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Three Essays on Monetary Policy and Exchange Rate Behavior

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THREE ESSAYS ON MONETARY POLICY AND EXCHANGE RATE BEHAVIOR

by,

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In response to the 2007 financial crisis and recession, the Federal Reserve System (the Fed) implemented conventional monetary policy by lowering the Federal funds rate in order to stimulate the economy. However, the Federal funds rate reached its zero-lower bound in November 2008, which meant that lowering the Federal funds rate was no longer an option, because it could not be lowered any further. As a result, the Fed began to implement unconventional monetary policy, by making large-scale asset purchases (LSAPs) usually referred to as quantitative easing (QE). This dissertation studies how monetary policy in the context of the move to unconventional monetary policy affects the behavior of the U.S. dollar vis a vis a number of important currencies. Three different perspectives concerning this policy move are offered.

The first essay examines how exchange rates are impacted by conventional and unconventional monetary policy using daily data. In addition, I test if there is any change in the volatility of exchange rates in the long run overall, pre and post November 2008. I employ a generalized autoregressive conditional heteroskedastic (GARCH) model to estimate the volatility of five exchange rates, namely the Australian dollar, the Canadian dollar, the Euro, the British pound, and the Japanese yen against the US dollar. Results show that interest rate spreads have significant impacts on exchange rate returns under conventional monetary policy regime, while the spreads have no impacts under unconventional regime. With respect to the impact on

volatility in the long run, overall there is no significant change pre and post November 2008 for four out of the five cases.

The second essay focuses on the impact of monetary policy on exchange rate volatility from a narrower perspective. The analysis zeros in on the immediate effects of policy announcements on the volatility of the US dollar in the conventional versus unconventional monetary policy period. The advantage of using intraday data is that it enables me to better isolate the response of exchange rate movements to monetary announcements and separate those from other possible shocks in the same day. Focusing on the 25 minutes around the announcements, I find that the monetary policy announcements significantly impact exchange rate volatility. Compared with the conventional regime period, the impacts under the unconventional regime are greater for some exchange rates while they remain the same for the others.

The third essay examines the impact of monetary policy on exchange rates from the perspective of an emerging economy, Mexico. High frequency (second-by-second) data are used in this paper. This essay focuses on the impact of monetary policy on the volatility of the Mexican peso/U.S. dollar exchange rate, and compares it with the results in the second essay. I incorporate Mexico's monetary policy to examine how the exchange rate volatility responds to monetary policy originating from both the US and Mexico. Results show that the volatility responds more to U.S. monetary policy compared to Mexican monetary policy. Besides, the impacts of the U.S. announcements last for longer periods than the Mexican announcements.

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Wan Wei

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CHAPTER I

INTRODUCTION

Monetary policy refers to the actions conducted by a central bank to influence the amount of money and credit in order to further promote a nation's economy. The Federal Open Market Committee (FOMC), a committee within the Federal Reserve (the Fed) in the US, takes the responsibility to conduct monetary policy. Prior to November 2008, the Fed generally conducted monetary policy via open market operations with the intent of keeping the federal funds rate, the interest rate at which depository institutions lend reserve balances to each other overnight, around the target proposed by the FOMC. This manner of conducting monetary policy prior to November 2008 is referred to as conventional monetary policy.

In order to counteract the recession caused by the financial crisis of 2007, the Fed used conventional monetary policy and lowered the Federal funds rate, until reaching the zero lower bound. From the end of 2008, the Fed started to conduct unconventional monetary policy by making large scale assets purchases (LSAPs), also referred to as quantitative easing (QE). Under QE, the Fed made large scale purchases of long term securities aimed to exert downward pressure on long-term interest rates to promote economic activity and make financial conditions more accommodative[1].

An exchange rate is the price of a currency in terms of another currency and is determined in the foreign exchange market via forces of supply and demand. The foreign

[1] Board of Governors of the Federal Reserve System, http://www.federalreserve.gov/monetarypolicy/bst_openmarketops.htm

exchange market “underpins all other financial markets” and is by far the largest financial market (Levinson 2005). The foreign exchange rate can impact a country’s international trade activities, influence the flow of international investment and affect domestic interest and inflation rates (Levinson 2005). The stability of foreign exchange markets contributes to the overall stability of the financial markets as a whole which may, in turn, affect the stability of the economy.

As one of the most essential financial markets, it provides an important channel through which monetary policy affects economic conditions. Therefore, it is of importance to understand how monetary policy impacts the foreign exchange market. Indeed, monetary policy has direct and indirect influences on exchange rates. For one thing, the goals of monetary policy are to promote maximum employment, stable prices and moderate long term interest rates, which may in turn affect the exchange rate. For another, given that monetary policy is closely related to interest rates while interest rates can impact the exchange rate, it is logical to claim that monetary policy may influence the exchange rate.

Given that monetary policy and the exchange rate are tightly linked, it is of interest to know how the shift in monetary policy ended up impacting the exchange rate. Does the behavior of the exchange rate differ prior to and post November 2008? This dissertation examines how monetary policy influences the behavior of the US dollar vis a vis several important currencies. These impacts are studied from three different perspectives in this dissertation.

The first essay investigates how exchange rates are impacted by conventional and unconventional monetary policy using daily data. In this essay, I examine the long run response of both the exchange rate return and its volatility to the monetary policy change which took place at the end of 2008. A generalized autoregressive conditional heteroskedastic (GARCH) model is employed to answer the research question. Five exchange rates are

studied in this essay, which are the Australian dollar, the Canadian dollar, the Euro, the British pound, and the Japanese yen against the US dollar. Two conclusions can be made from the study. First, the spreads between domestic long interest rate and foreign long term interest rates have substantial impacts on exchange rate returns during the conventional monetary policy period in three cases and one case respectively, while the neither spreads influence the returns under the unconventional monetary policy regime. Second, the shift of monetary policy does not lead to significant changes in the overall volatility of the exchange rates in the long run. In all, this essay addresses how the patterns of exchange rate volatility are impacted by the policy shift in the long run.

Given that monetary policy and exchange rate behavior are closely related, in the first essay, it is surprising that I do not find any structural change in exchange rate volatility under the two different monetary policy regimes using daily data. Therefore, it is logical to ask, is it really the case that the policy change had no impact on exchange rate volatility at all? Does the new policy lead to any change in the intraday pattern of volatility that cannot be captured in a daily setup? In order to continue to assess whether there is any influence of the shift of monetary policy on exchange rate volatility on an intraday basis, I continue to investigate using higher frequency data.

The second essay, therefore, takes a different perspective by focusing on the impact of monetary policy on exchange rate volatility from an intraday perspective. The study concentrates on the immediate effects of monetary policy announcements on the volatility of six exchange rates during the conventional versus unconventional monetary policy period. Second-by-second exchange rate data are analyzed in this study allowing me to assess the immediate responses to announcements under the two policy regimes. In addition, the use of this high frequency data enables me to isolate the response of exchange rate movements to monetary policy announcements from other possible shocks. The regressions are estimated

separately for six exchange rates, namely the Australian dollar, the British pound, the Canadian dollar, the Euro, the Japanese yen, and the Swiss franc against the U.S. dollar over the two different regime periods. These seven currencies are the most frequently traded currencies according to the latest Triennial Central Bank Survey from the Bank for International Settlement in 2013[2]. Moreover, these currencies represent different time zones, which can also capture the feature of the 24-hour foreign exchange markets. Focusing on the 25 minutes around the announcements, I find that monetary policy announcements contribute to a higher volatility of the exchange rates relative to non-announcement periods. Moreover, announcements under the unconventional regime lead to even higher increases in volatility compared with the conventional regime for some exchange rates.

The third essay examines the impacts of monetary policy announcements on exchange rate volatility from the perspective of an emerging economy. Specifically, I explain the case of the Mexican peso, which was the most frequently traded emerging market currency in 2013 according to the latest Triennial Central Bank Survey from the Bank for International Settlement. Similar to the previous essay, second-by-second intraday data is used in this paper. When incorporating Mexico's monetary policy in the analysis, I find that peso/dollar volatility increases more when responding to US monetary policy compared to Mexican monetary policy. Furthermore, the impacts of US monetary policy announcements on the volatility remain for a longer period of time than Mexican announcements.

This dissertation contributes to a deeper understanding of monetary policy and exchange rate behavior for the benefit of policy makers as well as market participants. First, it provides insights to US policy makers to evaluate the effects of unconventional monetary policy more comprehensively, as this research analyzes how the implementation of unconventional monetary policy affects the stability of the foreign exchange market. Second,

[2] "Triennial Central Bank Survey -- Global foreign exchange market turnover in 2013," Bank for International Settlement

it helps market participants understand that monetary policy announcements could be an important source of systematic risk. Third, the central banks of Europe, UK, and Japan also began their implementation of unconventional monetary policy after the US. Therefore analyzing the impacts of unconventional monetary policy on the exchange rate behavior will provide other central banks with knowledge to proceed. Fourth, this research also presents emerging market central banks with evidence on the effects of the US unconventional monetary policy on their own economies. Moreover, this study provide intuition about how the exchange rate may respond to unconventional monetary policy when the Fed initiates another round of new monetary policy in the non-expansionary or even contractionary policy phase of the business cycle.

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CHAPTER 2

THE EFFECTS OF MONETARY POLICY SHIFT ON EXCHANGE RATEBEHAVIOR

2.1 Introduction

In order to influence the availability and cost of money and credit, central banks use monetary policy tools to directly influence interest rates. Before November 2008, the Federal Reserve System (the Fed) implemented monetary policy by adjusting the federal funds rate, the interest rate at which banks and other depository institutions (banks and credit unions) lend money to each other on an overnight basis. We use the term, conventional monetary policy, to refer to using the federal funds rate (an overnight and short term interest rate) as the operating target, therefore describing the operations of the Fed prior to November 2008.

In response to the recession that followed the Financial Crisis, the Fed implemented expansionary monetary policy by lowering the federal funds rate. The federal funds rate dropped from 4.25 percent in December, 2007 to 0.00 percent in November 2008, at which point conventional monetary policy lost its power to stimulate the economy because the federal funds rate could not be lowered any further. In its effort to continue to counteract the recession, the Fed began to implement unconventional monetary policy, by making large-scale asset purchases (LSAPs), often referred to as quantitative easing (QE). Under QE, the Fed tried to stimulate economic activity by influencing long-term interest rates (instead of short term interest rates), since at the time long-term interest rates were well above zero. Figure 2.1 plots long term and short term interest rates from 2000 to 2013 for the US. As

shown on the graphs, long-term interest rates continued to experience fluctuations after the policy change, while the federal funds rate was stuck at the zero lower bound. Figure 2.2 to Figure 2.6 plot the interest rates for Australia, Canada, Euro Area, UK and Japan respectively. It is interesting to see that short term interest rates in these countries had a sudden and drastic decline around 2008-2009 period, while the decrease in the long term rates were not as significant as the short term rates.

The relationship between exchange rates and interest rates has been an important focus in international economics. We know that exchange rates are linked to interest rates and therefore foreign exchange rates can be influenced by interest rates movements. Theoretically, exchange rates can be impacted by interest rates in at least two ways. When domestic interest rates increase relative to foreign interest rates, domestic assets, denominated in the domestic currency, become more attractive thereby inducing a greater demand for the domestic currency. This causes domestic currency to appreciate, as predicted by Interest Rate Parity theory. The other view claims that an increase in the domestic interest rates induces a contraction in domestic output through a credit channel. This "output effect" tend to weaken the domestic currency (Hnatkovska et al 2013). Whether short term or long term interest rates are more influential is debatable.

Given that short term interest rates stopped varying, post November 2008, and therefore, presumably, lost their influence on the exchange rate, it is natural to ask, do movements in long term interest rates similarly impact exchange rates? Do long term interest rates influence exchange rates in the same manner that short term interest rate do? Are exchange rates impacted differently by the change in behavior of short and long term interest rates under the two monetary regimes?

Even though the exchange rate is not one of the direct objectives of monetary policy, monetary policy may have other direct or indirect influences on exchange rates. The Fed

announced that the goals of monetary policy are promoting maximum employment, stable prices and moderate long term interest rates[3]. We know that employment, prices, and long term and short term interest rates, in turn, may affect the exchange rate. Moreover, given that monetary policy is closely linked to interest rates, while interest rates can influence the exchange rate, it is reasonable to expect that different monetary policy may have different impacts on the exchange rate. In the light of the change in the way monetary policy was conducted, from conventional to unconventional, it is of interest to know how and whether this change in policy regime ended up changing exchange rate behavior.

In this paper, we focus on the behavior of the exchange rate, by tracking both the level and its volatility. The Fed's QE policy seemed to have been effective in stimulating the economy since the U.S. economy started growing again in June 2009[4]. But what other impacts did the policy have? Did the sensitivity of foreign exchange rates to monetary policy differ under the two regimes? Some researchers claim unconventional monetary policy may lead to distortion in exchange rates and other assets prices, which may result from "excessive speculation"(Shaun K. Roache and Marina V. Rousset 2013), thus leading to a higher volatility in the foreign exchange markets. On the contrary, there is also evidence showing that financial market volatility is low under the unconventional monetary policy regime. For example, Tan and Kohli (2011) find that stock market volatility was artificially low after the implementation of QE.

There are several reasons for wishing to understand how exchange rate levels and volatility are impacted by monetary policy. First of all, there is a significant amount of uncertainty regarding the impacts of the new policy tools on financial markets. The nexus

[3] Board of Governors of the Federal Reserve System, "Statement on Longer-Run Goals and Monetary Policy Strategy"

[4] The recession begun in December 2008 and officially ended in June 2009, according to the Business Cycle Dating Committee of the National Bureau of Economic Research, the official arbiter of such dates. http://www.nber.org/cycles/cyclesmain.html

between monetary policy and financial stability has aroused people's attention (Fischer 2016). Exchange rate stability is one of the most important components of financial stability. Studying the volatility of exchange rates under different monetary policies can also provide more information to evaluate the effectiveness of monetary policy on the economy as a whole. Second, exchange rate volatility may affect international trade by increasing risk to multinational firms. Some studies find that exchange rate volatility affects trade negatively (e.g. Byrne 2008). Third, volatility may also impact international reserves, since the value of international reserves are affected by the movements of exchange rates. For central banks wishing to hold low risk assets, a very volatile currency may prove undesirable to hold. (Diebold and Nerlove 1989). Fourth, previous research indicates that foreign exchange volatility may affect a variety of asset prices and trading volume, indicating that exchange rate volatility may have significant impacts on all financial markets (Menkhoff et al 2012). Finally, understanding the impacts of unconventional monetary policy on the exchange rate will provide other central banks with knowledge to proceed. Take Europe, for example. They are similarly faced with a monetary policy "problem" given that the interest rate cannot be lowered anymore and they have begun implementing the use of unconventional policies (Blackstone and Lawton 2014).

In this paper, November 2008 is a critical time because it is when the short term interest rate hit the zero lower bound in the US. For that reason, it is also when monetary policy shifted from the conventional to the unconventional regime. We need to understand the effects of this change by answering the following questions. First, were exchange rates impacted differently by interest rates pre- and post-November 2008? Since short-run interest rates were no longer changing, and they could not be used to impact exchange rates after November 2008, it is natural to ask how and whether exchange rates are similarly affected by long-term interest rates during the post-November 2008 period. Second, I test whether the

volatility of exchange rates changed during the post-November 2008 period. In other words, I examine whether the exchange rate became more or less volatile due to the shift in the monetary procedures from conventional (influencing the Federal funds rate) to unconventional (QE) policy.

2.2 Literature Review

Previous work that is pertinent to our topic can be divided into four broad groups. The first group of studies discusses the relationships between monetary policy and interest rates, and the second group the relationship between interest rates and exchange rate levels. A third strand of literature examines the direct impact of monetary policy on exchange rate levels. A fourth group of studies investigates how monetary policy influences exchange rate volatility.

Starting with the first group, Wright (2012) and Wu (2014) both find evidence that monetary shocks had significant impacts on long-term interest rates since the federal funds rate reached and got stuck at the zero lower bound. Wright (2012) shows the results with respect to Treasury yields using 2-year, 5-year, 10-year, and 30-year Treasury rate futures, while Wu (2014) concludes unconventional monetary policy lowered ten-year Treasury bond yield. In addition, the Fed's forward guidance, a tool that tries to influence the market expectations of the future course of monetary policy, also resulted in the gradual extension of market expectations for the duration of the LSAP program, thus reinforcing the LSAP's impact to keep term premiums low (Wu 2014).

While the studies above suggest that monetary policy impacts interest rates, another branch of research focuses on the link between interest rates and the exchange rate. Hacker et al (2014) find that interest rate differentials have substantial effects on exchange rate movements using Granger causality tests. In another paper, Wang et al (2013) find that the U.S. dollar tends to appreciate against five currencies, the Australian dollar, the Canadian

dollar, the Euro, the Japanese yen and the British pound, when the target Federal funds rate increases, and depreciate when the target Federal funds rate decreases.

Given that monetary policy affects interest rates and interest rates influence exchange rates, it should not be surprising that researches have linked monetary policy to exchange rates, thus constituting a second body of literature. Glick and Leduc (2013) examine the effects of unconventional monetary policy on the value of the US dollar against the British pound, the Canadian dollar, the Euro, and the Japanese yen. They find that monetary policy surprises, observed due to changes in interest rate futures prices, have a significant impact on the dollar exchange rates in narrow windows around announcements. The impacts of the monetary policy surprises are the same under the two different monetary policy regimes. A similar result is obtained by Neely (2010). His paper investigates the impact of the Fed's unconventional monetary policy announcements in 2008-2009 on five exchange rates and finds that the depreciations of the US dollar due to the monetary policy announcements are consistent with estimates of the impacts of conventional monetary policy shocks. In short, conventional and unconventional monetary policy has the same impacts on exchange rate levels based on these studies.

