variances of both exchange rate changes (a_{14}) and intervention (a_{24}) while shocks to intervention increased the variance of unexpected volumes (a_{42}). It seems therefore that intervention was the genesis for volatility transmission in the system. There was also significant positive volatility spillovers from intervention to exchange rates (b_{12}), interest rates (b_{32}) and unexpected volumes (b_{42}). Higher variance in unexpected volumes also lowered volatility in exchange rates (b_{14}) and intervention (b_{24}) reinforcing the results from the a parameters above. These results highlight the central role of intervention as a catalyst for change in this system and also show the important role unexpected volume plays in the transmission of policy signals to the market and volatility transmission in the foreign exchange market.

The Inflation Targeting Exchange Rate Appreciation Period

The inflation targeting regime with a generally appreciating exchange rate began effectively on March 27, 2001 and ended on January 6, 2006 when the credit rating of Iceland was downgraded and the Krona began a long depreciating trend. This period was characterised by robust economic growth, generally rising domestic interest rates (a trend which escalated in 2004), a few large and many small purchasing interventions and rising liquidity in the foreign exchange market. The estimated results for this period are detailed in Table 4.3 below.

The coefficient δ_{14} was again significant and positive as in the first period but δ_{24} was now marginally significant and positive but the coefficient on the dummy variable δ_{24S} was still negative, indicating that increased unexpected volumes still led to a scaling back of central bank intervention activity. Very importantly, the coefficients δ_{12}, δ_{12S} and δ_{12C} were still positive but insignificant indicating that even large and consistent interventions did not have an impact on exchange rates. This is not surprising since there were very few large interventions in this period and the central bank concentrated on making numerous small purchases of foreign exchange to boost foreign exchange reserves in a period when the central bank was relatively unconcerned by developments in the foreign exchange market since the rate was appreciating and trading volume was on the rise.

Table 4.3: Inflation Targeting Exchange Rate Appreciation Period Estimated Coefficients for the VAR-GARCH Model for Iceland

	ER(i=1)	*I(i=2)*	*RR(i=3)*	*UV(i=4)*	ΔFFR	ΔCP	*H11*
				Mean Equations			
δ_{1i}	0.069	0.131	0.081	-0.073[a]	-0.142		
δ_{12s}		0.023					
δ_{12c}		0.079					
δ_{2i}	-0.002	1.114[a]	-0.003	0.001[c]	0.011[b]	-0.000001[b]	
δ_{21s}	0.003						
δ_{24s}				-0.003[b]			
δ_{25s}						-0.000002	
δ_{3i}	-0.009[b]	-0.059[a]	-0.184[a]		0.015		
δ_{4i}	0.017	-0.001		0.093[b]			-0.016
				Variance Equations			
a_{1i}	-0.247	-0.002[a]	0.015	-0.102			
a_{2i}	0.112	0.603[a]	0.008	0.088[a]			
a_{3i}	0.193	-0.007[b]	0.840[a]	3.767[a]			
a_{4i}	-0.041	-0.001	-0.077[a]	0.816[a]			
b_{1i}	-0.195[b]	-0.007[a]	-0.001	0.018			
b_{2i}	0.082	2.856[a]	-0.069[a]	0.031			
b_{3i}	0.012	0.025	0.110[a]	-0.269			
b_{4i}	-0.072[b]	0.008[c]	0.006	0.118[a]			
$LB(10)$	10.133 (0.43)	8.316 (0.60)	6.352 (0.82)	7.338 (0.69)			
$LBs(10)$	15.159 (0.13)	13.090 (0.21)	15.914 (0.13)	12.987 (0.22)			
LLR	-1008						

Notes: Same as Table 2.

The central bank also seemed to have abandoned its "leaning against the wind" behaviour in this environment since the coefficient δ_{21} is now insignificant. Also of note is the fact that the central bank appears to have "leaned with the wind" for large exchange rate changes since the coefficient of the dummy for large exchange rate changes δ_{21S} is now positive and significant. In this period, there was some large purchasing of foreign exchange interventions made around a few instances when the exchange rate depreciated indicating that the central bank may have wanted to promote this depreciating trend in an environment where the rate was generally appreciating in a situation where the economy may have been overheating. The coefficient capturing the impact of exchange rate trends on interest rates δ_{31} is also negative and significant indicating that as the exchange rate appreciated (falling rate) the interest rate generally rose which corroborates the "leaning with the wind" behaviour by the central bank captured by the coefficient δ_{21S}. This may reflect the fact that in a period of a generally appreciating exchange rate driven by robust growth the central bank may have been purchasing foreign exchange to boost reserves but at the same time was trying to restrain inflationary pressures by raising policy interest rates for a significant part of the period.

The fact that the coefficient δ_{32} is -0.059 and significant indicates that the central bank is signaling monetary policy with central bank intervention which characterizes the earlier part of the period when direct interventions by the central bank was consistent with its interest rate policy, that is, the policy interest rate was falling (loosing policy) and foreign exchange purchasing interventions (loosing policy by selling domestic currency) were made. The fact that this coefficient is negative in a period where for most of the period (after 2003) interest rates were rising (tightening policy) and the central bank was intervening purchasing foreign exchange (loosing policy) and therefore central bank policy in the foreign exchange market appears to be inconsistent is most likely due to the fact that the central bank was purchasing foreign exchange more frequently, consistently and with larger interventions in the first part of the period (before 2003) when interest rates were falling.