The fourth body of literature analyzes the linkage between monetary policy and exchange rate volatility. In an earlier paper, Pozo (1988) studies how five major currency exchange rates behave under different monetary operating procedure in the US. The Fed used non-borrowed reserves as its operating target between October 6, 1979 and Sept 30, 1982, while using the Federal funds rate as the operating target before and after that period. By conducting F tests and modeling the symmetrical stable Paretian (SSP) distribution, she comes to the conclusion that exchange rate volatility is higher in the non-borrowed reserves target period. Lastrapes (1989) examines the effects of shifts in U.S. monetary policy regimes on the volatility of foreign exchange rates by estimating an ARCH process. The results

indicate that U.S. monetary policy significantly affects the conditional variance, a measure of volatility obtained from the ARCH process, of nominal exchange rates. His results are mostly consistent with Pozo (1988) given that four out of the five exchange rates exhibit more uncertainty during the period in which the Fed used non-borrowed reserves as the operating target.

In modeling exchange rate volatility, a generalized auto regressive conditional heteroscedasticity (GARCH) process is a good approach to model financial market volatility (Engle 1982 and Bollerslev 1986), because it characterizes the phenomenon of volatility clustering. Although uncertainty and volatility are not interchangeable terms in finance, volatility can be used as an important proxy to measure uncertainty (Takaishi 2017). Baillie and Bollerslev (1989) further find that exchange rate returns can be well modeled by a GARCH (1, 1) process. In line with Baillie and Bollerslev (1989), Anderson and Bollerslev (1998) demonstrate that ARCH and stochastic volatility models provide good forecasts for daily exchange rates. Following Anderson and Bollerslev (1998), I use a GARCH process to measure exchange rate volatility in the two monetary policy regime periods.

More specifically, I examine how exchange rates respond to short-term and long-term interest rates during the different monetary policy regimes. In addition, I analyze whether the new monetary policy results in an increase, decrease, or no change in exchange rate volatility.

2.3 Empirical Study

2.3.1 Data

Five pairs of currencies are studied in this paper; the Australian dollar (AUD), the Canadian dollar (CAD), the Euro (EUR), the British pound (GBP) and the Japanese yen (JPY) against the US dollar (USD). The sample period spans from January 4, 2000 to November 22, 2013 on a daily basis except for the Euro. The EUR/USD sample period is shorter; ranges

from September 6, 2004 to November 22, 2013, with the period of study constrained on account of the availability of the long term interest rate for the Euro Area[5]. The exchange rate data are obtained from Federal Reserve Bank of St. Louis. Figure 2.7 to Figure 2.11 plots the returns of the five exchange rates. According to the plots, exchange rate returns seem to be more volatile during a short period at the end of 2008. However, whether there is any structural change in the volatility in the long run needs to be tested in the empirical model.

The short term interest rates used in this paper are the federal funds rate for the U.S., 30-day bank accepted bills rate for Australia, the Overnight Money Market Financing Rate for Canada, three-month Euro Interbank Offered Rate (EURIBOR) for Euro Area, three-month London Interbank Offered Rate (LIBOR) for the U.K., and Uncollateralized Overnight Call Rate for Japan. The long term interest rates for the six countries are the 10-Year Treasury Constant Maturity Rate (US), the 10-year Government Bond yield (Australia, Canada, UK, and Japan). The details of the short term and long term interest rates for each country are displayed in Table 2.1 and Table 2.2.

2.3.2 Empirical Model

I used a generalized autoregressive conditional heteroskedastic (GARCH) model to estimate exchange rate returns and exchange rate volatility. The specification is as follows ,

$$r_t = c_1 + \beta_1(1 - D_t)(i_t - i_t^*) + \beta_2 D_t(i_t - i_t^*) + \gamma_1(1 - D_t)(I_t - I_t^*) + \gamma_2 D_t(I_t - I_t^*) + \rho D_t + \varepsilon_t \quad (2.1)$$

$$h_t = c_2 + \theta\varepsilon_{t-1}^2 + \varphi h_{t-1} + \delta D_t \quad (2.2)$$

where r_t is the exchange rate return derived from the daily spot exchange rate ($r_t = \ln\frac{e_t}{e_{t-1}}$). The variable i_t is the US federal funds rate, while I_t is long-term interest rate (the 10-Year US Treasury Constant Maturity Rate). The variables i_t^* and I_t^*, are the foreign short-term and long-term interest rates respectively. The dummy variable D_t, distinguishes the conventional

[5] Based on my communication with ECB on April 8, 2016, data for yield curve spot rate (10-year maturity) are not publicly available for the period before September 6, 2004.

from the unconventional monetary policy regime, where $D_t = 0$ before November 2008 and 1 after that. Therefore $(1 - D_t)$ would be equal to 1 before November 2008 and 0 after that.

Equation (2.1) models exchange rate returns. The coefficients β_1 and γ_1 indicate the impact of the short term interest rate and the long term interest rate in the pre-November 2008 period. The coefficients β_2 and γ_2 illustrate the impact of the interests rate movements in the post- November 2008 period. If these coefficients are statistically significant, this implies that interest rates have substantial impacts on the exchange rate during the corresponding period. For example, if β_1 is statistically significant, it implies that the short term interest rate spread has an impact on the exchange rate return before November 2008. If β_2 is not statistically significant, it indicates that the short interest rate spread has no impact on exchange rate returns after November 2008. The significance of the coefficients γ_1 and γ_2 suggest whether the long term interest rate spread affects exchange rate returns in the pre- and post-November 2008 periods.

The second regression that is displayed above (equation (2.2)) is the conditional variance equation modeling exchange rate volatility. The dummy variable D_t is added as an exogenous variable in the variance equation to test if there is any change in the overall volatility of the daily exchange rate return in the post-November 2008 period relative to the earlier period. The regressions are estimated separately for the five exchange rates.

2.4 Results

2.4.1 Effects of Interest Rates on Exchange Rate Returns

Table 2.3 presents the estimation results for equation (2.1) for the five exchange rates. First, let us examine EUR/USD as an example to explain the results of the estimation. The coefficient, β_1, is negative and statistically significant for the Euro/USD equation, indicating that the spread between the US short term interest rate and the Euro Area's short term interest

rate has a substantial impact on exchange rate returns, before November 2008. Specifically, if the US interest rate increases relative to the Euro area's interest rate, this will lead to a depreciation in the US dollar against the Euro (an appreciation of the Euro against the US dollar). That is to say, a one percent increase in the short term interest rate spread leads to a 0.1 basis point decline in the Euro/dollar exchange rate return. The coefficient γ_1 is statistically significant as well, implying that the long term interest rate spread between the US and the Euro area also has an influence on the exchange rate return before November 2008. The positive sign of γ_1 suggests that an increase in the US long term interest rate relative to the Euro area's long term interest rate will result in an appreciation in the US dollar against the Euro. Specifically, a one percentage increase in the long term interest rate spread will lead to a 0.26 basis point increase in the Euro/dollar exchange rate returns.

That short term and long term interest rates spreads have different impacts on Euro/dollar exchange rate returns may be explained as follows. The dollar appreciates again Euro when the US long term interest rate increases relative to the Euro Area's long term interest rate for the reason that the increasing interest rate will attract foreign investors to invest in the US, leading to a higher demand for the US dollar, which in turn drives up the value of the dollar against the foreign currency. When the US short term interest rate increases relative to the Euro Area's short term interest rate, production is discouraged due to higher borrowing costs. Consequently, a deficit in the current account may lead to less demand for US dollar which exerts downward pressure on the value of the domestic currency.

The coefficients β_2 capture the impact of the interest rate spread on the exchange rate in the post 2008 period. The estimation result for β_2 is not statistically significant, which suggests that the short term interest rate spread between the US and the Euro area no longer impacts the exchange rate. The estimation result of γ_2 is not statistically significant, either. This indicates that the long term interest rate spread between the US and Euro area also lost

its impact on the exchange rate after the federal funds rate was stuck at zero after November 2008.

Based on the results of all five exchange rates overall, an increase in the long term interest rate spread (the difference between US interest rate and foreign interest rate) leads to an appreciation of the US dollar in three out of the five cases (AUD, EUR and GBP) during the pre November 2008 period, while an increase in the short term interest rate spread cause a depreciation of the US dollar in only one case (EUR) out of the five during the pre November 2008 period. With respect to the impacts during the post November 2008 period, neither the short term interest rate spread nor the long term interest rate spread has an impact on exchange rate returns for all five exchange rates.

One possible explanation of the above result is that, even though monetary policy puts downward pressure on long term interest rate, the effects die off rapidly (Wright 2012). That is to say, the short-lived impact of monetary policy on exchange rates along with interest rates may not be captured by the model used in this paper. The frequency of the daily data may not be high enough to provide good insights into how monetary policy impacts exchange rates in the case where the effects are short-lived. Another interpretation of the insignificance of the long term interest rate is from the nature of short term interest rates and long term interest rates. Long term interest rates have two major determinants, average of expected future short term interest rates and the term premium (Wu 2014). With short term interest rates stuck at the zero lower bound, long term interest rates were mainly influenced by the term premium. However, through the Fed's "forward guidance" in the post-November 2008 period, the public gradually extended their expectation for the duration of the LSAP program, thus generating a more persistent effect of the LSAP to keep term premiums low (Wu 2014). In this context, the variation of long term interest rates in the post-November 2008 period was

not as much as they were in the pre-November 2008 period. Hence, the impacts of long term interest rates were weakened.

2.4.2 Effects of Unconventional Monetary Policy on Exchange Rate Volatility

Turning next to the variance equation results displayed in Table 2.3, the coefficients on the ARCH term (θ) and GARCH (φ) term are significantly different from zero for all five exchange rates, which is in line with the feature that exchange rates exhibit volatility clustering. A dummy variable is added in the variance equation in the model to test if there is any structural shift in the overall volatility of the exchange rates.

The significance of δ reveals if there is structural change in volatility. The estimation suggests that δ is not statistically significant for four exchange rates as shown in Table 2.3 with the exception of CAD/USD. The volatility of the daily exchange rate returns neither increases nor decreases significantly after the federal funds rate hit the zero lower bound in November 2008 for AUD/USD, EUR/USD, GBP/USD and JPY/USD. In the case of CAD/USD, however, the estimation result for δ is positive and statistically different from zero, implying that overall volatility of the daily CAD/USD exchange rate returns increased significantly after the federal funds rate reached its zero lower bound in November 2008. Overall, I find that four out of the five exchange rates in this paper do not experience change in their volatility after November 2008. Hence, the implementation of unconventional monetary policy does not lead to significant changes in the volatility of these exchange rates in the long run overall.

Why was volatility not impacted by the change in policy? To understand this one might wish to consider two separate responses to the implementation of unconventional monetary policy. First, unconventional monetary policy may be expected to play an important role in promoting economy recover after the financial crisis; however, there is uncertainty about the impacts of the policy on financial markets due to unfamiliarity by the market participants of

the new policy, thus leading to higher volatility in financial markets. Moreover, one of the effects that the policy may have is distorting exchange rates and other asset prices, which may result from "excessive speculation" (Shaun K. Roache and Marina V. Rousset 2013). These arguments suggest that exchange rate volatility may increase after the policy change in November 2008 on account of unfamiliarity with the new policy and distortions introduced by the new policy.

Second, however, the Fed's unconventional monetary policy may contribute to low volatility in financial market according to an alternative point of view. The Fed may be very interested in making unconventional monetary policy successful and therefore bends over backwards to make the policy transparent, reducing uncertainty. The idea that the Fed has been successful in this regard is backed up by the finding of Tan and Kohli (2011) who show that stock market volatility has been artificially low after the implementation of QE. Possible reasons for such are: QE investments may keep security prices from falling, hence ensuring the investors; QE operation is viewed as a stable process that can be performed for a long period of time, therefore reducing uncertainty of Fed's continuing monetary policy. Therefore, uncertainty of Fed's monetary policy may not be that high due to the stable and transparent process of QE operations in the long run, causing exchange rates to be less volatile than before. If the two effects on the exchange rate volatility counteract each other at the same time, the volatility may not be change significantly, as the results show.

It has been discussed above that the volatility may not be changed substantially in the long run. What about the patterns in the short run? Impacts may differ in the short-run. That is to say there could be intraday effects on exchange rate volatility, however they are washed out because only daily data are examined in this study. Therefore, short-live effects on the volatility can only be investigated in an intraday model setup. Based on the results in this study, the implementation of unconventional monetary policy does not lead to higher

volatility in the foreign exchange market. In the next chapter we will take another look at this question.

2.5 Conclusion

This paper examines the behavior of exchange rates in response to the policy change implemented by the Fed due to the federal funds rate being stuck at the zero lower bound since November 2008. First and second moments of exchange rates are studied in this paper. Several conclusions are derived from this analysis. First, during the pre-November 2008 period, long term interest rate spreads played an important role in determining exchange rate return for three out of the five currency pairs, which are the AUD/USD, EUR/USD and GBP/USD, while the short term interest rate spread mattered only in the case of EUR/USD. During the post-November 2008 period, however, neither long term nor short term interest rate spreads affected exchange rate returns significantly. Interest rates seemed to lose their influence on exchange rate returns after the policy change.

The second conclusion is in regards to the effect of unconventional monetary policy on the volatility of exchange rate returns. There is no significant change in the volatility in the long run due to the recent policy change in 2008 for four out of the five cases. This implies that unconventional monetary policy does not contribute to higher volatility in the foreign exchange market in the long run for AUD/USD, EUR/USD, GBP/USD and JPY/USD. The exception is CAD/USD, for which the volatility rises significantly during the post November 2008 period.

We find it interesting that there are no significant changes in the volatility of exchange rates following the introduction of unconventional monetary policy. But these results are contingent on taking a long run approach. We now shift our attention to considering a narrower time period. Movements of exchange rates take place so rapidly that the daily

exchange rate data used in this paper may not capture enough variations of the exchange rate within a day. Therefore, higher frequency data with narrower time windows are used in the following chapters to analyze whether there are more immediate impacts of monetary policy on exchange rate behavior.

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Table 2.1 Short Term Interest Rates for Each country and the Data Sources

Country	Short term interest rate	Data Source
US	Federal funds rate	The Federal Reserve Bank of St. Louis https://research.stlouisfed.org/fred2/series/DFF
Australia	30-day bank accepted bills rate	Bank of Australia http://www.rba.gov.au/statistics/tables/xls-hist/f01dhist.xls
Canada	Overnight Money Market Financing Rate	Bank of Canada http://www.bankofcanada.ca/rates/interest-rates/canadian-interest-rates/
Euro Area	three-month Euro Interbank Offered Rate	Bank of Finland http://www.suomenpankki.fi/en/tilastot/korot/pages/tilastot_markkina-_ja_hallinnolliset_korot_euriborkorot_pv_chrt_en.aspx
UK	three-month London Interbank Offered Rate	The Federal Reserve Bank of St. Louis https://research.stlouisfed.org/fred2/series/GBP3MTD156N
Japan	Uncollateralized Overnight Call Rate	Quandl.com https://www.quandl.com/data/BOJ/STSTRDCLUCON-Call-Rates-Uncollateralized-Overnight-Daily

Table 2.2 Long Term Interest Rates for Each Country and the Data Sources

Country	Long term interest rate	Data Source
US	10-Year Treasury Constant Maturity Rate	The Federal Reserve Bank of St. Louis https://research.stlouisfed.org/fred2/series/DGS10
Australia	10-year Government Bond yield	Bank of Australia http://www.rba.gov.au/statistics/tables/xls-hist/f02dhist.xls
Canada	10-year Government Bond yield	Bank of Canada http://www.bankofcanada.ca/rates/interest-rates/lookup-bond-yields/
Euro Area	10-year Government Bond yield	European Central Bank http://sdw.ecb.int/browseExplanation.do?REF_AREA=308&node=2018801&PROVIDER_FM_ID=&FREQ=B&INSTRUMENT_FM=KR&DATA_TYPE_FM=CHG&sfl5=3&sfl4=4&DATASET=0#FM - Financial market data2
UK	10-year Government Bond yield	Bank of England http://www.bankofengland.co.uk/boeapps/iadb/index.asp?Travel=NIxIRx&levels=1&XNotes=Y&C=C6S&A55047XNode41513.x=1&A55047XNode41513.y=2&XNotes2=Y&Nodes=X4051X4052X4053X4058X41513&SectionRequired=I&HideNums=-1&ExtraInfo=true#BM
Japan	10-year Government Bond yield	Quandl.com https://www.quandl.com/data/YC/JPN10Y-Japanese-Government-10-Year-Bond-Yields

Table 2.3 Empirical Results for AUD/USD, CAD/USD, EUR/USD, GBP/USD, and JPY/USD

$$r_t = c_1 + \beta_1(1 - D_t)(i_t - i_t^*) + \beta_2 D_t(i_t - i_t^*) + \gamma_1(1 - D_t)(I_t - I_t^*) + \gamma_2 D_t(I_t - I_t^*) + \rho D_t + \varepsilon_t \quad (2.1)$$

$$h_t = c_2 + \theta\varepsilon_{t-1}^2 + \varphi h_{t-1} + \delta D_t \quad (2.2)$$