In terms of the volatility transmission in the foreign exchange market, the coefficients a_{12} and a_{32} both significant at -0.002 and -0.007 respectively indicate that shocks to intervention reduces volatility in the exchange rate and interest rates. Intervention therefore seems to be able to temper volatility in the exchange rate although it was not effective in this period in affecting the trend of the rate. The fact that intervention lowered the variance of interest rates also suggests that there is greater substitutability between these two policy instruments in this period relative to the first period. The fact that the coefficient a_{43} is negative and significant indicate that shocks to interest rates lowers volatility in unexpected volumes adding further evidence of the apparent greater traction of interest rate policy in this period relative to the first. Additionally, shocks to unexpected volumes significantly increases the volatility of direct intervention (a_{24}) as well as interest rates (a_{34}) which suggest that these two policy instruments are indeed responding to signals from unexpected volumes.

The impact of past variances of variables in the VAR GARCH on each other also seems to corroborate these above results. The coefficient b_{12} is negative and significant indicating that volatility in intervention reduces volatility in exchange rates. The volatility in interest rates also appears to significantly reduce volatility in intervention, reinforcing the evidence of an apparent tradeoff between volatility of interest rates and intervention. An important result is that volatility in intervention activity increases volatility in unexpected volumes (b_{42}) which is consistent with the literature on the central bank as an informed trader in the foreign exchange market. In this framework, central bank trades (intervention) emit new information to the market which generates a cascade of trade (unexpected volume) from other agents in the market. Very interestingly, this does not seem to be accompanied by greater volatility in prices implying that the market is comfortable with the exchange rate trends being signaled by the central bank in its interventions in this period[49]. Also of note is the fact that coefficient b_{41} was significant and negative indicating that exchange rate volatility reduced volatility in unexpected volumes implying that agents in the market may withdraw whenever exchange rate volatility increased. This is a very important result for the central bank because it highlights the need to monitor exchange rate volatility and unexpected volume especially in a developing market where liquidity may not be as deep and small volume changes may elicit huge swings in the exchange rate.

The Inflation Targeting Exchange Rate Depreciation Period

This period was characterised by a depreciating exchange rate, high and/or rising interest rates, relatively high traded volume but with the central bank continuing a policy of only making small purchasing interventions to boost foreign exchange reserves. The estimated results for this period are detailed in Table 4.4 below.

[49] The market would have been comfortable with an appreciating exchange rate in a period when the economy was growing strongly.

Table 4.4: Inflation Targeting Exchange Rate Depreciating Period Estimated Coefficients for the VAR-GARCH Model for Iceland

	ER(i=1)	*I(i=2)*	*RR(i=3)*	*UV(i=4)*	ΔFFR	ΔCP	*H11*
				Mean Equations			
δ_{1i}	-0.040	1.143[b]	3.189	0.346[a]	0.179		
δ_{12s}		3.698[a]					
δ_{12c}		3.733[a]					
δ_{2i}	0.003	0.173	0.175	-0.005	-0.062[a]	0.00001[a]	
δ_{21s}	0.001						
δ_{24s}				0.011[b]			
δ_{25s}						-0.00002	
δ_{3i}	0.001[b]	-0.020	-0.083[c]		-0.009[b]		
δ_{4i}	0.009	0.430[b]		0.270[a]			0.003
				Variance Equations			
a_{1i}	0.039	0.001	-0.001	-0.013			
a_{2i}	1.831[c]	-0.171	-0.141[a]	-4.825[a]			
a_{3i}	5.931[b]	-1.097[a]	0.782[a]	-3.116[a]			
a_{4i}	-0.002	0.019	0.002	-0.274			
b_{1i}	0.358[b]	-0.010[a]	-0.002[a]	-0.099[a]			
b_{2i}	-2.031	-0.054	-0.076[a]	0.944			
b_{3i}	-4.371[a]	-0.330[b]	0.379[a]	-0.303			
b_{4i}	0.836[a]	0.001	0.001	0.455[a]			
$LB(10)$	12.801 (0.23)	18.642 (0.10)	11.489 (0.25)	14.898 (0.13)			
$LBs(10)$	11.514 (0.31)	10.351 (0.43)	2.415 (0.99)	5.890 (0.82)			
LLR	-989						

Notes: Same as Table 2.

In this environment it was not surprising that δ_{12}, as well as δ_{12S} and δ_{12C}, the coefficients on the dummy for intervention size and consistency respectively were all positive and significant indicating that intervention purchases of foreign exchange led to a depreciation in the Krona. This result is mostly coincidental since the central bank in this period was essentially making small purchasing intervention not geared to changing the trend but this inadvertently may have helped to reinforce the depreciating trend. The coefficient δ_{21} which measures the tendency of the central bank to lean against the wind was actually positive suggesting that the central was "leaning with the wind" but it was marginally insignificant.

In this period the central bank seemed to focus more on using increases in the policy interest rate to deal with the economic challenges it faced. This is borne out by the fact that the coefficient δ_{31} was positive and significant indicating that exchange rate depreciation (positive exchange rate changes) generated increases in interest rates. The coefficient δ_{34} is negative and significant reflecting the fact that the central bank was raising domestic policy rates as international rates were falling in an attempt to stem inflationary trends.

In terms of volume, increases in unexpected volume was positively associated with exchange rate depreciation (δ_{14}) and intervention purchases (δ_{24S}). This is as a result of the dominance of these trends in the foreign exchange market during this period. Very interestingly the coefficient δ_{25} is now positive and significant indicating that the central bank was operating more like a profit driven dealer riding the exchange rate trend. This seems to be borne out by the fact that the central bank continued to make small purchases of foreign exchange as the exchange rate depreciated and this activity was associated with increases in unexpected volumes since δ_{42} is positive and significant.

In terms of the volatility consequences of these relationships and policy implementation, there were some significant changes from the previous inflation targeting sub-period. In particular, shocks to unexpected volume lowers the volatility of intervention and interest rates which implies that the central bank may be scaling back its policy interventions when there are unexpectedly large spikes in volume. This is most likely due to the fact that spikes in unexpected volumes were now viewed as destabilizing and the central bank was aware that its policy interventions might accentuate these developments. This is a plausible explanation since in this period there were many speculative inflows related to the carry trade phenomenon which was driven by the huge differentials between international interest rates and Icelandic interest rates so interest rate policy in particular may have been changed based on these shocks to unexpected volume.