		AUD/USD	CAD/USD	EUR/USD	GBP/USD	JPY/USD
Mean Equation	β_1	-0.0001383	0.0001774	**-0.0010049***	-0.0001956	0.0000536
	p-value	(0.375)	(0.374)	(0.001)	(0.137)	(0.589)
	β_2	0.0002836	-0.0004616	-0.0002533	0.0001605	-0.0004363
	p-value	(0.578)	(0.290)	(0.405)	(0.776)	(0.906)
	γ_1	**0.0011372***	-0.0001165	**0.0025607***	**0.0007819***	0.0003988
	p-value	(0.021)	(0.702)	(0.003)	(0.027)	(0.153)
	γ_2	-0.0001782	-0.00076	-0.0005688	-0.0006257	-0.000046
	p-value	(0.858)	(0.926)	(0.289)	(0.491)	(0.901)
	ρ	-0.0007433	-0.0002505	**-0.0009391**	0.0001476	0.001495
	p-value	(0.868)	(0.599)	(0.044)*	(0.710)	(0.130)
Variance Equation	θ	**0.05665***	**0.1296***	**0.0858***	**0.04373***	**0.05197***
	p-value	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
	φ	**0.9346***	**0.8572***	**0.9014***	**0.9483***	**0.9452***
	p-value	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
	δ	-0.1132	**0.9533***	1.5831	-0.0886	7.3186
	p-value	(0.640)	(0.007)	(0.229)	(0.740)	(0.99)

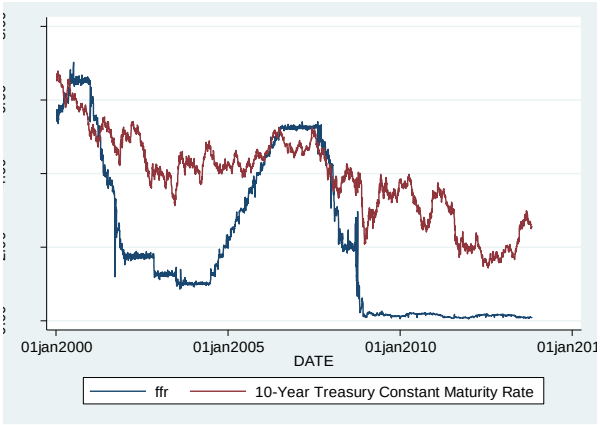

Figure 2.1 US Short Term and Long Term Interest Rates

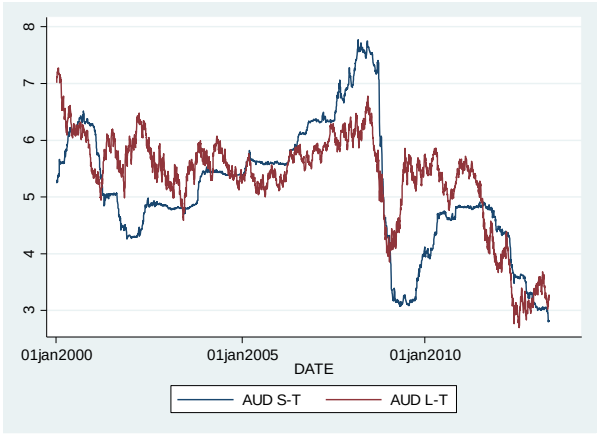

Figure 2.2 Australia's Short Term and Long Term Interest Rates

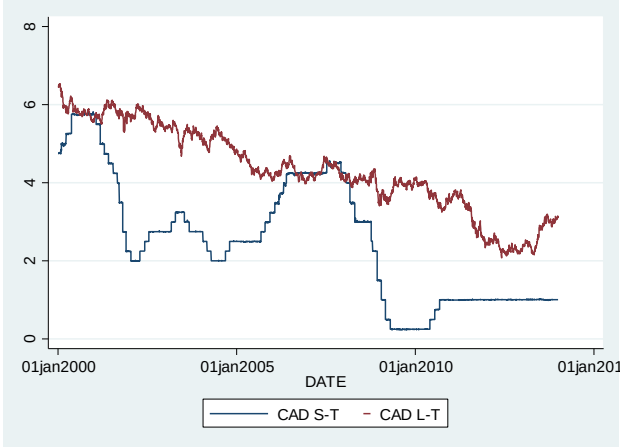

Figure 2.3 Canada's Short Term and Long Term Interest Rates

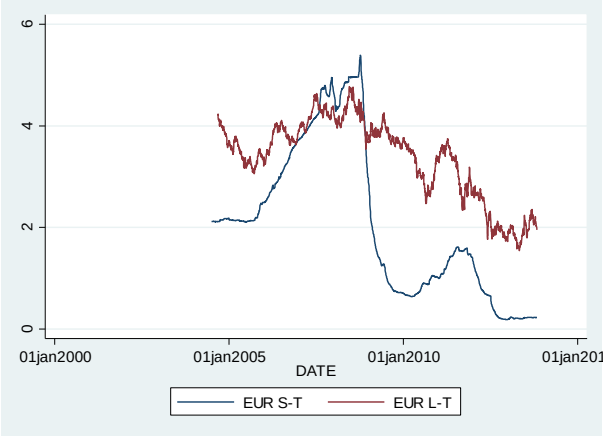

Figure 2.4 Euro Area's Short Term and Long Term Interest Rates

Figure 2.5 UK's Short Term and Long Term Interest Rates

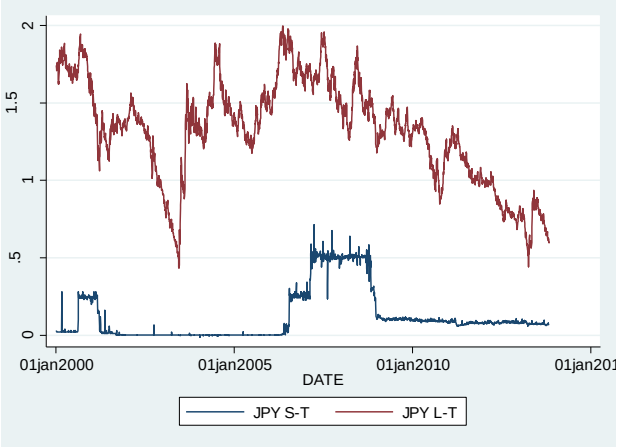

Figure 2.6 Japan's Short Term and Long Term Interest Rates

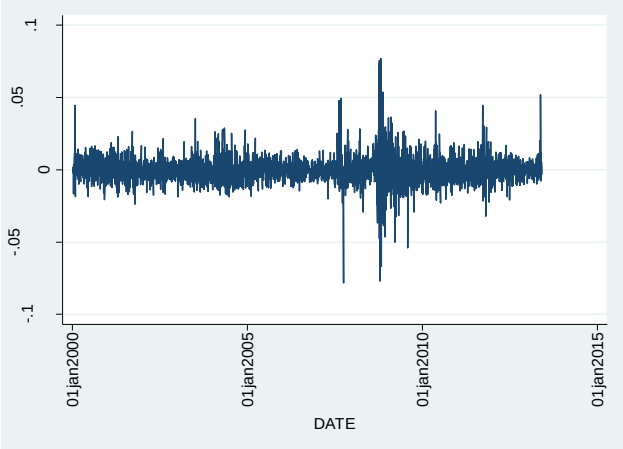

Figure 2.7 AUD/USD Exchange Rate Return

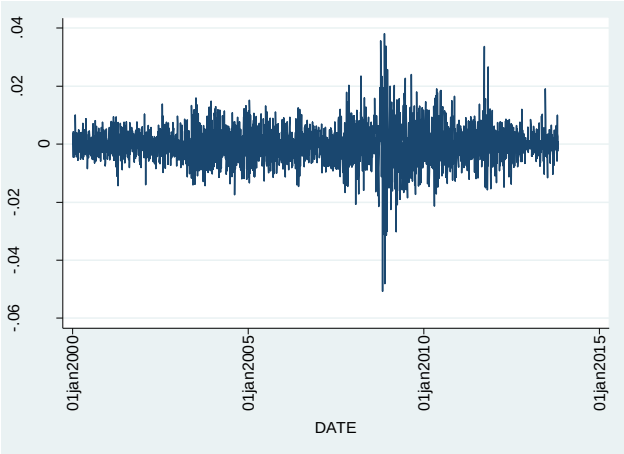

Figure 2.8 CAD/USD Exchange Rate Return

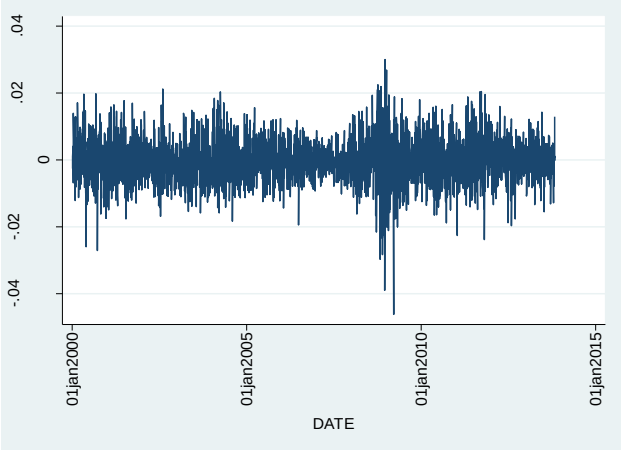

Figure 2.9 EUR/USD Exchange Rate Return

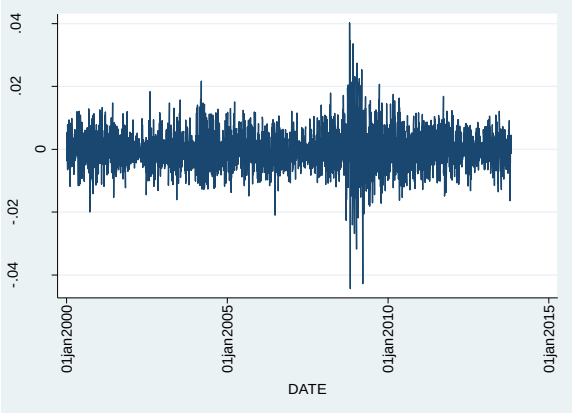

Figure 2.10 GBP/USD Exchange Rate Return

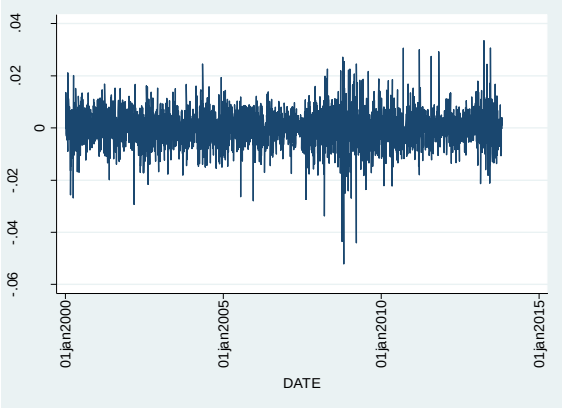

Figure 2.11 JPY/USD Exchange Rate Return

CHAPTER 3

THE EFFECTS OF CONVENTIONAL AND UNCONVENTIONAL MONETARY POLICY ON EXCHANGE RATE VOLATILITY

3.1 Introduction

This paper studies the impact of unconventional and conventional monetary policy announcements on the volatility of the U.S. dollar with respect to six currencies, the Australian dollar, British pound, Canadian dollar, Euro, Japanese yen, and Swiss franc. Narrow windows around policy announcements and high-frequency second-by-second intraday data are used in the analysis. The data used span from October 2001 to February 2014.

The term "monetary policy" refers to the monetary actions undertaken by a central bank, such as the Federal Reserve in the United States, to control the availability and cost of money and credit with the final intent of promoting favorable economic conditions. The Federal Open Market Committee (FOMC), a committee within the Federal Reserve System, makes crucial decisions about monetary policy. The FOMC meets about eight times each year to determine the policy to be implemented during the interval between meetings. The decisions made in the meeting are revealed to the public by the announcements made after each meeting. In this paper, I examine the changes, if any, in exchange rate volatility around FOMC announcements under the two monetary policy regimes.

In response to the 2007 financial crisis and recession, the Fed used conventional monetary policy to help steer the economy onto a better trajectory. Under conventional monetary policy the Fed lowers the Federal funds rate in order to stimulate the economy.

However, the Fed ran into a problem in October 2008, since the federal funds interest rate reached zero in October 2008, in effect a lower bound for interest rates, therefore leaving the Fed with no more room to continue to stimulate the economy[6] using conventional monetary policy. In its effort to continue to counteract the recession, the Fed adopted a new and unproven method to conduct monetary policy. It began to implement a type of unconventional monetary policy, by making large-scale asset purchases (LSAPs) usually referred to as quantitative easing (QE). Under QE, the Fed tries to influence long-term interest rates instead, which at the time were well above zero.

However, we still do not know the full impact of this new unconventional monetary policy on financial markets, including the foreign exchange market, one of the most important financial markets. Moreover, an important channel of monetary policy transmission mechanism is through the value and behavior of the country's currency in the foreign exchange markets. For this reason, it is important to understand the impact of the new policy tool on the foreign exchange market.

Prior research on the impact of unconventional versus conventional monetary policy on exchange rates has focused on how the two policies affect the level of the exchange rate. Glick and Leduc (2013) examine the effects of unconventional monetary policy on the level of the U.S. dollar against four other currencies. Using intraday data, they find that "monetary policy now has much the same bang per surprise on the value of the dollar as previously," meaning that the effects of the policy on the level of the exchange rate are the same across monetary policy regimes. However, in order to evaluate unconventional monetary policy comprehensively, the volatility of exchange rates should also be taken into account.

[6] In all fairness, nominal interest rates can go below zero as in the case of another policy experiment undertaken by the European Central Bank (ECB) as recently reported by the *Wall Street Journal*, "Lowering the rate on overnight bank deposits at the ECB into negative territory--effectively forcing banks to pay to deposit excess funds--would put the ECB into uncharted territory as the first major central bank to experiment with such a policy. A negative rate could encourage banks to lend money to each other, but could also have adverse effects on bank profits." (Blackstone, Brian and Lawton, Christophoer, "ECB's Sabine Lautenschläger: Open to Negative Rates, Asset Purchases," *The Wall Street Journal*, March 10, 2014)

The intent of this paper is to answer two sets of questions. First, do monetary policy announcements affect exchange rate volatility? Specifically, do we observe a change in the volatility of the exchange rate around the time that monetary announcements are made? And if so, are those changes in volatility such that exchange rates become more or less volatile relative to non-announcement periods? Second, does the effect differ across the conventional and unconventional monetary policy regimes? If yes, which one has larger effects on the volatility? In sum, the null for the first hypothesis is that monetary policy announcements have no effects on exchange rate volatility while the alternative is that monetary policy announcements have effects on exchange rate volatility. The null for the second hypothesis is that the impacts of monetary policy announcements stay the same across the two monetary policy regimes while the alternative is that the impacts are different across regimes.

Monetary policy announcements can impact exchange rate volatility through different channels. There are at least four different methods by which monetary policy announcements are thought to affect exchange rate volatility. They are the Efficient Market Hypothesis, via interest rate parity, through the signaling channel, and through the portfolio balance channel.

First, according to the Efficient Market Hypothesis, financial markets are "informationally efficient". “Price changes should reflect the arrival and processing of all relevant new information” (Andersen and Bollerslev 1998). Therefore a monetary announcement is providing the market with new information concerning the direction the Fed is taking with respect to monetary policy. We might therefore expect that this new information will be reflected in additional trading activity that causes exchange rates to become more volatile. In addition, the arrival of information explains the remarkable periodic clustering variation in intraday returns (Gau and Hua 2007). The information is interpreted differently and market participants may be responding to the new information in different ways, hence the market returns become more volatile.

The second channel by which monetary policy announcements may affect the exchange rate is through Uncovered Interest Rate Parity (UIRP). UIRP may influence the setting of the spot exchange rate. Interest rate parity is a no-arbitrage condition representing an equilibrium state under which investors will be indifferent to investment in two countries[7]. According to UIRP, the change in interest rates that results from monetary policy announcements may result in changes in exchange rates due to the availability of arbitrage opportunities that subsequently move the exchange rate until there are no more arbitrage opportunities and equilibrium is once again established. In this way, the exchange rate can be impacted by monetary policy announcements.

A third mechanism by which monetary policy announcements may impact the volatility of the exchange rate is through the signaling channel. The signaling channel suggests that the central banks can signal to market participants the "appropriate" levels of macroeconomic and financial variables even if the central bank does not have enough resources to change market outcomes. For example, monetary policy announcements of large scale asset purchases (LSAP), could have induced investors to revise down their expectations for future short-term interest rates. They may have also expected that the near-zero federal funds rate target will last for a longer time period (Bauer and Rudebusch 2011.) Besides, since market participants have different data sets, they may conduct different actions while facing the same signal, which may result in higher volatility in the market.

A fourth avenue by which monetary policy announcements can impact the exchange rate is through the portfolio balance model. In the portfolio balance approach, domestic and foreign bonds are not perfect substitutes. Investors construct portfolios using domestic money and domestic bonds, and foreign currency and foreign currency denominated bonds. Whenever aggregate economic conditions change, investors adjust their portfolios to a new

[7] Feenstra, Robert C.; Taylor, Alan M. (2008). *International Macroeconomics*. New York, NY

equilibrium, based on a variety of fundamental conditions, i.e. wealth, tastes, expectation, and etc. Thus, these actions will result in the buying and selling of assets across markets, which in turn will influence exchange rates. Different market participants will have different adjustments to make, some buying a particular foreign currency, others selling causing market prices to jump around, impacting volatility.

3.2 Literature Review

Relevant empirical literature linking monetary policy to exchange rate behavior can be divided into three categories. The first category covers the impact of monetary policy change on exchange rate volatility in the long run using daily, weekly or even lower frequency data. The second category examines how exchange rate volatility is impacted by macroeconomic news and announcements using intraday exchange rate data. This group of papers provides evidence that exchange rate volatility does respond to new information. The third category of studies in the literature on monetary policy and the exchange rate focuses on the change to unconventional monetary policy and considers how such is impacting the value of the US dollar.