Also of note is the fact that both a_{23} and a_{32} were negative and significant indicating that a shock to either one of the policy instruments lowered volatility in the other suggesting some level of substitution between these two policy instruments. Also, as already outlined, shocks to exchange rates in this period (large depreciations) was associated with increased volatility of interventions (a_{21}) and interest rates (a_{31}) mirroring the results from the mean equations where the central bank policy instruments, particularly interest rates, are responding to exchange rate developments.

In terms of the impact of past variance on current variances of variables in the VAR GARCH, b_{12} and b_{13} were both negative and significant indicating that the volatility of direct intervention and interest rates lowered the volatility of exchange rates. The fact that b_{31} is also significantly negative suggests that there is some tradeoff between exchange rate and interest rate volatility. It appears therefore that these policy instruments may not have been effective in changing the exchange rate trend but were able (especially interest rates) to reduce the volatility of the exchange rate during this period. The fact that the coefficients b_{23} and b_{32} are both negative and significant suggests some substitutability between these two policy instruments. Interestingly, the coefficient b_{41} was positive and significant indicating that exchange rate volatility increased the volatility of unexpected volume but the coefficient b_{14} was significantly negative implying volatility in unexpected volume lowered volatility in exchange rates. This could be reflecting the sequence of volatility spillovers in the foreign exchange market with exchange rate dynamics the trigger for volatility transmission in the foreign exchange market but with unexpected volume reflecting the second round actions of informed traders one of which was the central bank. If the central bank dominated volume and was able to calm the market by its presence then volatility in unexpected volume would lower volatility in the exchange rate.

The Last Period: The Post-Crisis Period

This period runs from October 15, 2008 to August 30, 2010, the end of the period under review. This was the period after the failure of the major banks and the closure of the foreign exchange market. The foreign exchange market re-opened but with restrictions on capital flow which in effect represented a different policy regime to the one that preceded the crisis. This period was characterised by a sharp contraction in trading volume as agents retreated from the foreign exchange market and the associated low liquidity, an initial period of depreciation followed by the strengthening of the currency and falling interest rates. The estimated results for this period are detailed in Table 4.5 below.

Table 4.5: last Period Estimated Coefficients for the VAR-GARCH Model for Iceland

	ER(i=1)	*I(i=2)*	*RR(i=3)*	*UV(i=4)*	*ΔFFR*	*ΔCP*	*H11*
				Mean Equations			
δ_{1i}	0.119	1.330[a]	-2.061	-0.007	0.670		
δ_{12s}		0.375[c]					
δ_{12c}		-0.383					
δ_{2i}	-0.001	0.539[a]	0.231	0.0001	0.017	-0.00001	
δ_{21s}	0.011						
δ_{24s}				0.0001			
δ_{25s}						-0.00001	
δ_{3i}	-0.001[c]	0.0001		0.004	-0.155		
δ_{4i}	-0.069	-0.269		-0.055			-0.021
				Variance Equations			
a_{1i}	0.783[a]	0.001[b]	-0.0003	-0.021			
a_{2i}	-0.421[a]	0.897[a]	0.017[a]	-1.045[b]			
a_{3i}	-1.886[b]	0.0007	0.626[a]	-16.335[a]			
a_{4i}	0.014[c]	0.00004	0.007[a]	0.442[a]			
b_{1i}	0.590[a]	-0.001	-0.0001	-0.029			
b_{2i}	1.999[a]	0.638[a]	-0.0006	-1.663[b]			
b_{3i}	3.254	-0.644	0.529[b]	13.320			
b_{4i}	-0.055[a]	0.0004	-0.002[a]	0.171[b]			
$LB(10)$	16.787 (0.07)	12.991 (0.27)	9.911 (0.44)	15.878 (0.10)			
$LBs(10)$	7.747 (0.65)	1.179 (0.99)	0.918 (0.99)	1.377 (0.99)			
LLR	-243						

Notes: Same as Table 2.

In this environment central bank interventions appeared to have been effective as the coefficient δ_{12} was positive and significant. This is understandable given the conditions that prevailed in the market such as the fact that central bank sales of foreign exchange accounted for the lion's share of total volume in the market. Moreover, the policy changes such as exchange controls reinforced the central bank dominance and influence in the market. The fact that interventions were also mostly large sales of foreign exchange, consistent with the market expectations given market conditions and unambiguous in terms of its objective all contributed to a strong policy signal from the central bank and bolstered the effectiveness of direct interventions.

In this period increases in policy interest rates was also used to support the exchange rate at least up until the end of April 2009. Thereafter, interest rates were lowered as the exchange rate strengthened and inflationary pressures eased. It is therefore not surprising that the coefficient δ_{13} was negative and significant indicating that increases in the interest rate led to a decrease in the exchange rate or an appreciation. The fact that the coefficient δ_{31} is very small but significantly negative reflects the fact that for some parts of this period the exchange rate depreciated (positive changes in the exchange rate) as interest rates were reduced since inflationary pressures were easing. This is situation that have developed at times when objectives in the foreign exchange market (to strengthen the exchange rate) conflicted with domestic policy objectives such as improving economic growth by making monetary policy more accommodating as inflation pressures eased. Additionally, in this period unexpected volume had little or no impact since liquidity in the foreign exchange market had dried up and the supply of foreign exchange to the market by the central bank was predictable.