In an earlier paper, Pozo (1988) studies the volatility of five major exchange rates under different monetary operating procedure in the US. She was motivated by a change in Fed policy, resulting in the Fed using non-borrowed reserves as its operating target between October 6 1979 and September 30 1982. In contrast, the Federal funds rate was used as the operating target before and after that period. The results indicate that the exchange rate volatility is higher in the non-borrowed reserves target period.

A similar result is obtained by Lastrapes (1989), who examines the effects of shifts in U.S. monetary policy regimes on the volatility of foreign exchange rates by estimating an ARCH process. Consistent with Pozo (1988), four out of the five exchange rates in the study

are more volatile during the period that the Fed used non-borrowed reserves as the operating target.

The second category of studies linking monetary policy to exchange rates shows how exchange rate volatility is impacted by macroeconomic news and announcements using intraday exchange rate data. This group of papers provides additional evidence that exchange rate volatility does respond to news.

Andersen and Bollerslev (1998) find macroeconomics announcements have a large impact on the Deutsche mark-dollar volatility when the information is released using five-minute returns as the unit of observation. The majority of the releases induce the volatility to increase by approximately 5% for a typical trading day. They also find that the induced volatility increases are short-lived. Bauwens et al (2005) use 5-minute high-frequency data to show the significant impact of the scheduled news' release on exchange rate volatility during the pre-announcement periods. However, they do not find significant change in the volatility during the post-announcement period.

Gau and Hua (2007) discuss the impact of public news arrival on the New Taiwan dollar/US dollar exchange rate volatility using data at 15-minute intervals. Chang and Taylor (2003) uncover that DM/USD volatility is significantly impacted by US and German macroeconomic news and German Bundesbank monetary policy news using minute data. Evans and Speight (2010) examine how intraday volatility responds to macroeconomic news using five-minute returns for Euro-Dollar, Euro-Sterling and Euro-Yen exchange rates. The results indicate that the predominant reaction of volatility occurs in response to US macroeconomic news, while Eurozone, German and UK announcements also have significant impacts on exchange rate volatility.

The third category of papers linking monetary policy and exchange rates takes the recent monetary policy change into account. However, the research to date is only concerned

with the impact of the monetary policy announcements on the level of exchange rate using intraday data. They do not consider the announcements' impacts on volatility. One such example is Glick and Leduc (2013).

In examining the effects of unconventional monetary policy on the level of the U.S. dollar against four other currencies, Glick and Leduc (2013) find that the effect of news on the exchange rate under the new policy has been as strong as it was when the Federal Reserve used the Federal Funds rate as its operating target. Neely (2013) studies the impact of the Federal Reserve's unconventional monetary policy announcements in 2008-2009 on five exchange rates. He finds that the depreciations of the US dollar, resulting from the monetary policy announcements, are consistent with estimates of the impacts of conventional monetary policy shocks. He further concludes that unconventional monetary policy can result in the depreciation of US dollar even at the zero lower bound.

This paper contributes to the accumulating empirical literature addressing and comparing the impact of both unconventional and conventional monetary policy announcements on the volatility of the exchange rate. The use of high frequency data allows me to better isolate the response of exchange rate movements to monetary announcements, and separate those from other possible shocks that take place several times a day. In addition, using intraday exchange rate data I can isolate U.S. monetary policy from foreign monetary policy. The hypothesis is tested using six different exchange rates and hence six distinct cases.

3.3 Empirical Model

This paper aims to study the responsiveness of the volatility of the exchange rate with respect to FOMC announcements. To be more specific, I pose the following hypotheses. For the first first hypothesis, the null (H_0) is that there are no differences in the volatility of the exchange rate immediately before, during and immediately following FOMC announcements.

The Alternative hypothesis (H_1) is that there are differences in the volatility of the exchange rate immediately before, during and immediately following announcements. For the Second hypothesis, the null (N_0) is that The impacts of FOMC announcements on exchange volatility are the same under different monetary policy regimes. The alternative hypothesis (N_1) is that the impacts of FOMC announcements on exchange rate volatility are not the same under different monetary policy regimes.

The second-by-second exchange rate data are from ForexTickData[8]. They provide intraday spot exchange rate data on the Australian dollar (AUD), Canadian dollar (CAD), Swiss franc (CHF), Euro (EUR), Great British pound (GBP), all against the US dollar. The data used span from October 2001 to February 2014. Figure 3.1 through Figure 3.6 display a sample subset of the returns for the second by second data for each of the currencies from November 24 2008 to November 26 2008. These represent 259,200 observations. There was an announcement made on November 25 at 8:15 am. The arrow on the X-axis shows the time when the announcement took place. The exchange rate AUD/USD, displayed in Figure 3.1, appears to fluctuate by larger margins upon the announcement. The exchange rate CHF/USD in Figure 3.3, however, does not seem to display a different pattern at the time of the announcement. Figure 3.7 combines the plots for all the six exchange rates. Visually and in the aggregate it seems that the returns fluctuate more around the announcement period.

Table 3.1 shows the descriptive statistics for 5-minute returns of the six exchange rates over the sample period. Inspection of the remaining data suggests that the 5-minute returns exhibit skewness and kurtosis, features commonly observed in high-frequency data (Wang et al 2001). Take the first line for example. On average, the 5-minute return for the USD/AUD exchange rate over the sample period exhibits appreciation of the Australian

[8] http://www.forextickdata.com/

dollar vis-a-vis the U.S. dollar. The distribution of return is positively skewed and shows considerable kurtosis.

The volatility of the exchange rate is measured by the standard deviation of exchange rate returns over a 5 minute interval. During each 5 minute time interval, I have second by second data (60X5)=300 observations. I obtain the second by second return and hence end up with 299 returns. From that series I obtain the standard deviation of returns for the 5 minute interval. Table 3.2 displays the descriptive statistics for the volatility of the six exchange rates. The third column of the table shows the average of the volatility of each exchange rate. According to the descriptive statistics, it appears that the Australian dollar is most volatile while the British pound is least volatile.

Regarding the announcement data, the FOMC makes around eight FOMC announcements each year, and the exact time of each announcement is obtained from the official Federal Reserve website[9]. My sample period for conventional monetary policy actions extends from October 2001until October 2008 at which time the federal funds target rate reached its lower bound. The events in the conventional policy period consist of 58 FOMC announcements. For the unconventional policy period, there were 50 FOMC announcements between November 2008 and February 2014. Table 3.3 presents examples of the FOMC announcements under conventional policy regime and unconventional regime.

I use ordinary least squares (OLS) method to model the impact of announcements on exchange rate volatility. To study how volatility changes around announcements, I divide the time around announcements into three periods; the pre-announcement period, the contemporaneous period and the post-announcement period. The observation windows are equal to 5 minutes before the announcement (pre-announcement period), 5 minutes just after the announcement (contemporaneous period), and 15 minutes after the contemporaneous

[9] http://www.federalreserve.gov/monetarypolicy/fomc_historical.htm

period (post-announcement period, which is 20 minutes after the announcement). As an example, Figure 3.8 demonstrates the time line around the monetary policy announcements made December 16, 2008.

The regression that I estimate is as follows:

$$\mathrm{vol}_t = \alpha\,\mathrm{vol}_{t-1} + \beta\,\mathrm{PRE}_t + \beta'(\mathrm{UCMP}_t \times \mathrm{PRE}_t) + \gamma\,\mathrm{CONT}_t + \gamma'(\mathrm{UCMP}_t \times \mathrm{CONT}_t) + \delta\,\mathrm{POST}_t + \delta'(\mathrm{UCMP}_t \times \mathrm{POST}_t) + \mathrm{constant} + \theta\,\mathrm{UCMP}_t + e_t \qquad (3.1)$$

where vol is the standard deviation of exchange rate return per five-minute time interval. This is calculated from second-by-second spot exchange rate data. The dummy variable, PRE_t represents the pre-announcement period, hence PRE_t=1 if t is 5 minutes before announcements and 0 otherwise. The variable denoted CONT_t is a dummy variable representing the contemporaneous period. This means CONT_t = 1 if t is 5 minutes after the announcement and 0 otherwise. The dummy variable, POST_t represents the post-announcement period, where POST_t=1 if t is 20 minutes after the announcement and 0 otherwise. The dummy variable, UCMP_t, distinguishes the conventional from the unconventional monetary policy regime. Therefore UCMP=0 before October 2008 and 1 after that.

The coefficients on PRE_t, CONT_t, and POST_t (β, γ, and δ) provide evidence on the impact of announcements on exchange rate volatility before the policy change. The coefficients on the interaction terms, $(\mathrm{UCMP}_t \times \mathrm{PRE}_t)$, $(\mathrm{UCMP}_t \times \mathrm{CONT}_t)$ and $(\mathrm{UCMP}_t \times \mathrm{POST}_t)$, β', γ', and δ', capture the change in the impact of announcements on volatility before and after the policy change. Therefore the significance level of β', γ', and δ' indicate whether the impacts of announcements on volatility are different under the two different policy regimes. Statistical significance implies that the impacts are different. Furthermore, $\beta + \beta'$, $\gamma + \gamma'$, and $\delta + \delta'$ capture the impact of announcements on exchange rate volatility after the

policy change and can therefore help us discover whether the difference is of economic significance. The coefficient θ captures the structural shift, if any, of the overall volatility in the non-announcement periods.

3.4 Results

The results of estimating equation (3.1) for the 6 exchange rates are presented in Table 3.4. Turning first to the Australian dollar, the coefficient on PRE, β, is not statistically significantly different from zero, suggesting that relative to non-announcement periods (e.g. when referring to Figure 3.8, the periods before 9:55 12/18/2008 and after 10:15 12/16/2008), volatility does not change substantially immediately before announcements in the case of the Australian dollar. The coefficients γ and δ, however, are positive and statistically significantly different from zero, which means the volatility of the Australian dollar increases in the contemporaneous period and post announcement period. Focusing on the coefficients on the interaction terms (β', γ', and δ'), which indicate whether there is change in the impact of the announcements on the volatility under the different monetary policy regimes, the three coefficients are not statistically significantly different from zero. In other words, the FOMC announcements have the same impact on the USD/AUD exchange rate volatility under the different monetary policy regimes.

Take the Japanese yen for another example. The coefficients β, γ and δ are positive and significantly different from zero, indicating the increase in the volatility of the yen during the three periods around announcements. The coefficients β' and γ' are also positive and significantly different from zero, which implies the impact of announcements become greater under the unconventional policy regime compared to under the conventional policy regime.

Next, if I compare the results for all the six exchange rates together, five exchange rates present higher volatility during announcements, compared to non-announcement periods,

under the conventional policy regime. The results are also different for the exchange rates when I take the policy shift into account. The effects of the announcements in the contemporaneous period under unconventional regime are greater than the effects under conventional regime, with γ' being positive and significantly different from zero， for all the exchange rates except the Australian dollar. The impacts are the same under different policy regimes in the post-announcement period for all six exchange rates. Turning to the pre-announcement period, the influence of the announcements under conventional regime is smaller in the case of the Euro, the influence is greater in the case of the Japanese yen while the influence is of no difference in the case of the other four exchange rates. The coefficient on the lagged volatility variable, α, is positive and significantly different from zero for all six exchange rates, which implies the persistence of exchange rate volatility. The Australian dollar and the Swiss franc have greater persistence in the volatility compared to the other exchange rates. Besides, all the six exchange rates increase in volatility in non-announcement under unconventional regime according to the significance of coefficient θ.

The rise in volatility in the announcement periods is substantial compared to the non-announcement periods. Take the contemporaneous period under conventional monetary policy for example. The volatility of the Australian dollar (AUD) increases by $9.26(\times 10^{-5})$, which is almost triple the overall average of volatility of $3.03(\times 10^{-5})$. The volatility of the Canadian dollar (CAD) increases by $3.4(\times 10^{-5})$ compared to $2.04(\times 10^{-5})$ in non-announcement periods. The volatility of the Swiss franc (CHF) increases by $6.93(\times 10^{-5})$ which is an almost three fold increase in the overall volatility $2.49(\times 10^{-5})$. In short, the monetary announcements cause significant and sizeable responses in volatility for five of the six exchange rates in the pre-announcement period, and for all six exchange rates in the

contemporaneous and post-announcement periods. This indicates that these announcements cause immediate pronounced increases in volatility[10].

According to the results, the FOMC announcements lead to larger exchange rates fluctuations around announcements under both policy regimes. The greatest change in the impact of announcement on exchange volatility over the two regimes is in the contemporaneous period. Under unconventional monetary policy regime, the monetary announcements cause even greater responses in volatility for five out of the six exchange rates in the contemporaneous period. It causes greater responses for one out of the six exchange rates in the pre-announcement period and during the post-announcement period.

3.5 Robustness Check

One question that may be worth asking is whether the different impact of announcements on the volatility is due to the monetary policy shift or to the recession. In effect I conduct a robustness check of the results taking this question into account. The recent recession, having begun in December 2007, lasted 18 months[11]. To make sure that the change in the impact of announcement on the volatility is not due to the recession, I drop the observations for the recession period, and estimate the same regression.

The regression results are displayed in Table 3.6. The results are consistent with the main results in the previous section. The only difference is that the volatility of the Australian dollar does not respond to announcements under both policy regimes. Hence, the overall finding of a difference in the impact of announcements under the different monetary policy regimes does not appear to be due to the Great Recession.

[10] Table 5 displays the average volatility during different periods pre and post November 2008 to provide a simple and clear comparison of the volatilities.
[11] The recession begun in December 2007 and officially ended in June 2009, according to the Business Cycle Dating Committee of the National Bureau of Economic Research, the official arbiter of such dates.
http://www.nber.org/cycles/sept2010.html

3.6 Monetary Policy Revisited

Some argue that the effects of expansionary monetary policy announcements and contractionary announcements are asymmetric with respect to their impacts on the financial markets. In this section, I test for this asymmetry. In order to do so, I distinguish expansionary announcements from others. I use different methodologies to determine whether announcements are expansionary or contractionary (i.e. the type of announcements) under conventional monetary regime versus under unconventional regime, for the reason that the Fed uses different approaches to implement monetary policy over the two regime periods.

Under conventional monetary policy, I use the change in the federal funds rate to identify the type of announcements. If the change in the federal funds rate was negative, i.e. the Fed was lowering the rate, the announcement is considered as expansionary under conventional monetary policy regime. On the other hand, if the change in the federal funds rate was zero or positive, it is counted as "non-expansionary." Among the 59 FOMC announcements under conventional policy regime in the sample, there are 13 announcements pointing to a negative change in the Federal funds rate, hence the policy stance is identified as expansionary. The remaining 46 announcements are defined as non-expansionary.

While it is straight forward to categorize announcements as expansionary or not under conventional monetary policy (since we need only consider in which direction, if any, the federal funds rate is posed to move); under unconventional monetary policy regime, it is less obvious whether announcements are expansionary or not, given that the federal funds rate remained at the zero lower bound during the whole unconventional policy regime period. To define the announcements as expansionary or non-expansionary, I need to first analyze how the monetary policy is describe by the FOMC using the information in the statement for each

FOMC meeting released by the Board of Governors of the Federal Reserve System website[12]. Then I am able to identify whether an announcement is expansionary or not.

By consulting the statements for each FOMC meeting, I categorize the monetary policy according to four different criteria that are described. These four criteria revolve around securities, the credit environment, policy intentions and interest rates.

The first criterion is with respect to securities. The statements indicate the amount of securities the Federal Reserve will purchase or roll over if the securities are maturing. Securities include agency mortgage-backed securities, agency debt, and long-term treasury securities.

The second criterion concerns the credit environment. For example, in the statement released on March 18, 2009, the FOMC announced that "the Federal Reserve has launched the Term Asset-Backed Securities Loan Facility to facilitate the extension of credit to households and small businesses and anticipates that the range of eligible collateral for this facility is likely to be expanded to include other financial assets[13]." On the other hand, the Fed has made statement such as "the Federal Reserve has been closing the special liquidity facilities that it created to support markets during the crisis[14]." A statement of this sort would be classified as non-expansionary.

The third criterion is about the intention of the policy; Announcements (statements) point out whether actions are intended to stimulate the economy or to cool down the economy. For example, "to support a stronger economic recovery" or "to promote a stronger pace of economic recovery," is used in the statement to describe the expansionary intention of the policy. On the other hand, an announcement made that include the following type of statement, "in order to promote a smooth transition in markets, the Committee will gradually

[12] http://www.federalreserve.gov/monetarypolicy/fomccalendars.htm
[13] http://www.federalreserve.gov/newsevents/press/monetary/20090318a.htm
[14] http://www.federalreserve.gov/newsevents/press/monetary/20100316a.htm

slow the pace of its purchases of both agency debt and agency mortgage-backed securities[15]," suggests non-expansionary policy. Such an announcement was made on January 27, 2010 for example.

The fourth criterion refers to the federal funds rate or long term interest rates. Statements might suggest that the FOMC anticipate the length of the federal funds rate staying at the lower bound, the FOMC expects lower levels for the federal funds rate for an extended period, or expects the policy "should put downward pressure on long-term interest rates and help make broader financial conditions more accommodative[16]." An example of this is the announcement made on September 21, 2011.

The first criteria is mentioned in all the FOMC statement under unconventional policy in the sample period which is not surprising because the Fed is implementing unconventional monetary policy by making large scale asset purchases. In the context of the federal funds rate being set to the zero lower bound, the fourth criteria is mentioned in almost all the FOMC statement. Therefore, I define the type of monetary policy based on criteria II and III. When refereeing to criterion II, the policy announcement is considered as expansion, if the FOMC is lauching to loosen the credit environment, while it is non-expansionary if the FOMC is closing "the special liquidity facilities that is created to support markets during the crises." Regarding criterion III, the announcement is considered as expansionary if the intention of the policy is to "support a stronger economic recovery," while it is non-expansionary if the policy is to promote a smooth transition in the markets.

Under unconventional monetary policy regime, the Federal Reserve had 43 FOMC announcements from November, 2008 to February 2014. Among the 43 announcements, 32 are identified as expansionary policy announcements, and the remaining 11 non-expansionary announcements using the criteria described above. (See Table 3.7 for the category each

[15] http://www.federalreserve.gov/newsevents/press/monetary/20100127a.htm
[16] http://www.federalreserve.gov/newsevents/press/monetary/20110921a.htm

announcement is in.) The regression distinguishing expansionary and non-expansionary announcements is as follows:

$$\mathrm{vol}_t = \alpha\,\mathrm{vol}_{t-1} + \sum_{j=1}^{2}\sum_{\tau=1}^{3}\beta_{j,\tau}\,d_{j,\tau,t} + \sum_{j=1}^{2}\sum_{\tau=1}^{3}\gamma_{j,\tau}\,(\mathrm{UCMP}_t * d_{j,\tau,t}) + \delta\mathrm{UCMP}_t + c + \epsilon_t \quad (3.2)$$

The variable denoted $d_{j,\tau,t}$ is a dummy variable representing an announcement of category j during the period τ. The dummy variable is equal to 1 if there is a FOMC announcement during the time interval t and is 0 otherwise. The index τimplies a time window around each announcement: a pre-announcement period (τ=1), a contemporaneous period(τ=2), and a post-announcement period(τ=3). The index j indicates the category of the announcement: an expansionary announcement (j=1), and a non-expansionary announcement (j=2). The dummy variable UCMP distinguishes the different monetary policy regimes. It is equal to 0 before October 2008 and equal to 1 after that. The interaction term $\mathrm{UCMP}_t * d_{j,\tau,t}$ captures the change in the impact of announcements on exchange rate volatility under different regimes.

There were 58 announcements over the time period of analysis under the conventional regime. Thirteen are considered as expansionary because of the decrease in the federal funds rate target. There were 43 announcements under the unconventional regime, of which 32 are considered as expansionary according to evaluation of the four criteria described earlier.

Results of equation (3.2) are reported in Table 3.8. The βcoefficient show whether volatility increases significantly around announcements under the conventional monetary policy regime. Based on the results, the volatility of all the exchange rates increase significantly, responding to expansionary announcements under conventional policy regime, while five out of the six increases responding to non-expansionary announcements. The coefficient γ reveals whether the impacts of announcements on volatility are significantly different under the different regimes. Results show that in the pre-announcement periods, the

impact of expansionary announcements under unconventional regime is smaller than that under conventional regime for three out of the six exchange rates. However, results are mixed for contemporaneous periods. Regarding the non-expansionary announcements, however, the impacts of these announcements are greater under unconventional regime for the pre-announcement and contemporaneous announcements for three exchange rates. There is no significant difference in the post-announcement period for the case of the Japanese yen (JPY). According to these results, in general, it appears that the impacts of non-expansionary monetary policy announcements on exchange rate volatility are the same or greater under unconventional monetary policy relative to conventional monetary policy during the pre-announcement and contemporaneous periods; while the impacts of expansionary announcements are the same or less under unconventional monetary policy relative to conventional monetary policy with the exception of the Euro and the British pound during the contemporaneous period.

While the estimated value for β indicate the impact of announcements on volatility under conventional regime and the estimatedγ indicate the change in this impact, they do not tell us whether the impacts of announcements on volatility are significant under the unconventional monetary policy regime. The impact of announcements under unconventional regime is captured by $\beta_{j,\tau} + \gamma_{j,\tau}$. Therefore I conducted a T test to examine whether the volatility is impacted significantly around announcements under the unconventional regime.

$$H0: \beta_{j,\tau} + \gamma_{j,\tau} = 0$$

$$H1: \beta_{j,\tau} + \gamma_{j,\tau} \neq 0$$

If I fail to reject the null, it means that the impacts of announcements on the volatility are not statistically different when compared with the unconventional regime. If I reject the null, it implies that the volatility changes significantly around announcement under unconventional regime.

Table 3.9 shows results and p-values of T tests (in the parenthesis) of the linear combination of β and γ. Compared to β, which show the impact of announcements on volatility under conventional regime, four out of the six exchange rates become more volatile in the pre-announcement periods after October 2008 while five out the six are more volatile before October 2008 conditioning on the fact that the announcement is expansionary. The volatility of four exchange rates respond significantly to non-expansionary announcements in the pre-announcement period under unconventional regime compared to five under conventional regime. Three exchange rates become more volatile in the post-announcement period under unconventional regime compared to five under conventional regime if the announcement is non-expansionary.

Hence, in addition to the results that the impacts of announcement on volatility are different before and after the policy change, fewer exchange rates respond significantly to announcements under unconventional monetary policy regime with respect to volatility. Besides, none of the exchange rates decreases in volatility around announcements.

3.7 Conclusion

This paper examines six exchange rates, the Australian dollar, the Canadian dollar, the Swiss franc, the Euro, the Great British pound, and the Japanese yen all against the U.S. dollar, to determine if there is substantial impact on the volatility of these exchange rates around monetary policy announcements. This paper also investigates the change in this impact due to the change in monetary policy regime. Two conclusions follow from the results reported here. First, exchange rate volatility increases significantly around announcements compared to non-announcement period. Second, there is evidence that the increases in the volatility around announcement are different under the different monetary policy regimes and those differences depend on the category of the announcement, whether expansionary or not.

These findings have important implications. First, they indicate that US monetary policy announcements significantly affect the volatility of exchange rates around announcements. Hence, US monetary policy announcements may be a crucial source of systematic risk to market participants. Second, implementing the new monetary policy leads to a greater volatility of exchange rates in announcement periods. This is to say that market participants respond more strongly to announcements under unconventional monetary policy regime. Hence, the results suggest that implementation of QE may contribute to an increase in the volatility during the announcement period.

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Table 3.1 Descriptive Statistics for Five-Minute Returns of the Six Exchange Rates

	obs	mean	std dev	variance	skewness	kurtosis
USD/AUD	924772	1.54E-08	0.0000142	2.02E-10	724.1082	646251.1
CAD/USD	924573	6.57E-10	2.79E-06	7.77E-12	38.50704	55019.93
CHF/USD	923013	4.53E-09	5.05E-06	2.55E-11	166.81	75949.66
USD/EUR	924750	-1.88E-09	4.53E-06	2.06E-11	-341.7688	235849.5
USD/GBP	912281	6.68E-10	2.62E-06	6.84E-12	98.23094	69821.45
JPY/USD	918229	-1.78E-09	5.70E-06	3.25E-11	-94.52381	96092.77

Table 3.2 Descriptive Statistics for the Average of the Volatility of the Six Exchange Rate Returns, Measured by the Standard Deviation of the Second by Second Exchange Rate Returns Over a 5 Minute Interval.

exchange rate	obs	volatility(avg)	min	max
USD/AUD	924710	0.0000303	0	0.2679638
CAD/USD	924502	0.0000204	0	0.0018159
CHF/USD	922945	0.0000249	0	0.0646486
USD/EUR	924684	0.0000227	0	0.0025362
USD/GBP	912220	0.0000186	0	0.0026952
JPY/USD	918153	0.0000259	0	0.0038201

Table 3.3 Example of FOMC Announcements Under Both Monetary Policy Regimes.

conventional period		unconventional period	
Date	Time	Date	Time
January 30, 2002	14:15	January 28, 2009	14:15
March 19, 2002	14:15	March 18, 2009	14:15
May 7, 2002	14:15	April 29, 2009	14:15
June 26,2002	14:15	June 24, 2009	14:15
August 13,2002	14:15	August 12, 2009	14:15
September 24, 2002	14:15	September 23, 2009	14:15
November 6, 2002	14:15	November 4, 2009	14:15
December 10, 2002	14:15	December 16, 2009	14:15

Table 3.4 Results of Estimating Equation (3.1) for All the Six Exchange Rates

$$\mathrm{vol}_t = \alpha\,\mathrm{vol}_{t-1} + \beta\,\mathrm{PRE}_t + \beta'\mathrm{UCMP}_t \times \mathrm{PRE}_t + \gamma\,\mathrm{CONT}_t + \gamma'\mathrm{UCMP}_t \times \mathrm{CONT}_t + \delta\,\mathrm{POST}_t + \delta'\mathrm{UCMP}_t \times \mathrm{POST}_t + \theta\,\mathrm{UCMP}_t + \mathrm{constant} + e_t \quad (3.1)$$

	USD/AUD(*10^{-5})	CAD/USD(*10^{-5})	CHF/USD(*10^{-5})	USD/EUR(*10^{-5})	USD/GBP(*10^{-5})	JPY/USD(*10^{-5})
α	**430.62*** **	**64313.64*** **	**1922.29*** **	**59428.67*** **	**56785.03*** **	**53177.14*** **
t-stat	(4.14)	808.41	24.58	720.25	676.59	603.72
β	3.35	**1.86*** **	**3.54*** **	**2.66*** **	**2.0*** **	**2.49*** **
t-stat	(0.93)	11.26	3.58	17.37	13.32	12.64
β'	-0.327	-3.46	-0.579	**-0.546****	0.0873	**0.799*** **
t-stat	-0.06	-0.25	-0.39	-2.36	0.39	2.65
γ	**9.26****	**3.46*** **	**7.04*** **	**4.55*** **	**3.05 *** **	**4.62*** **
t-stat	2.56	20.94	7.12	29.62	20.35	23.44
γ'	-0.0368	**2.0*** **	**3.5****	**3.52*** **	**2.07*** **	**4.47*** **
t-stat	-0.01	8.01	2.35	15.21	9.14	14.82
δ	**4.69****	**0.512*** **	**3.96*** **	**0.789*** **	**0.687*** **	**1.02*** **
t-stat	2.25	5.36	6.94	8.90	7.92	8.94
δ'	0.503	0.17	0.49	-0.0415	0.00186	-0.152
t-stat	0.16	1.18	0.57	-0.31	0.01	-0.88
θ	**0.415*** **	**0.223*** **	**2.26*** **	**0.0994*** **	**0.175*** **	**0.0687*** **
t-stat	7.07	81.49	14.03	39.68	71.00	21.29
constant	**2.84*** **	**0.631*** **	**2.33*** **	**0.874*** **	**0.728*** **	**1.18*** **
t-stat	73.26	279.26	216.97	361.33	337.43	385.44

Notes:
*indicates that the coefficient is significant at the 10% level
**indicates that the coefficient is significant at the 5% level
*** indicates that the coefficient is significant at the 1% level.

Table 3.5 Average Volatility of the Six Exchange Rates During Different Periods, Namely Non-Announcement Period, Pre-Announcements Period, Contemporaneous-Announcement Period, and Post-Announcement Period.

	average volatility ($*10^{-5}$)							
	conventional				unconventional			
	non ann	pre	cont	post	non ann	pre	cont	post
AUD	2.85	6.21	12.13	7.56	3.26	6.29	12.5	8.48
CAD	1.77	4.67	7.1	4.86	2.39	4.74	9.37	6.38
CHF	2.39	5.95	9.48	6.44	2.61	5.58	13.21	7.19
EUR	2.16	5.43	8.65	5.78	2.4	4.84	11.91	7.0
GBP	1.69	4.24	6.19	4.3	2.09	4.35	8.5	5.33
JPY	2.52	5.45	8.7	5.93	2.67	6.2	13.64	7.27

Table 3.6 Robustness Check Results

	USD/AUD(*10^{-5})	CAD/USD(*10^{-5})	CHF/USD(*10^{-5})	USD/EUR(*10^{-5})	USD/GBP(*10^{-5})	JPY/USD(*10^{-5})
α	**205.11***	**60790.71*****	**1539.42*****	**54784.31*****	**49259.09*****	**46055.4*****
P value	0.065	0.00	0.00	0.00	0.00	0.00
β	1.62	**0.842*****	2.47	**2.11*****	**1.46*****	**1.4*****
P value	0.701	0.00	0.108	0.00	0.00	0.00
β'	1.37	**1.03*****	0.488	0.00835	**0.602*****	**2.09*****
P value	0.828	0.00	0.832	0.742	0.01	0.00
γ	5.51	**3.14*****	**6.09*****	**4.52*****	**3.11*****	**3.41*****
P value	0.193	0.00	0.00	0.00	0.00	0.00
γ'	3.47	**2.0*****	2.99	**3.14*****	**1.74*****	**5.03*****
P value	0.584	0.00	0.196	0.00	0.00	0.00
δ	3.36	**0.603*****	**3.45*****	**0.95*****	**0.858*****	**1.14*****
P value	0.169	0.00	0.00	0.00	0.00	0.00
δ'	1.48	0.119	0.805	0.0262	-0.0225	-0.122
P value	0.687	0.405	0.546	0.858	0.87	0.948
θ	**0.223*****	**0.228*****	**0.198*****	**0.0635*****	**0.153*****	**0.0691*****
P value	0.001	0.00	0.00	0.00	0.00	0.00
constant	**2.64*****	**0.628*****	**2.23*****	**0.943*****	**0.809*****	**1.27*****
P value	0.00	0.00	0.00	0.00	0.00	0.00

Notes:
*indicates that the coefficient is significant at the 10% level
**indicates that the coefficient is significant at the 5% level
*** indicates that the coefficient is significant at the 1% level.

Table 3.7 Monetary Policy Announcements Under Unconventional Regime and the Criteria

Announcement date	Whether expansionary	which criteria satisfied	Announcement date	Whether expansionary	which criteria satisfied
Dec. 16, 2008	yes	I II	Aug. 9, 2011	yes	I III IV
Jan. 28, 2009	yes	I II	Sept. 21, 2011	yes	I III IV
Mar. 18, 2009	yes	I II IV	Nov. 2, 2011	yes	I III IV
Apr. 29, 2009	yes	I II IV	Dec. 13, 2011	yes	I III IV
Jun. 24, 2009	yes	I IV	Jan. 25, 2012	yes	I III IV
Aug. 12, 2009	no	I III IV	Mar. 13, 2012	yes	I III IV
Sept. 23, 2009	no	I III IV	Apr. 25, 2012	yes	I III IV
Nov. 4, 2009	no	I III IV	Jun. 20, 2012	yes	I III IV
Dec. 16, 2009	no	I III IV	Aug. 1, 2012	yes	I III IV
Jan. 27, 2010	no	I III IV	Sept. 13, 2012	yes	I III IV
Mar. 16, 2010	no	I II IV	Oct. 24, 2012	yes	I III IV
Apr. 28, 2010	no	I II IV	Dec. 12, 2012	yes	I III IV
May 9, 2010	no	I II IV	Jan. 30, 2013	yes	I III IV
Jun. 23, 2010	no	II IV	Mar. 20 2013	yes	I III IV
Aug. 10, 2010	no	I II IV	May 1, 2013	yes	I III IV
Sept. 21, 2010	no	I II IV	Jun. 19, 2013	yes	I III IV
Nov. 3, 2010	yes	I III IV	Jul. 31, 2013	yes	I III IV
Dec. 14, 2010	yes	I IV	Sept. 18, 2013	yes	I III IV
Jan. 26, 2011	yes	I III IV	Oct. 30, 2013	yes	I III IV
Mar. 15, 2011	yes	I III IV	Dec. 18, 2013	yes	I III IV
Apr. 27, 2011	yes	I III IV	Jan. 29, 2014	yes	I III IV
Jun. 22, 2011	yes	I III IV			

Table 3.8 Results of Estimating Equation (3.2) for All the Six Exchange Rates

$$\mathrm{vol}_t = \alpha\,\mathrm{vol}_{t-1} + \sum_{j=1}^{2}\sum_{\tau=1}^{3}\beta_{j,\tau}\,d_{j,\tau,t} + \sum_{j=1}^{2}\sum_{\tau=1}^{3}\gamma_{j,\tau}\,(\mathrm{UCMP}_t * d_{j,\tau,t}) + \delta\mathrm{UCMP}_t + c + \epsilon_t \quad (3.2)$$

				AUD(*10^{-5})	CAD(*10^{-5})	CHF(*10^{-5})	EUR(*10^{-5})	GBP(*10^{-5})	JPY(*10^{-5})
CONVENTIONAL	EXP	PRE	$\beta_{1,1}$	6.79	**4.34*** **	**6.59** **	**3.03*** **	**2.46*** **	**4.37*** **
		CONT	$\beta_{1,2}$	**22.52*** **	**5.47*** **	**12.14*** **	**6.47*** **	**4.09*** **	**10.21*** **
		POST	$\beta_{1,3}$	**9.47** **	**0.63*** **	**5.93*** **	**0.752*** **	**0.784*** **	**0.811*** **
	NON-EXP	PRE	$\beta_{2,1}$	2.25	**1.11*** **	**2.6***	**2.53*** **	**1.8*** **	**1.89*** **
		CONT	$\beta_{2,2}$	5.23	**2.85*** **	**5.47*** **	**3.87*** **	**2.75 *** **	**2.8*** **
		POST	$\beta_{2,3}$	3.23	**0.477*** **	**3.35*** **	**0.673*** **	**0.628*** **	**0.888*** **
UNCONVETNIOAL	EXP	PRE	$\gamma_{1,1}$	-4.09	**-2.76*** **	-3.84	**-1.09*** **	-0.5	**-1.56*** **
		CONT	$\gamma_{1,2}$	-13.5	-0.198	-1.05	**1.61*** **	**1.09*** **	**-1.65*** **
		POST	$\gamma_{1,3}$	-4.16	0.00451	-1.35	-0.0619	-0.0978	-0.192
	NON-EXP	PRE	$\gamma_{2,1}$	1.29	**1.5*** **	1.15	0.227	**0.753***	**3.01*** **
		CONT	$\gamma_{2,2}$	475	**3.3*** **	3.06	**3.91*** **	**2.17*** **	**7.61*** **
		POST	$\gamma_{2,3}$	1.5	0.231	0.624	-0.341	-0.125	**-1.11*** **
		UCMP	δ	**0.415*** **	**0.223*** **	**0.214*** **	**0.095*** **	**0.173*** **	**0.0646*** **
			c	**2.84*** **	**0.631*** **	**2.34*** **	**0.829*** **	**0.721*** **	**1.1*** **

Notes:
*indicates that the coefficient is significant at the 10% level
**indicates that the coefficient is significant at the 5% level
*** indicates that the coefficient is significant at the 1% level.