In terms of the volatility consequences of these developments, shocks to exchange rates reduced volatility in intervention (a_{21}) and interest rates (a_{31}) but increased volatility in unexpected trading volumes (a_{41}) reflecting the fact that adjustments were occurring through the exchange rate and trading volumes. Shocks to intervention also increased volatility in the exchange rate (a_{21}) so the bolstering of the exchange rate may have been bought at the cost of increased exchange rate volatility. Shocks to interest rates also increased the volatility of unexpected volume so use of the two policy instrument seems to have achieved their objective with respect to stabilising the exchange rate trend but also contributed to volatility in the exchange rate and unexpected volumes. This implies that although the central bank policy signals were clear, it took time for agents in the market to assimilate the signals into prices which contributed to short-run volatility in prices and trading volume. It also may indicate that there was still a lot of heterogeneity among agents in the market with respect their exchange rate expectations which would not be surprising given the scale of the crisis and the level of risk aversion in the market in this period. Also noteworthy, was the fact that shocks to unexpected volumes decreased the volatility in both policy instruments (a_{24} and a_{34}) which indicates that in the face of instability manifested in huge swings in unexpected volumes the central bank's policy implementation became more consistent, that is, policy changes were generally made in the same direction and there were fewer policy reversals.

In terms of the significant volatility spillovers from past variances, past volatility in exchange rates leads to increased volatility in intervention (b_{21}) but lower volatility in unexpected volumes (b_{41}), the latter result possibly reflecting the fact that volatility manifests itself in either unexpected volumes or exchange rate but in this period of low volume that was tightly controlled by the central bank most of the volatility in the market manifested itself in prices. Past volatility in interest rates also led to lower volatility in unexpected volumes (b_{43}) as this period was characterised by greater use of the policy interest rate combined with a period when volume was tightly controlled. Volatility in unexpected volume led to a reduction in the volatility of intervention (b_{24}), mirroring the results which implied that increased disorderliness in the market in the form of volatility in volumes led to adjustments in policy implementation to promote consistency.

A Comparison of the Full Period to Sub-Period Empirical Results

As argued at the beginning of this chapter the distinct differences in policy regimes and market condition regimes across the full sample meant that the full sample results would be an average of the various sub-samples and therefore was not likely to yield sensible results in terms of picking up the different dynamics between the policy instruments and market conditions variables over time. The discussion of the results above bear this out as there are several important instances where the effectiveness of policy instruments changed over time, as well as key relationships between the variables of interest.

The results for the full sample (see Table 4.6) indicate that intervention is only effective when it is relatively large and consistent. This result hold in the first period but in the inflation targeting period (see Table 4.7) only consistent interventions were effective, that is δ_{12C} was significantly positive. The results obtained when the inflation targeting period was split into one sub-period when the exchange rate was appreciating and a second when it was depreciating revealed that not even large and consistent interventions were effective in the first sub-period while interventions were effective in the second sub-period. The full inflation targeting period being an average of these two sub-samples generated less accurate results. In the last period only large interventions were effective. These results vindicate the decision to split the full period into different samples based on different policy and market conditions regimes. It also demonstrated that interventions that were large and/or consistent tended to be more effective irrespective of the state of the market.

Table 4.6: Full Sample Estimated Coefficients for the VAR-GARCH Model for Iceland

	ER(i=1)	*I(i=2)*	*RR(i=3)*	*UV(i=4)*	ΔFFR	ΔCP	*H11*
			Mean Equations				
δ_{1i}	0.056[c]	-0.199	-0.005	-0.037[a]	-0.421		
δ_{12s}		0.344[a]					
δ_{12c}		0.304[c]					
δ_{2i}	-0.0001	0.986[a]	0.091[b]	0.001	-0.086[c]	0.00003[a]	
δ_{21s}	0.024[c]						
δ_{24s}				0.001			
δ_{25s}						0.0000001	
δ_{3i}	0.00002	-0.001	-0.148[a]		-0.007		
δ_{4i}	0.067	0.148[b]		0.119[a]			0.001
			Variance Equations				
a_{1i}	0.966[a]	-0.009	-0.001	-0.050			
a_{2i}	-0.387[b]	0.745[a]	-0.001	-0.067[a]			
a_{3i}	0.160	0.002	0.799[a]	0.064			
a_{4i}	-0.001	0.001[c]	0.001	0.986[a]			
b_{1i}	0.326[a]	-0.0001	-0.0005	-0.048			
b_{2i}	-0.315[c]	1.758[a]	0.0003	0.295[c]			
b_{3i}	0.059	0.120[a]	0.590[a]	-0.106			
b_{4i}	0.009	-0.019[a]	-0.009	0.163[a]			
$LB(10)$	14.992 (0.13)	16.248 (0.12)	12.769 (0.15)	4.920 (0.89)			
$LBs(10)$	0.811 (0.99)	0.386 (0.99)	0.516 (0.99)	12.461 (0.25)			
LLR	-3896						

Notes: Same as Table 2.

Table 4.7: Inflation Targeting Period Estimated Coefficients for the VAR-GARCH Model for Iceland

	ER(i=1)	*I(i=2)*	*RR(i=3)*	*UV(i=4)*	ΔFFR	ΔCP	*H11*
			Mean Equations				
δ_{1i}	-0.167	-0.013	-0.596[c]	0.001	0.008		
δ_{12s}		-0.053					
δ_{12c}		1.494[b]					
δ_{2i}	-0.001[c]	0.969[a]	0.033c	-0.001	0.0001	0.000003[c]	
δ_{21s}	-0.001						
δ_{24s}				0.003[a]			
δ_{25s}						-0.0001	
δ_{3i}	0.0001	-0.003	-0.182[a]		-0.001		
δ_{4i}	0.006	0.174[c]	0.001		0.169[a]		
			Variance Equations				
a_{1i}	0.471[a]	-0.001	0.001	0.034			
a_{2i}	0.018	-0.746[a]	-0.003	-0.262[c]			
a_{3i}	-0.448	0.002	-0.989[a]	-0.193			
a_{4i}	0.021	0.005	0.005	0.983[a]			
b_{1i}	0.986[b]	0.003	0.001	-0.044			
b_{2i}	0.035	1.714[a]	-0.001	0.211			
b_{3i}	0.083	-0.035	-0.145[a]	-0.007			
b_{4i}	0.007	-0.006[a]	0.0003	0.176[b]			
$LB(10)$	4.981 (0.94)	8.197 (0.63)	7.298 (0.68)	13.139 (0.21)			
$LBs(10)$	1.128 (0.99)	2.937 (0.98)	2.734 (0.98)	1.184 (0.99)			
LLR	-1249						

Notes: Same as Table 2.