Table 3.9 Results for T-test

	AUD ($*10^{-5}$)	CAD($*10^{-5}$)	CHF($*10^{-5}$)	EUR($*10^{-5}$)	GBP($*10^{-5}$)	JPY($*10^{-5}$)
$\beta_{1,1} + \gamma_{1,1}$	2.89 (0.53)	**1.58(0.000***)**	2.75(0.100)	**1.93(0.000***)**	**1.96(0.000***)**	**2.81(0.000***)**
$\beta_{1,2} + \gamma_{1,2}$	**9.02(0.050*)**	**5.28(0.000***)**	**11.09(0.000***)**	**8.08(0.000***)**	**5.17(0.000***)**	**8.55(0.000***)**
$\beta_{1,3} + \gamma_{1,3}$	**5.31(0.045**)**	**0.675(0.000***)**	**4.58(0.000***)**	**0.69(0.000***)**	**0.686(0.000***)**	**0.619(0.000***)**
$\beta_{2,1} + \gamma_{2,1}$	3.55(0.689)	**2.61(0.000***)**	3.74(0.245)	**2.75(0.000***)**	**2.55(0.000***)**	**4.9(0.000***)**
$\beta_{2,2} + \gamma_{2,2}$	9.98(0.259)	**6.16(0.000***)**	**8.53(0.008***)**	**7.78(0.000***)**	**4.92(0.000***)**	**10.44(0.000***)**
$\beta_{2,3} + \gamma_{2,3}$	4.74(0.354)	**0.708(0.002***)**	**3.97(0.033**)**	0.332(0.113)	**0.503(0.015**)**	-0.218(0.402)

Notes:
*indicates that the coefficient is significant at the 10% level
**indicates that the coefficient is significant at the 5% level
*** indicates that the coefficient is significant at the 1% level.

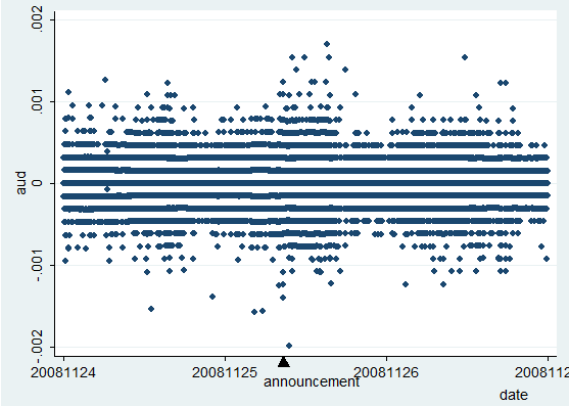

Figure 3.1 Second-by-Second Data for AUD/USD from November 24, 2008 to November 26, 2008

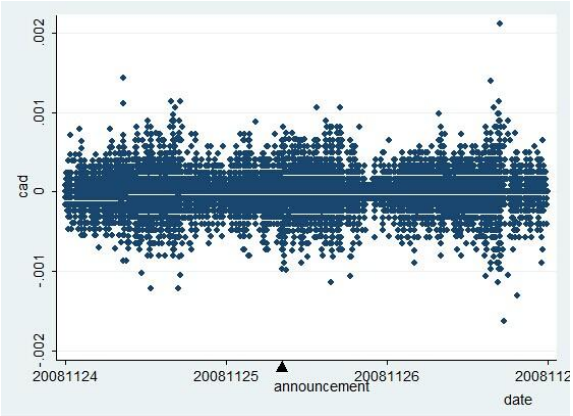

Figure 3.2 Second-by-Second Data for CAD/USD from November 24, 2008 to November 26, 2008

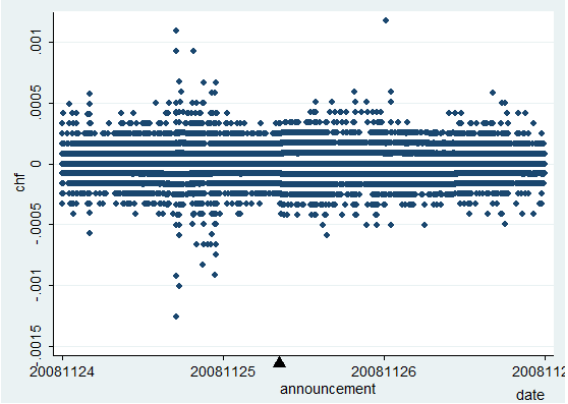

Figure 3.3 Second-by-Second Data for CHF/USD from November 24, 2008 to November 26, 2008

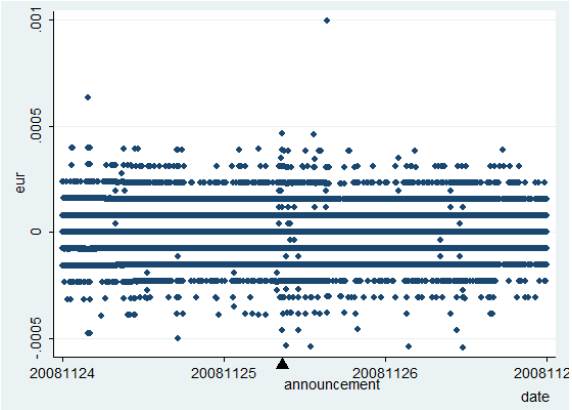

Figure 3.4 Second-by-Second Data for EUR/USD from November 24, 2008 to November 26, 2008

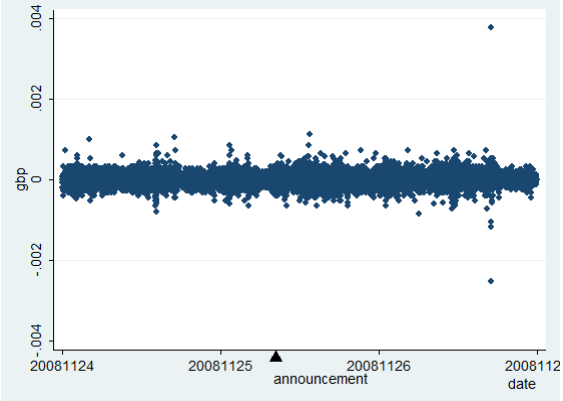

Figure 3.5 Second-by-Second data for GBP/USD from November 24, 2008 to November 26, 2008

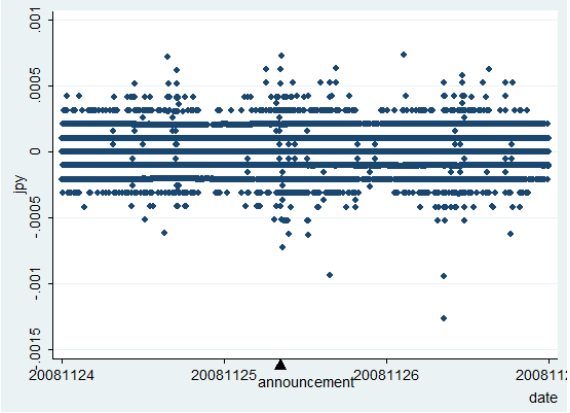

Figure 3.6 Second-by-Second Data for JPY/USD from November 24, 2008 to November 26, 2008

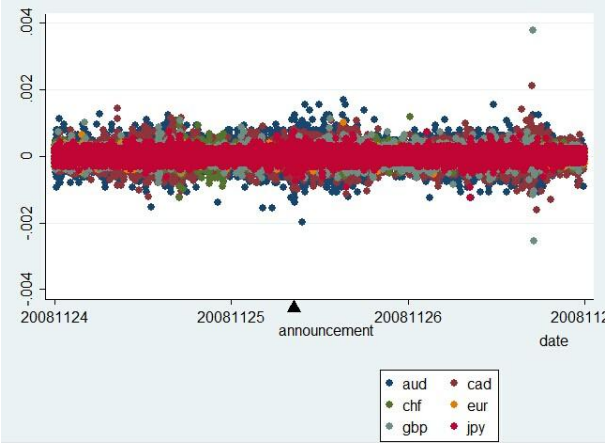

Figure 3.7 Second-by-Second Data for All the Six Exchange Rates from November 24, 2008 to November 26, 2008

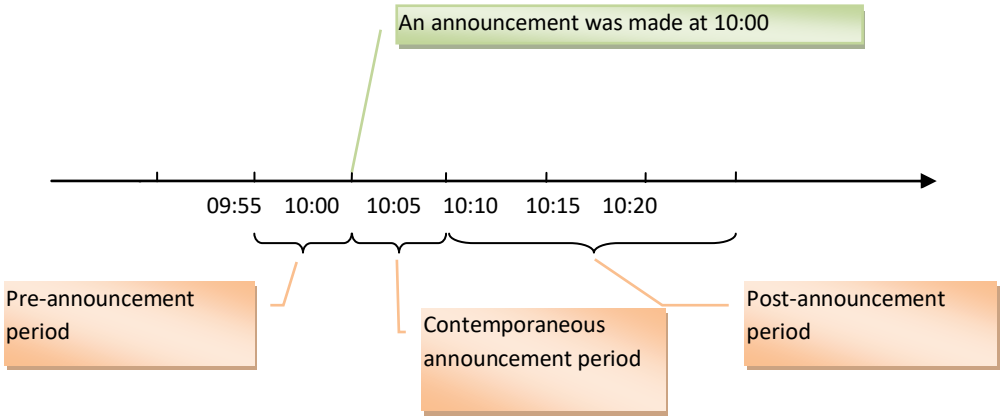

Figure 3.8 An Example of the Time Line Around Monetary Policy Announcements (An announcement was made at 10:00 am on December 16, 2008)

CHAPTER 4

MONETARY POLICY AND EXCHANGE RATE VOLATILITY OF THE MEXICAN PESO AGAINST THE US DOLLAR

4.1 Introduction

There is a large literature investigating the relationship between monetary policy and exchange rates, as, for example, Bawens et al. (2005), Glick and Leduc (2013), and Neely (2013). In the previous chapter, I showed that US monetary policy announcements can lead to higher exchange rate volatility around announcement periods for six advanced countries' currencies against the US dollar. That study, and others related to it, has paid little attention to the relationship between monetary policy announcements and the reaction of currencies in the case of emerging markets. This essay extends understanding of this topic by focusing on the Mexican peso, an important emerging market economy currency, against the US dollar. Moreover, I incorporate both US monetary policy announcements as well as Mexico's monetary policy announcements to more fully examine how exchange rate volatility responds to monetary policy originating from different countries.

In order to encourage a strong economic recovery following the global financial crisis, the Federal Reserve initiated unconventional monetary policy by making large scale assets purchases. It was not clear how and whether this policy would be successful nor was it understood how such a program would impact other important variables in the world and the macro-economy in general. The world has become more globalized and integrated, with faster and stronger transmissions of economic news and policy actions across borders. So while the highly

accommodative monetary policy did help stimulate the US economy, it also had considerable impacts on assets prices and capital flows potentially impacting emerging market economies. The financial sectors in emerging market economics are relatively small and less developed. Hence, it is natural to be concerned with those markets and ask, how did the emerging markets respond to large advanced countries' monetary policy?

I have chosen the Mexican peso as my research focus for the following reasons. First, the peso is the eighth most traded currency in the world. Moreover, the peso was the most-traded emerging market currency in 2013 [17] as displayed in Figure 4.1 which details turnover in the world's most-traded currencies. The Mexican peso's popularity may be due to its use "by investors as a proxy for less liquid emerging market currencies[18]." Hence, it is a good currency to sample in the context of studying an emerging market currency. Second, Mexico, as an export-oriented country and a member country of the North American Free Trade Agreement (NAFTA), is the United States' second largest trading partner (total value of $515,063 million was traded in 2014), while the US is Mexico's largest trading partner[19]. Because Mexico is an important export market for US goods and services, the peso/dollar exchange rate is important to both countries. Figure 4.2 and Figure 4.3 display the top five export and import trading partners of Mexico and the US respectively. Third, the United States is the largest origin of foreign direct investment (FDI) in Mexico[20] (US$ 8997.3 million in 2013). The top five home countries of inward FDI in Mexico in 2012 are reported in Figure 4.4 revealing that the US is far ahead of all the other investing countries. It therefore follows that the behavior of the dollar/peso exchange rate looms large given that Mexico and the US are tightly linked by a variety of economic activities.

[17] "Triennial Central Bank Survey -- Global foreign exchange market turnover in 2013," Bank for International Settlement
[18] "Latin American currencies feel more pain," ft.com, July 20, 2015, Pan Yuk
[19] Trade Data, The World Bank, "http://wits.worldbank.org/CountryProfile/en/Country/MEX/Year/2014/Summary"
[20] "https://stats.oecd.org/Index.aspx?DataSetCode=FDI_FLOW_PARTNER"

Mexican monetary policy actions are taken by the *Banco de México*, the central bank of Mexico, with the aim to influence interest rates and inflation expectations so as to affect the price level and to stabilize inflation. Similar to US monetary policy, *Banco de México* makes monetary policy announcements around eight times per year and it implements monetary policy by setting a target for the overnight interest rate. It conducts open market operations to provide or withdraw liquidity and thereby hit its interest rate target.

Four possible models, the efficient market hypothesis, interest rate parity, the signaling model, and the portfolio balance model, can provide a framework for modeling the impacts of monetary policy announcements on exchange rate volatility. These were described in the previous chapter. The Efficient Market Hypothesis maintains that financial markets are "informationally efficient", and the arrival and processing of all relevant new information (announcements) will lead to price changes. Therefore, in the foreign exchange market, the exchange rate will respond to monetary policy announcements since they provide new information. Uncovered Interest Rate Parity posits a relationship between interest rates and exchange rates. The change in interest rates that results from monetary policy announcements may cause changes in exchange rates due to the possible availability and carrying out of arbitrage opportunities. The signaling model suggests that the central banks can signal to market participants the "appropriate" exchange rate even though the central bank does not have enough resources to set market outcomes. For example, the quantitative easing announcements could have induced investors to revise down their expectations for future short-term interest rates. When investors have different interpretations of the information, despite facing the same signal, fluctuations in the financial markets are likely to follow. In the portfolio balance model, investors construct portfolios using both domestic bonds and foreign bonds, which are not perfect

substitutes. When aggregate economic conditions change, investors adjust their portfolio accordingly to a new equilibrium. These activities, on the part of many investors, will influence the exchange rate behavior in the foreign exchange markets.

In this chapter, I examine whether exchange rate volatility responds differently to monetary policy depending on the country of origin of announcements. Specifically, this essay answers the following three questions. First, does US monetary policy have a significant impact on peso/dollar exchange rate volatility? Second, does Mexican monetary policy have a significant impact on peso/dollar exchange rate volatility? Third, are the impacts of monetary policy originating from the two countries the same or not? I investigate the volatility dynamics before, during and after monetary policy announcements, and compare them to periods with no announcements. The empirical analysis is conducted using high-frequency data, specifically second-by-second peso/dollar spot exchange rates. The sample used in the empirical study ranges from November 2011 to February 2014. The dataset also includes the monetary policy announcements from both the US and Mexico over the entire time period.

As a preview of the results, I find that the peso/dollar volatility increases before and during monetary policy announcements regardless of whether the announcement is from the US or Mexico. But of particular interest is that the increase in volatility lasts longer in response to US announcements relative to Mexican announcements. In comparing the size of the impacts, US monetary policy announcements tend to have larger influences on the volatility of the peso/dollar exchange rate.

4.2 Literature Review

The impact of news and announcements on exchange rate behavior has been studied in a number of dimensions. Fatum et al (2012), for example, investigates the effect of macroeconomic announcements on the yen/dollar exchange rate using 5-minute intraday data from 1999 to 2006. They found that the exchange rate responded differently depending on the country of origin of announcements. Their results show that 12 out of the 19 US macro news variables that they studied have considerable impacts on the exchange rate, while six out of the 16 Japanese macro news variables impact the exchange rate substantially. In addition, with respect to the magnitude, the impact of US news is larger than the impact Japanese news.

Several studies link macroeconomic announcements to the volatility of exchange rates. Andersen and Bollerslev (1998) find macroeconomic announcements have substantial impacts on Deutsche mark/dollar volatility using five-minute returns as the unit of observation. Their study finds that the volatility increases by approximately 5% in response to new information, though the induced increases in volatility are short-lived. Since that finding, it has become common to employ high frequency data of exchange rates to explore the responses of exchange rate volatility to macroeconomic news and announcements, (e.g., Chang and Taylor (2003), Bawens et al (2005), Gao and Hua (2007), Evans and Speight (July, 2010).) Chang and Taylor (2003) discover that DEM/USD volatility is significantly impacted by both US and German macroeconomic news, as well as by German Bundesbank monetary policy news using minute data. Bauwens et al (2005), using 5-minute data, show that the scheduled news' release has substantial influence on euro/dollar exchange rate volatility during the pre-announcement period, while the impacts are insignificant during the post-announcement period. Gao and Hua (2007) explore the impacts of public news arrival on the New Taiwan dollar/USD exchange rate

volatility and find that news related to both the US and Taiwan have significant and positive impacts on exchange rate volatility. In their research, Evans and Speight (2010) find that the volatility of three exchange rates (euro/dollar, euro/sterling and euro/yen) respond to US macroeconomic news, while they also respond to Eurozone, German and UK announcements. While these works provide evidence that exchange rate volatility is influenced by new information, they are limited in our understanding of volatility because only advanced economy currencies are studied.

A number of studies point out that the volatility of the exchange rate is impacted differently by news and announcements originating from different countries. Harada and Watanabe (2009) examine the effects of macroeconomics announcements on the yen/dollar exchange rate using five-minute exchange rate data. Evans and Speight (December, 2010) investigate the reaction of Euro returns volatility to a wide range of macroeconomic news using five-minute returns for three exchange rates. Ito and Roley(1986) study the impacts of news on yen/dollar exchange rate movements. Omrane and Hafner (2013) investigate the relationship between GBP/USD and JPY/USD volatilities and macroeconomic news. All the above studies find that the most important and most profound effects on exchange rate volatility are generated by US announcements. However, none of these studies covers the impacts of unconventional monetary policy announcements after the financial crisis. In addition, none of the emerging market economy currencies are studied in these papers.

Recent studies that consider unconventional monetary policy, e.g., Glick and Leduc (2013), and Neely (2013) merely focus on the level of the exchange rate rather than the volatility. While they find that unconventional monetary policy has remarkable effects on AUD/USD, CAD/USD,

EUR/USD, JPY/USD, and GBP/USD currency pairs, neither of them considers monetary policy announcements emanating from counties other than the US.

This essay contributes to the literature in several ways. First, this essay is perhaps one of the first studies in this research area that use second-by-second exchange rate data in the context of emerging market currencies. Second, this extends previous studies with respect to the impacts of advanced economy's monetary policy on an emerging market economy's currency. Third, I investigate volatility responses to US unconventional monetary policy announcements, and compare them with the responses to Mexico monetary policy announcements, focusing on the 25 minutes around announcements to capture volatility dynamics before, during and after monetary policy announcements.

4.3 Empirical Study

4.3.1 Exchange Rate Data

For my analysis, I used the second-by-second peso/dollar exchange rate data obtained from ForexTickData[21]. The sample ranges from November, 2011 to February, 2014. There is one observation of the exchange rate for each second. The exchange rate returns are used to calculate the volatility because it makes the change independent of scale. To obtain the volatility measurement, I first divide the sample into numerous five-minute intervals. During each five-minute time interval, I have $(60 \times 5)=300$ observations for exchange rate returns based on the second-by-second data. The use of high frequency data allows me to better isolate the response of exchange rate movements to monetary announcements, and separate those from other possible

[21] http://www.frextickdata.com/

shocks that take place several times a day. In addition, using intraday exchange rate data I can isolate US monetary policy from foreign monetary policy.

The upper part of Table 4.1 shows the descriptive statistics for the returns per five-minute interval with five other exchange rates among the advanced nations. The peso/dollar has the largest range in terms of exchange rate returns with the smallest minimum value and the greatest maximum value. The lower part of Table 4.1 shows the descriptive statistics for the volatility of the returns during each five-minute interval. The average volatility is interpreted as mean of volatility on the fourth column of the table. Apparently, the peso/dollar has the highest average volatility. Based on these, the peso/dollar exchange rate tends to have higher volatility compared to exchange rates for the advanced countries. Figure 4.5 displays a subset of the second-by-second return data for the peso/dollar exchange rate from November 4, 2013 to November 6, 2013, with 259,200 observations over the three days. It can be seen that the exchange rate returns fluctuate drastically during the sample period.

4.3.2 Monetary Policy Announcements Data

The Federal Open Market Committee (FOMC), a committee within the Federal Reserve System, makes decisions about monetary policy. The FOMC meets about eight times each year to determine the policy to be implemented during the interval between meetings. The goal of US monetary policy is to achieve maximum employment and stable prices. The decisions made in the meetings are released to the public after each meeting. During the sample period, 26 monetary policy announcements were made by the FOMC.

Banco de México makes monetary policy announcements around eight times per year and implements monetary policy by setting a target for the overnight interest rate. The announcements of monetary policy are scheduled to appear on Banco de México's website after

their meetings scheduled on Fridays at 9:00 a.m. (GMT-6) after each meeting. During the period of my study, Banco de México had 26 monetary policy announcements. The announcement schedule is reported in Table 4.2.

4.3.3 Empirical Model

The focus of the paper is threefold. First, to determine wheterh peso/dollar volatility responds to US monetary policy announcements. Second, does the volatility respond to Mexican monetary policy announcements? Third, do monetary policy announcements have different impacts on exchange rate volatility depending on the country of origin of the announcement? In order to answer these questions, I estimate the following regression:

$$\begin{aligned} vol_t = \alpha\, vol_{t-1} + \beta_1\, PRE\_US_t + \beta_2\, CONT\_US_t + \beta_3\, POST\_US_t + \gamma_1\, PRE\_MX_t \\ + \gamma_2\, CONT\_MX_t + \gamma_3\, POST\_MX_t + c \\ + \epsilon_t \end{aligned} \tag{4.1}$$

where vol_t is the standard deviation of the peso/dollar exchange rate return per five-minute time interval, which is calculated from the second-by-second exchange rate data. The rest of the independent variables are dummy variables representing different periods around announcements emanating from different countries. The dummy variable, PRE_US_t, represents the pre-announcement period for the US monetary policy announcements. Hence, $PRE\_US_t = 1$ if t is 5 minutes before the FOMC made the announcements, and 0 otherwise. The variable denoted $CONT\_US_t$ is a dummy variable represents the contemporaneous period for the US monetary policy. That means $CONT\_US_t = 1$ if t is in the 5-minute interval immediately after the US monetary policy announcements and 0 otherwise. The dummy variable, $POST\_US_t$ indicates the post-announcement period for the US, where $POST_US_t = 1$if t is in the 15-minute time interval right after the contemporaneous period and 0 otherwise. The dummy variables, PRE_MX_t,

$CONT\_MX_t$, and $POST\_MX_t$, represent the pre-announcement period, the contemporaneous period, and the post-announcement period for Mexican monetary policy, announcements defined in the same way as above. Figure 4.6 illustrates the identification of the three announcement periods on an announcement day.

The coefficients on PRE_US_t, $CONT\_US_t$, and $POST\_US_t$ (β_1, β_2, and β_3) indicate the impact of US announcements on volatility during the three announcement periods respectively, if any. The coefficients on, PRE_MX_t, $CONT\_MX_t$, and $POST\_MX_t$ (γ_1, γ_2, and γ_3) capture the impact of Mexican announcements on the peso/dollar volatility around announcements, if any.

4.4 Results

Equation (4.1) gauges the response of exchange rate volatility to US and Mexican monetary policy. Table 4.3 reports the estimations results of Equation (4.1). The β coefficients are positive and statistically different from zero. This implies that US monetary policy announcements have significant impacts on the volatility during the pre-announcement period, the contemporaneous period and the post-announcement period. The exchange rate is most volatile during the contemporaneous period with the volatility increasing by 615% compared to periods with no announcements[22].

Turning to the γ coefficients, which capture the impacts of Mexican monetary policy announcements on exchange rate volatility, only γ_1 and γ_2 are significantly different from zero. This indicates that the exchange rate volatility increases significantly during the pre-announcement period and the contemporaneous period, when Mexican monetary policy

[22] Table 5 provides a straightforward comparison of the volatility during different periods responding to monetary policy announcements.

announcements are made. The coefficient γ_3 is not significantly different from zero, meaning that the volatility is not substantially different during the post-announcement period compared with non-announcement periods. Peso/dollar exchange rate volatility starts increasing, responding to Mexican monetary policy announcement, five minutes before the announcement. The volatility reaches the highest level during the contemporaneous period, which is five minute after the announcement. The increase in volatility fades away during the post-announcement period.

While both US monetary policy and Mexican monetary policy announcements lead to an increase in the exchange rate volatility, the duration of the impacts are different. As described earlier, β_1 and γ_1 capture the impact of US announcements and Mexican announcements during the pre-announcement period respectively. The coefficients β_2 and γ_2 show the influence during the contemporaneous period, while β_3 and γ_3 indicate the influence during the post-announcement period. All the coefficients are significantly different from zero except γ_3. That is to say, the increase in the volatility due to US monetary policy announcements lasts through the post-announcement period at least, while the increase in the volatility due to Mexican monetary policy announcements only persists through the contemporaneous period, with the impact of Mexican announcements dying out during the post-announcement period. This result suggests that the influence of monetary policy announcements on peso/dollar exchange rate volatility is longer lasting with respect to the US relative to Mexican announcements.

Although the above discussion states that the duration of the impact of US announcements is longer than Mexican announcements, it does not reveal the difference in the scale of the impacts of announcements for the two countries. In order to know which monetary policy has a greater

impact on exchange rate volatility, I conduct t-tests to test the coefficients for the three periods around announcements respectively.

H0: $\beta_i = \gamma_i$

H1: $\beta_i > \gamma_i$

If I fail to reject the null, the impacts of announcements from the two countries are not significantly different. If I reject the null, it implies that the impacts of US policy announcements are greater than that of Mexican announcements. The results of the tests are reported in Table 4.4. The p-values are less than the critical value, therefore I can reject the null. This indicates that US monetary policy has greater impacts on peso/dollar exchange rate volatility than the Mexico monetary policy during all the three periods around announcements. That is to say, US monetary policy announcements lead to greater increases in exchange rate volatility compared to Mexican monetary policy announcements during the pre-announcement and contemporaneous periods. The post-announcement period is excluded here because the impacts of US announcements are present while the impacts of Mexican announcements die out during the post-announcement period.

4.5 Robustness Check

Intraday volatility in financial markets is found to present a U-shaped pattern over the trading day (Gau and Hua 2007, Anderson and Bollerslev 1997, Abhyankar et al 1997). That is to say, volatility is comparatively high at the opening and closing of trading. To justify that the increase in volatility is due to the monetary policy announcements rather than the opening and closing behavior of the foreign exchange market, I conduct a robustness check by considering the influence of the opening and closing of trading.

In this section, the opening and closing of two foreign exchange markets are considered, namely the US foreign exchange market, and the Mexican foreign exchange market. In the US, the foreign exchange market opens at 8:00 and closes at 17:00(EST), while the Mexican foreign exchange market opens at 7:30 and closes at 15:00 (local time), which are 8:30 and 16:00(EST). The regression are then modified by incorporating dummy variables representing the opening and closing hours of the two markets (with the shift of time due to Daylight Saving Time accounted for)

$$\mathrm{vol}_t = \alpha\,\mathrm{vol}_{t-1} + \sum_{j=1}^{2}\sum_{\tau=1}^{3}\delta_{j,\tau}\,d_{j,\tau,t} + \sum_{j=1}^{2}\sum_{k=1}^{8}\theta_{j,\tau}\,m_{j,\tau,t} + \epsilon_t \qquad (4.2)$$

where vol_t is the volatility measurement at time t, and the remaining are dummy variables with alternative meanings. The dummy variable $d_{j,\tau,t}$ represent the corresponding period around announcements with respect to country j. Specifically, j=1 if the announcement is made by the US, j=2 if the announcement is made by Mexico. The index τindicates a time window around each announcement: a pre-announcement period (τ=1), a contemporaneous period(τ=2), and a post-announcement period(τ=3). For example, $d_{1,3,t}$ represents the post-announcement period for a US monetary policy announcement.

The dummy variable $m_{j,\tau,t}$ is the dummy variable representing the opening hour and closing hour of a trading day. I divide the opening hour and closing hour into eight 15-minute intervals. The index k takes the value 1 to 4 if it is during the opening hour, and it takes the value 5 to 8 if it is during the closing hour. The index j is to distinguish the two countries' foreign exchange markets, 1 for the US and 2 for Mexico. For example, $m_{2,2,t}$ refers the second 15-minute time interval during the opening hour of the Mexican foreign exchange market.

The estimation results are reported in Table 4.6. The coefficients δs implies the impact of the monetary policy announcements of the specific country on the volatility during the corresponding periods. The results are consistent with the results in the previous section that US monetary policy announcements have a significant impact on the volatility during the pre-announcement, contemporaneous, and post-announcement periods while Mexican monetary policy announcements have considerable impacts during the first two periods, with the significance dying out during the post-announcement period.

In comparing the scale of the impacts of announcements from the two countries, a t-test is conducted as in the previous section. Results are reported in Table 4.7. The impacts of US announcements are significantly greater than the impacts of Mexican announcements during all the three periods around announcements. Therefore, the results of the robustness check are consistent with the results in the previous section.

4.6 Conclusion

This essay examines the impacts of US monetary policy announcements and Mexican monetary policy announcements on peso/dollar exchange rate volatility. While analyzing whether the announcements of the two countries affect the volatility respectively, I also compare if one is greater than the other. Results indicate that both US and Mexican monetary policy announcements have significant and positive impacts on the volatility, however, this impact lasts longer for US monetary policy announcements. Specifically, the US announcements cause an increase in exchange rate volatility over the pre-announcements, contemporaneous and post-announcement periods, while the Mexican announcements lead to an increase in the volatility over only the first two period. One possible explanation is that in addition to the direct impact of

US monetary policy on peso/dollar volatility, there might also be some indirect impact on it. For example, US monetary policy announcements might also lead to an increase in the Canadian dollar/ US dollar volatility, which may contribute to the increase in peso/dollar volatility through the spillover effect at a later time. Therefore, the increase in peso/dollar volatility due to US announcements has a longer duration than the increase caused by Mexican announcements.

Moreover, the impact of the US announcements is greater than that of the Mexican announcements. In other words, the US announcements lead to a greater increase in the exchange rate volatility compared with the Mexican announcements during the periods around announcements.

Overall, peso/dollar exchange rate volatility does respond to US and Mexican monetary policy announcements, while the responses are different in scale as well as duration according to the country of origin of the announcements. These findings have economic implications. It is found that US announcements have the most important and significant impact on the exchange rate volatility. Mexican monetary policy announcements appear to be less influential in driving exchange volatility. Therefore, as the largest and most advanced economy in the world, the US has a dominant impact on the foreign exchange market volatility compare to Mexico, an emerging market economy, with respect to the influence of monetary policy announcements. The peso is even more vulnerable because of the significant increase in volatility when US monetary policy announcements were made. Moreover, as the most-traded currency in emerging markets, the peso is considered "an ideal hedging instrument for speculators who are betting on the direction of other developing economies[23]." Since the Bank of Mexico just raised its benchmark rate and conducting actions to protect the peso from depreciating by selling the dollars, market

[23] "Mexico Warns, Leave the Peso Alone," Bloomberg Business Week, Feb. 29-Mar.6, 2016

participants and policy makers may be more sensitive to the changes in the exchange rate volatility. Accordingly, both market participants as well as the policy makers need to pay attention to the systematic risk caused by the monetary policy announcements emanating from both the US and the Mexico.

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Table 4.1 Descriptive Statistics for Exchange Rate Returns and Volatility (per five-minute interval)

	exchange rates	no. of obs	mean	std dev	min	max
Return	MXN	246576	1.25E-09	1.72E-06	-0.00329	0.001328
	AUD	246854	-1.35E-09	1.47E-06	-0.000101	6.38E-05
	CAD	246854	2.33E-09	1.12E-06	-0.000101	0.000102
	CHF	246857	9.84E-09	1.95E-06	-0.000205	0.000598
	EUR	246857	1.35E-09	1.25E-06	-7.25E-05	0.00014
	GBP	246853	9.25E-10	1.01E-06	-0.000032	6.11E-05
	JPY	246859	3.15E-09	1.38E-06	-0.000124	0.000203
Volatiltiy	MXN	246565	0.000192	0.000169	0	0.000806
	AUD	246852	2.58E-05	0.0000154	0	0.000689
	CAD	246849	1.97E-05	0.0000131	0	0.000325
	CHF	246852	2.42E-05	0.0000179	0	0.001197
	EUR	246852	2.03E-05	0.0000129	0	0.000743
	GBP	246850	1.72E-05	0.0000105	0	0.000322
	JPY	246852	2.20E-05	0.0000145	0	0.00094

Data souce: ForexTickData

Table 4.2 Schedule of Mexican Monetary Policy Announcements

date of announcement	time of announcement in GMT- 6 (Mexico City) time zone	date of announcement	time of announcement in GMT- 6 (Mexico City) time zone
November 26, 2010	9:00	July 20, 2012	9:00
January 21, 2011	9:00	September 7, 2012	9:00
March 4, 2011	9:00	October 26, 2012	9:00
April 15, 2011	9:00	November 30, 2012	9:00
May 27, 2011	9:00	January 18, 2013	9:00
July 8, 2011	9:00	March 8, 2013	9:00
August 26, 2011	9:00	April 26, 2013	9:00
October 14, 2011	9:00	June 7, 2013	9:00
December 2, 2011	9:00	July 12, 2013	9:00
January 20, 2012	9:00	September 6, 2013	9:00
March 16, 2012	9:00	October 25, 2013	9:00
April 27, 2012	9:00	December 6, 2013	9:00
June 8, 2012	9:00	January 31, 2014	9:00

Data source: Banco de Mexico, http://www.banxico.org.mx/viewers/JSP/calendarioDifusion_en.jsp?static=y

Table 4.3 Estimation Results

Equation estimated:

$$vol_t = \alpha\, vol_{t-1} + \beta_1\, PRE\_US_t + \beta_2\, CONT\_US_t + \beta_3\, POST\_US_t + \gamma_1\, PRE\_MX_t + \gamma_2\, CONT\_MX_t + \gamma_3\, POST\_MX_t + c + \epsilon_t \quad (4.1)$$

coefficient	Estimation($\times 10^{-5}$)	t stat.	p value
α	**54865.76*** **	326.24	0.00
β_1	**1.86*** **	6.87	0.00
β_2	**6.15*** **	22.74	0.00
β_3	**0.979*** **	6.26	0.00
γ_1	**1.12*** **	4.00	0.00
γ_2	**5.2*** **	18.50	0.00
γ_3	0.153	0.94	0.346
constant	**0.863*** **	201.43	0.00

Notes:
*indicates that the coefficient is significant at the 10% level
**indicates that the coefficient is significant at the 5% level
*** indicates that the coefficient is significant at the 1% level.