The coefficient δ_{13} capturing the impact of policy interest rate changes on the exchange rate indicated that this instrument was not effective over the full period and the first period. This coefficient for the full inflation targeting period on the other hand indicated it was effective. Separating the inflation targeting period into the two sub-samples suggested that this instrument was only effective in the second sub-sample when policy rates rose significantly. This instrument also appeared to be effective in the last period, especially initially when the central bank raised interest rates to unprecedented levels to stem the slide in the domestic currency.

In the very important area of the impact of unexpected trading volume on the exchange rate (δ_{14}), it was found that unexpected volumes tended to lead to an appreciation of the exchange rate for the full sample ostensibly because much of the unexplained volumes was driven by central bank intervention activity. This result held for the first period but the coefficient for the inflation targeting period was insignificant. The latter result was driven by the fact that this result only held for the first sub-sample of the inflation targeting period. In fact, the second sub-sample result indicated that spikes in unexpected volume actually led to a depreciation of the exchange rate and this could be explained by the fact that in this period when the exchange rate was depreciating, the central bank continued to make small purchases of foreign exchange which reinforced the depreciating trend. This coefficient was negative but insignificant in the last period due in large part to the fact trading volume dropped off sharply and because the central bank imposed tight controls on volume to deal with the crisis.

In terms of the impact of unexpected volume on central bank direct intervention in the foreign exchange market (δ_{24}), although the coefficient for the full sample was insignificant the coefficient for the first period was negative and significant indicating that increases in unexpected volume led to the central bank scaling back its intervention activities in an attempt to bring volumes back to normal since it knows its interventions leads to a cascade of trading volume. This may also reflect the fact that the central bank may feel that its interventions on days of very high volumes may not be as effective as day when volume is lower (Kim and Sheen, 2006).

The δ_{24} coefficient for the full inflation targeting period was negative but insignificant, however, the coefficient of the dummy for exchange rate trends δ_{24s} was positive and significant which suggests that when the exchange rate was depreciating increases in unexpected volume led to the central bank to increasing its intervention activity and in this case acting like a profit seeking dealer which was riding the exchange rate trend by purchasing foreign exchange. Further evidence is provided when one looks at the two sub-samples in the inflation targeting period. For the period when the exchange rate generally appreciated, although the coefficient for unexpected volume was positive and significant when the dummy for exchange trend was factored in the impact was negative and significant. On the other hand, in the depreciating period the impact was positive and significant when the dummy for exchange rate trend is factored in.

The impact of the change in central bank profits on central bank intervention activity also seems to be different depending on the policy and market regime shifts over time. As described above, if the coefficient is negative and significant it indicates that the central bank is comfortable with "leaning against the wind" since its profitability is on the increase but if positive it suggests that the central bank is acting like profit a profit seeking dealer. The coefficient δ_{25} is positive and significant for the full period and the inflation targeting period but is negative and significant for first period and insignificant for the last period suggesting that for most of the period under review the central bank was generally acting like a profit seeking dealer. In the first period, profits from intervention were increasing so the central bank was comfortable with "leaning against the wind" of the depreciating exchange rate trend by selling foreign exchange.

In the inflation targeting period profits were decreasing but the central bank on most days was purchasing foreign exchange. When this period is separated into appreciating and depreciating exchange rate sub-samples, δ_{25} is negative and significant in the appreciating period but positive and significant in the depreciating period. This means in the period when the rate was appreciating and profits falling (sometimes significantly in this period) the central bank was comfortable in purchasing foreign exchange because it leaned against the exchange rate trend and at the same time helped to bolster profits (selling domestic currency when its price was high). Over the part of the period when the exchange rate was depreciating and profits was still falling the central bank may have felt that it was in no position to support the rate by selling foreign exchange since this would add to central bank losses in a situation where the profitability of central bank intervention was falling. This may in part explain why the central bank did not act to support the exchange rate in the latter part of the inflation targeting period. The coefficient δ_{25} was negative but insignificant in the last period possibly because in this period the exchange rate first depreciated and then appreciated while profitability generally rose[50].

[50] Separating the last period into appreciating and depreciating exchange rate sub-samples may have provided more clarity but these sub-samples may have been too small to yield consistent results.

The impact of direct intervention on unexpected volume (δ_{42}) is significantly positive for the full period, as well as for the inflation targeting period implying that central bank intervention generally increased unexpected volumes. This is expected in the market microstructure literature in which the central bank is considered as an informed trader whose trades carry new information in the market. When the central bank intervenes it generates a cascade of trades as other agents gradually incorporate this new information into prices leading to a spike in volume that is unexpected since the intervention was not pre-announced. This coefficient was not significant in the first period, the last period and the sub-sample of the inflation targeting regime when the exchange rate was appreciating possibly because central bank intervention activity was more predictable in those periods.

In terms of the volatility transmission across different periods, shocks to different variables appeared to have relatively similar patterns of transmission across different variables. In particular, the coefficients a_{21} and a_{24} were both generally significantly negative while a_{42} was generally positive but only significant in the first and the full samples. Shocks to exchange rates and unexpected volumes therefore generally reduced volatility in intervention (more consistency) while shocks to intervention tended to increase volatility in unexpected volumes in keeping with the microstructure literature.

The slight difference in volatility transmission from shocks between sub-periods relates to the importance of interest rates in the last period where shocks to exchange rates and unexpected volumes significantly reduced volatility in interest rates (more consistency) while shocks to interest rates generally increased volatility in unexpected volumes. This different result in the last period is driven by the increased use of the policy interest rate changes to manage the situation. In this period also shocks to intervention increased exchange rate volatility while shocks to exchange rates tended to increase the volatility of unexpected volumes both of which is supported by the microstructure framework.

Volatility spillovers between variables were generally more mixed over sub-periods with volatility in unexpected volumes reducing volatility in intervention (b_{24}) in the first and the last periods (more consistency). This coefficient is not significant during the inflation targeting period possibly reflecting the lack of focus of direct interventions over this period. Volatility in intervention also generally led to a decline of volatility in unexpected volumes (b_{42}), suggesting that central bank intervention activities may have been successful in smoothing volatility in trading volumes.

The coefficient b_{14} was also generally negative and significant implying that volatility in unexpected volumes led to a decline in exchange rate volatility except in the last period when it led to an increase in exchange rate volatility. This is contrary to the mixture of distribution hypothesis (MDH) were a common trigger is driving exchange rate and volume dynamics in which case this coefficient should be positive. This again may reflect central bank intervention activity geared to promoting stability in exchange rate dynamics which drives much of the spikes in unexplained volume. This seems to be corroborated by the coefficient b_{21} which was significantly negative for the full sample and the first period but positive and significant for the last period. These results imply that in response to volatility in the exchange rate the central bank intervention activity became more focused except in the last period when the volatility in intervention activity increased. The latter result may simply be related to the magnitude of exchange rate changes in the start of the last period alongside massive selling interventions used to support the Krona.

lastly, the observation above that interest rate changes became more important in volatility transmission towards the end of the period consistent with more aggressive use of this instrument is borne out by the coefficients b_{13} and b_{31} which are both significantly negative suggesting that the central bank both respond to and try to control exchange rate volatility with policy interest rates. The coefficient b_{23} and b_{43} are also negative and significant implying that volatility in interest rates lead to decreases in volatility in intervention and unexplained volumes, implying that interest rate policy is being used more intensively relative to direct intervention in the latter part of the inflation targeting period and during the last period.

4.4 Summary

The results outlined above validate the importance of trading volume, especially unexpected volumes, in both triggering policy responses and in terms of its role in the transmission of policy response to the market. The separating out of the full period into sub-samples characterised by distinct policy and market conditions regimes was also validated as the effectiveness of policy instruments, the relationship between important market parameters and the transmission of volatility were in many cases different in the various sub-samples. The utility of the VAR-GARCH methodology was also illustrated as we were able to track the impact of policy instruments, the policy reaction function of the central bank and the inherent endogeneity of the variables in the mean equation of the multivariate GARCH model, as well as the transmission of volatility from the variance equations.

The results indicate that unexpected volumes have a significant impact on the exchange rate, both at levels and variance. Furthermore, the central bank takes unexpected volumes into account in its decisions not only to intervene but the nature of the intervention as well. The central bank was also able to control the dynamics of unexpected volumes with its direct intervention activities, as well as with policy interest rate changes. The state of the market and the policy regime was shown to be a significant determinant of the effectiveness of policy, validating the regime dependent approach taken in chapter 2. The importance of volume dynamics is a relatively new result building on the work of Kim and Sheen (2006) for Japan. These results demonstrate that the volume dynamics was important in Iceland over the period being studied and that volume dynamics were even more important in the lead up to the crisis in 2008 and in the post crisis period when liquidity in the market dried up. This suggests also that volume dynamics are important irrespective of the size and sophistication of the market and that studies that attempt to measure the impact of central bank policy interventions in the foreign exchange market without incorporating volume dynamics are fundamentally misspecified.

CHAPTER 5
CONCLUSION

5.0 Introduction

The results of most studies before 2000 on the effectiveness of direct intervention as a policy instrument have led to increasing skepticism about its usefulness in foreign exchange markets (Schultz, 2000). Recent studies that have utilised high frequency data on actual central bank intervention activity (purchases and sales of foreign exchange) in the foreign exchange market and the development of more appropriate empirical frameworks have, however, started to produce results which suggest that central bank intervention in the foreign exchange market might be effective after all depending on the state of the market, if its coordinated with monetary policy initiatives and if interventions were more consistent and/or significant. In this context, this thesis has sought to investigate the effectiveness of central bank policy intervention in the foreign exchange market of a variety of developed and emerging economies using actual high frequency data on central bank intervention and more appropriate and comprehensive empirical methodologies.

5.1 Summary of Findings

Chapter 1 reviewed global trends in foreign exchange markets such as the rapid growth of turnover, the increasing complexity of market most notably in the heterogeneity of agents in the market and the growth of new instruments, as well as the vulnerability of these markets to external influences and shocks. This chapter also looked at how the recent international financial crisis was transmitted through these markets, as well as the increased use and effectiveness of central bank direct intervention in the foreign exchange market to contain the crisis in so many countries. An implication of this development was that this instrument is likely to be used more intensely in the future and a better understanding of how this policy instrument operated in different countries and market conditions was critical to effectively dealing with some of the emerging financial challenges. This chapter also reviewed the literature on interventions to map how the empirical methodologies for measuring the effectiveness of direct intervention have improved over the years to determine the most appropriate framework to use to adequately capture the complex dynamics in the foreign exchange market in the context of direct central bank intervention in this market.

Chapter 2 investigated the impact of direct central bank intervention (sales and purchases of foreign currency) on the mean and variance of exchange rate returns in the foreign exchange markets for three developing markets, namely Croatia, Iceland and Jamaica and one developed market, Australia, for comparative purposes. In particular**,** following Hamilton (1994) we assume exchange rate dynamics are captured by a first-order Markov switching fixed transition probability (FTP) model where there are two regimes, one in which the market is characterized by stable conditions (liquidity trading state) with a relatively small mean and variance and another characterized by volatility (informed trading state) with relatively higher mean and variance. We then extend this fixed transition model to a time varying transition (TVTP) model by making the probability of switching from one regime to the next depend on exogenous variables, in this case central bank interventions (Filardo, 1994; Diebold et al., 1994).

We also innovate on previous studies using the Markov switching framework by including a policy interest rate as a control in the TVTP specification for monetary policy measures implemented around the same time as direct interventions and which can affect exchange rate dynamics. This control is also needed in cases where the direct intervention in the foreign exchange market may be partially sterilized as is often the case in developing and emerging markets. Additionally, we also look at the impact of intervention sales and purchases separately in our analysis, since in many regards they are different policy instruments. We also compare the intervention dynamics in developing countries with that of a developed market. Australia is used as the developed market for comparative purposes because its market though developed is not a dominant international centre for foreign exchange trading. Also, as with developing countries its market is dominated by the local dollar/US dollar trades. Moreover, its intervention volumes though larger are still comparable in size to the developing market reviewed in this study.

The results of our attempt to measure the effectiveness of central bank intervention using various TVTP specifications have generated a number of conclusions that potentially have important implications for intervention policy in the foreign exchange markets. The results show that there are two market conditions regimes, each characterized mainly by their variances. We find that direct intervention does have an impact on the probability of switching between regimes in the developed market but having little or no effect in the developing markets reviewed. Direct intervention in the developed market is generally found to be stabilizing when implemented in the volatile regime but de-stabilizing when implemented in the tranquil regime. We also find that intervention purchases and sales tend to have differential impacts since they are generally used to achieve different objectives.

Monetary policy is also found to impact on the transition probabilities and the impact of monetary policy on exchange rate returns tend to overshadow direct intervention, especially in the developing countries under review. In this group of countries, intervention practices such an infrequent interventions and partial sterilization of direct interventions may have led to monetary policy dominating direct intervention in the foreign exchange market. Contrary to the predominant view therefore, Australia, a developed market, had more success using direct intervention relative to the developing countries surveyed. The reason for this apparent anomaly seems to be that actual intervention practices such as having more frequent interventions and full and immediate sterilization of direct interventions to preserve its status as an independent policy instrument ensured its continued effectiveness in the foreign exchange market.

In Chapter 3 we examine the links between direct intervention, interest rate policy and exchange rate dynamics in Australia and Japan in a joint trivariate VAR-GARCH (1,1) framework using the BEKK parameterization. We study the Australian and Japanese foreign exchange markets to evaluate these issues since they are the largest developed markets in which central banks have intervened directly in the last decade. Their experiences with direct intervention and interest rate policy initiatives in the foreign exchange market are therefore among the few on which we can gauge how effective these policy instruments are likely to be in other developed markets. This is increasingly going to occupy the attention of these markets as major currencies come under pressure from the ongoing fallout from the international financial crisis. In this environment, central banks in these jurisdictions will have to manage their exchange rates more actively but would be constrained by the degree to which they can raise interest rates. The dynamic of the links and feedback effects between direct intervention and interest rate changes in these markets is therefore a critical policy issue which requires renewed attention using more appropriate research methodologies.

The study confirmed that the relationship of intervention to policy interest rates could generally be characterized by the “signaling” framework, in that direct interventions and interest rate policy were coordinated and consistent so that intervention sales of foreign exchange were usually backed up by subsequent increases in interest rates to reinforce the impact of the initial direct intervention. The results also confirmed the results of many past studies that intervention is effective in Australia and Japan in the sense that it tends to move the level of exchange rate changes in the desired direction. The study also confirmed that central banks generally intervened to “lean against the wind”.

The results from the variance equations also added to our knowledge in the sense that it showed that shocks to these policy instruments were not associated with increased exchange rate volatility in the short term. Indeed, quite to the contrary it showed that these policy instruments were generally successful in reducing exchange rate volatility in both countries, although Australia appeared to have greater success with direct intervention while Japan had more success with interest rate policy changes. Additionally, increased volatility in intervention (less consistency) had no negative consequences for Japan in terms of more volatile exchange rates since the volatility spillovers were negative but Australia paid significant indirect costs in terms of greater exchange rate volatility. In the case of interest rate policy, indirect volatility spillovers from the policy instrument to exchange rate volatility was positive in both countries but Japan paid a much higher price relative to Australia. Another noteworthy new insight from the results is that the lack of significant spillovers from exchange rate volatility to the volatility of direct intervention and interest rate changes also suggest that in both Australia and Japan the authorities was more concerned with countering undesirable trends in the exchange rate rather that dealing with excessive volatility.

Finally, the evidence from the conditional correlations suggests that the links between the policy instruments were in large part due to the fact that both were driven by common factors. In particular, both generally responded to exchange rate changes in the context of leaning against undesirable exchange rate trends. Additionally, this relationship was most clearly defined during periods of high exchange rate volatility when the policy interventions were large and the objective of policy interventions was very clear to agents in the market.

Given the observed correlation between trading volumes and prices, Chapter 4 examined whether volume dynamics have a significant impact on the effectiveness of central bank policy instruments directed at changing the price dynamics in this market. It examined the links at levels and variance between volumes and returns in a developing market, the Icelandic foreign exchange market, and the effect that central bank policy such as direct intervention and interest rate policy have on this relationship in a four variable VAR GARCH framework. Moreover, given that there appears to be distinct policy and market conditions regimes over the full period of the study which may mean that the significance as well as the nature of the relationship between policy and market conditions variables change over time, the VAR-GARCH model is estimated for four different periods. The first period was characterised by a crawling peg type exchange rate regime, the second an inflation targeting regime which was further divided into two sub-samples one characterised by exchange rate appreciation and the other in which exchange rate depreciation predominated and, a last period characterised by capital controls and the dominance of the central bank as market maker and the primary provider of liquidity to the foreign exchange market.

The results validate the importance of trading volume, especially unexpected volumes, in both triggering policy responses and in terms of its role in the transmission of policy response to the market. The separating out of the full period into sub-samples characterised by distinct policy and market conditions regimes was also validated as the effectiveness of policy instruments, the relationship between important market parameters and the transmission of volatility were in many cases different in the various sub-samples, validating the regime dependent approach taken in chapter 2. The results indicate that unexpected volumes have a significant impact on the exchange rate, both at levels and variance. Furthermore, the central bank takes unexpected volumes into account in its decisions not only to intervene but in crafting the nature of the intervention as well. The central bank was also able to control the dynamics of unexpected volumes with its direct intervention activities, as well as with policy interest rate changes.

These results demonstrate that the volume dynamics was important in Iceland over the period being studied and that volume dynamics were even more important in the lead up to the crisis in 2008 and in the post crisis period when liquidity in the market dried up. This adds to the evidence provided by Kim and Sheen (2006) of the importance of volume to the effectiveness of policy instruments in and the functioning of the foreign exchange markets. This suggests that volume dynamics are important irrespective of the size and sophistication of the market and that studies that attempt to measure the impact of central bank policy interventions in the foreign exchange market without incorporating volume dynamics are fundamentally mis-specified.

Contrary to the predominant view, the empirical results from this research shows that direct intervention is effective depending on the state of the market in which policy is being implemented, the size and consistency of policy instruments, the level of coordination between different policy instruments during central bank policy implementation in the foreign exchange market and the scale of the problem relative to the capacity of the central bank to intervene. It has also demonstrated that trading volume in this market is very important since it acts as a very important trigger for policy implementation and it is also central to the transmission mechanism for policy instruments, as well as to the transmission of volatility through the market.

The results also indicate volatility dynamics is important in the market and therefore empirical methodologies that do not include analysis of variances are incomplete and flawed. In particular, central banks not only respond to trends in exchange rates and volumes it considers to be undesirable but would often intervene if it feels that volatility in the market, whether in terms of prices or volumes or both, is too high. The results also indicate that central bank policy instruments can be successfully deployed to dampen volatility in the market.

The fact that previous studies would have found that these policy instruments were ineffective can be attributed in large part to the use of inappropriate proxies for central bank intervention and the fact that volume dynamics were not considered. Most importantly, however, is the fact that these studies used empirical frameworks that did not incorporate volatility dynamics, non-linearity, endogeniety and regime dependency inherent in the area of central bank policy effectiveness in the foreign exchange market. This study, by correcting many of these deficiencies in terms of the use of high frequency data together with more appropriate and comprehensive empirical frameworks, has shown that central bank policy interventions, both direct interventions in terms of purchasing and selling of foreign exchange and policy interest rate changes, can be effective, especially if implemented consistently and at the right time. This is critically important in the present difficult international economic environment since central banks would in all likelihood have to intervene more frequently in the foreign exchange market to deal with lingering vulnerabilities which manifest themselves in episodic volatility in exchange rates and trading volume.

APPENDIX

The VAR-GARCH models we consider have the following general form:

$$X_t = u + \alpha X_{t-1} + \varepsilon_t \tag{1}$$

where X_t is a vector of variables of interest (exchange rates, direct intervention, policy interest rates and trading volumes in the foreign exchange market) at time *t*, μ is a long term drift coefficient and ε_t is the error term at time *t*.

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:

$$vech(H_t) = A_0 + \sum_{j=1}^{q} B_j vech(H_{t-j}) + \sum_{j=1}^{p} A_j vech(\varepsilon_{t-j}\varepsilon'_{t-j}) \tag{2}$$

where $\varepsilon_t = H_t^{1/2}\eta_t \quad \eta_t \sim iid$ N(0,1). The notation *vech* (.) 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[51] 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.

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

The general form of the BEKK model is:

$$H_{t+1} = C'C + A'\varepsilon_t\varepsilon_t'A + B'H_tB \tag{3}$$

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 three and four variables multivariate GARCH models are outlined below in equations 4 and 5 respectively:

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \quad B = \begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix} \quad C = \begin{bmatrix} c_{11} & 0 & 0 \\ c_{21} & c_{22} & 0 \\ c_{31} & c_{32} & c_{33} \end{bmatrix} \tag{4}$$

where *C* is a 3x3 lower triangular matrix of unconditional variances and covariance, *A* is a 3x3 square matrix of parameters that show the correlation of conditional variances with past squared errors and *B* is a 3x3 matrix of parameters that measure the impact of past levels on current levels of conditional variances.

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} B = \begin{bmatrix} b_{11} & b_{12} & b_{13} & b_{14} \\ b_{21} & b_{22} & b_{23} & b_{24} \\ b_{31} & b_{32} & b_{33} & b_{34} \\ b_{41} & b_{42} & b_{43} & b_{44} \end{bmatrix} C = \begin{bmatrix} c_{11} & 0 & 0 & 0 \\ c_{21} & c_{22} & 0 & 0 \\ c_{31} & c_{32} & c_{33} & 0 \\ c_{41} & c_{42} & c_{43} & c_{44} \end{bmatrix} \tag{5}$$

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

$$L(\theta) = -\frac{TN}{2}\ln(2\pi) - \frac{1}{2}\sum_{t=1}^{T}(\ln\left|H_t\right| + \varepsilon_t' H_t^{-1}\varepsilon_t) \tag{6}$$

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.

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