Table 4.4 T-test Results

Hypothesis	p value
$H_0: \beta_1=\gamma_1$; $H_1: \beta_1>\gamma_1$	**0.0322****
$H_0: \beta_2=\gamma_2$; $H_1: \beta_1>\gamma_1$	**0.0084*****

Notes:
*indicates that the coefficient is significant at the 10% level
**indicates that the coefficient is significant at the 5% level
*** indicates that the coefficient is significant at the 1% level.

Table 4.5 Average Volatility During All Periods

	volatility ($*10^{-5}$)			
	non ann	pre	cont	post
US MP	1.91	4.29	9.56	6.0
MX MP	1.91	3.92	8.46	4.22

Data source: ForexTickData

Notes: This table displays the average volatility during the non-announcement period, the volatility during the three periods around US monetary policy announcements, and the volatility during the three periods around Mexican monetary policy announcements.

Explanation of abbreviations:
non ann: non-announcement period
pre: pre-announcement period
cont: contemporaneous-announcement period
post: post-announcement period

Table 4.6 Regression results of Equation (4.2)

Equation estimated:

$$vol_t = \alpha' vol_{t-1} + \sum_{j=1}^{2}\sum_{\tau=1}^{3} \delta_{j,\tau} d_{j,\tau,t} + \sum_{j=1}^{2}\sum_{k=1}^{8} \theta_{j,\tau} m_{j,k,t} + \epsilon_t \quad (4.2)$$

	coefficient	s.d.	t	p	Explanation
α'	**53299.85*** **	0.001701	313.35	0.00	
$\delta_{1,1}$	**1.83*** **	2.69E-06	6.8	0.00	US, pre
$\delta_{1,2}$	**6.15*** **	2.69E-06	22.83	0.00	US, cont
$\delta_{1,3}$	**1.02*** **	1.56E-06	6.57	0.00	US, post
$\delta_{2,1}$	**1.2*** **	2.8E-06	4.28	0.00	MX, pre
$\delta_{2,2}$	**5.28*** **	2.8E-06	18.88	0.00	MX, cont
$\delta_{2,3}$	0.26	1.62E-06	1.61	0.108	MX, post
$\delta_{1,1}$	**0.536*** **	2.77E-07	19.31	0.00	US, open
$\theta_{1,2}$	**0.575*** **	2.78E-07	20.72	0.00	US, open
$\theta_{1,3}$	**0.877*** **	5.05E-07	17.37	0.00	US, open
$\theta_{1,4}$	**0.509*** **	5.05E-07	10.1	0.00	US, open
$\theta_{1,5}$	**0.116*** **	2.77E-07	4.17	0.00	US, close
$\theta_{1,6}$	**0.15*** **	2.51E-07	5.98	0.00	US, close
$\theta_{1,7}$	0.0325	2.89E-07	1.12	0.261	US, close
$\theta_{1,8}$	**0.301*** **	2.78E-07	10.83	0.00	US, close
$\theta_{2,1}$	0.078	5.58E-07	1.4	0.162	MX, open
$\theta_{2,2}$	-0.0238	5.58E-07	-0.43	0.67	MX, open
$\theta_{2,3}$	**0.475*** **	3.11E-07	15.28	0.00	MX, open
$\theta_{2,4}$	**0.293*** **	3.1E-07	9.45	0.00	MX, open
$\theta_{2,5}$	**0.259*** **	3.07E-07	8.42	0.00	MX, close
$\theta_{2,6}$	**0.214*** **	3.07E-07	6.97	0.00	MX, close
$\theta_{2,7}$	**0.238*** **	3.07E-07	7.76	0.00	MX, close
$\theta_{2,8}$	**0.274*** **	3.07E-07	8.92	0.00	MX, close
c	**0.845*** **	4.32E-08	195.73	0.00	constant

Notes:
*indicates that the coefficient is significant at the 10% level
**indicates that the coefficient is significant at the 5% level
*** indicates that the coefficient is significant at the 1% level.

Table 4.7 T-test results

Hypothesis	p value
$H_0: \delta_{1,1}=\delta_{2,1}$; $H_1: \delta_{1,1}>\delta_{2,1}$	**0.0541***
$H_0: \delta_{1,2}=\delta_{2,2}$; $H_1: \delta_{1,2}>\delta_{2,2}$	**0.0142****

Notes:
*indicates that the coefficient is significant at the 10% level
**indicates that the coefficient is significant at the 5% level
*** indicates that the coefficient is significant at the 1% level.

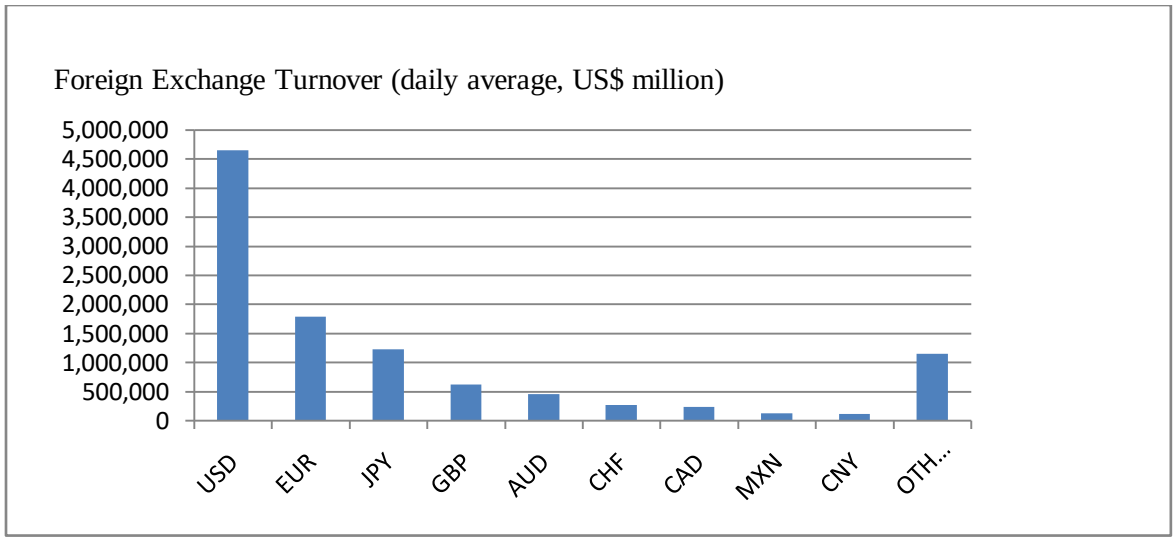

Figure 4.1. OTC Foreign Exchange Turnover Currency in April 2013 (latest data available)
Date source: "Triennial Central Bank Survey - Global foreign exchange market turnover in 2013," Bank for International Settlement
Explanation of abbreviations:
USD: US dollar
EUR: euro
JPY: Japanese yen
GBP: British pound
AUD: Australian dollar
CHF: Swiss franc
CAD: Canadian dollar
MXN: Mexican peso
CNY: Chinese yuan

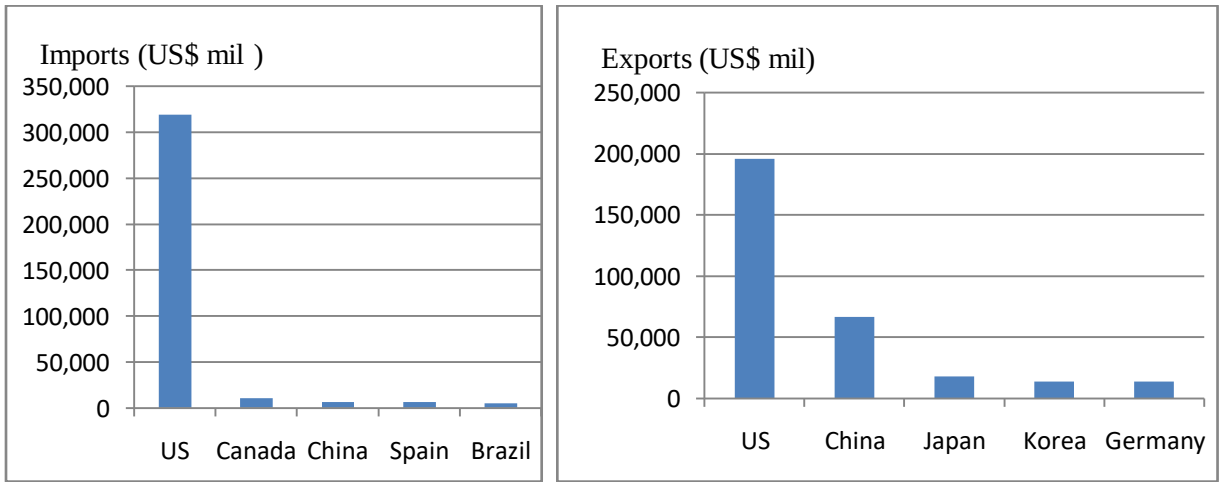

Figure 4.2 Top 5 Import and Export Partners of Mexico in 2014
Date source: The World Bank, "http://wits.worldbank.org/CountryProfile/en/Country/MEX/Year/2014/Summary"

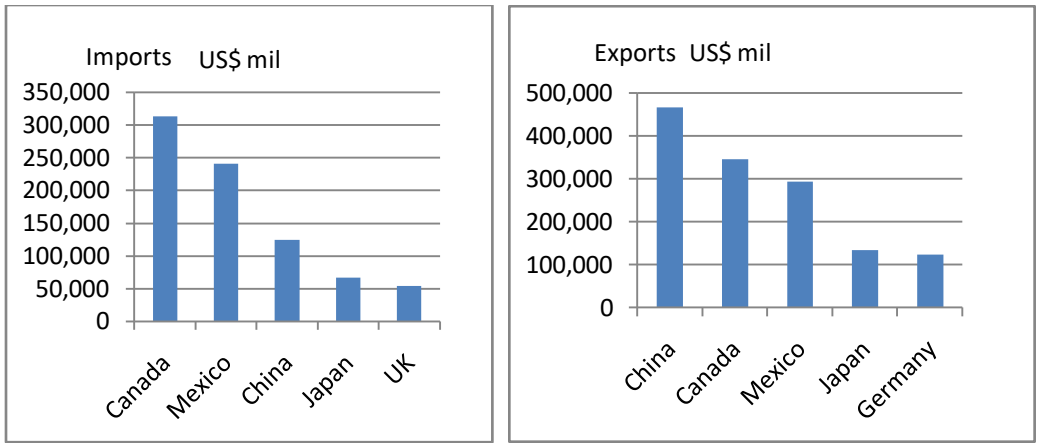

Figure 4.3 Import and Export Partners of the US in 2014 (top 5 partner countries)
Date source: The World Bank, "http://wits.worldbank.org/CountryProfile/en/Country/MEX/Year/2014/Summary"

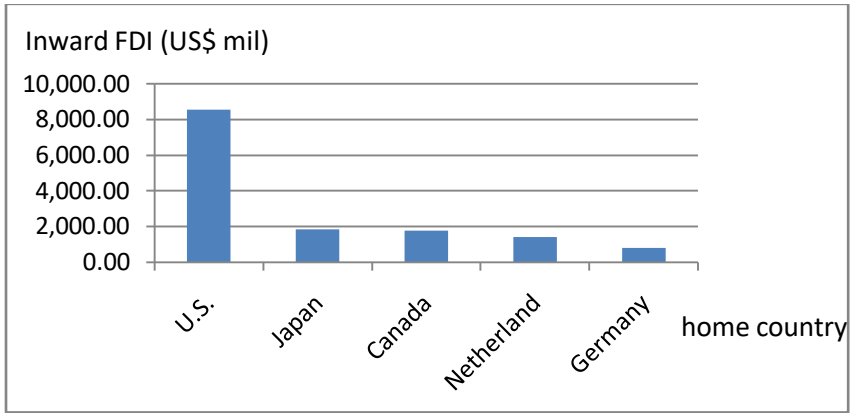

Figure 4.4 Inward FDI Flow in Mexico in 2012 (top 5 partner countries)
Data source: "https://stats.oecd.org/Index.aspx?DataSetCode=FDI_FLOW_PARTNER"

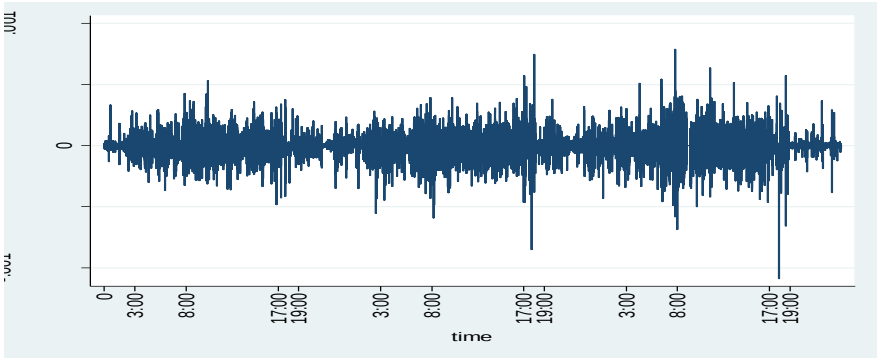

Figure 4.5 Peso/dollar Exchange Rate Returns (November 4, 2013 – November 6, 2013)
Data source: ForexTickData

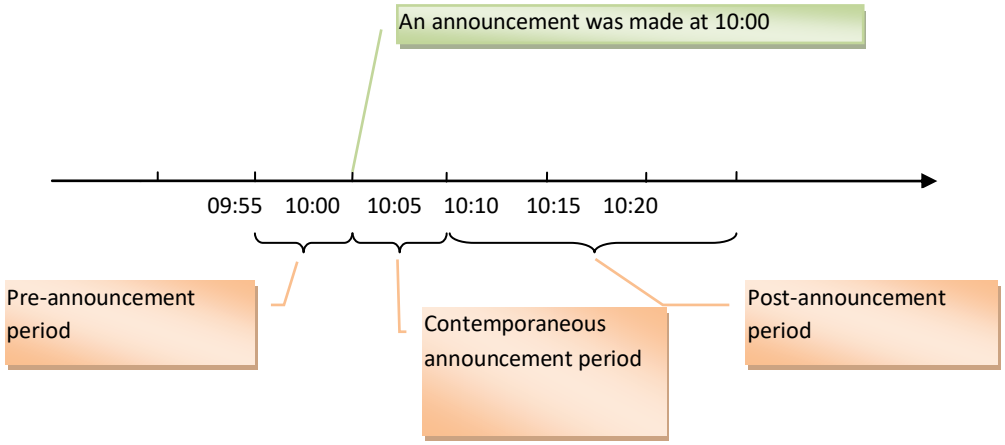

Figure 4.6 An Example of the Time Line Around Monetary Policy Announcements

CHAPTER 5

CONCLUSION

Monetary policy is one of the most important tools used to promote favorable economic conditions. Such was the case after the recent financial crisis. The Fed found it necessary to switch from conventional monetary policy to unconventional monetary policy because the short term interest rate reached the zero lower bound. Moreover, since stability of the financial markets is one of the most important indicators of the economic conditions and stability and the foreign exchange market is one of the most important financial markets, it is of great importance to study the effects of monetary policy and the change in monetary policy on exchange rate behavior.

This dissertation investigates the relationship between monetary policy and exchange rate behavior with respect to three different areas. While the first essay analyzes the overall impacts of monetary policy on the exchange rate and its volatility using daily data, the second and third essays examine the intraday effects of monetary policy announcements on exchange rate volatility. In addition, the third essay focuses on an emerging market currency, namely the Mexican peso.

This dissertation contributes to the area of the impacts of monetary policy on exchange rate behavior in various ways. First, it generally analyzes the overall impact of monetary policy on the daily exchange rate and its daily volatility by taking the recent policy change into account. It provides an evaluation of the impact of monetary policy change on exchange rate behavior from a broad perspective by separating the sample period into two long periods, conventional and

unconventional monetary policy regime periods. Given that the study finds no significant change in the daily volatility during the two periods, I further investigate the question by focusing on the short time periods around monetary policy announcements and break down the time window into three. In this way, I am able to examine the intraday impact of monetary policy on the foreign exchange rate volatility in more detail. While most studies consider only advanced countries' currencies, I brought the Mexican peso into discussion in order to provide a more comprehensive understanding of this topic.

Several conclusions can be surmised from the three essays. To begin with, in the first essay, I find that long term interest rate spreads have significant impacts on exchange rate returns for AUD/USD, EUR/USD, and GBP/USD, while short term interest rate spreads have remarkable influences on EUR/USD during the periods prior to November 2008. However, neither short term interest rate spreads nor long term interest rate spreads impact exchange rate returns post November 2008. One explanation for this result may be that both short term and long term interest rates experienced less variation post 2008, thus having little impact on exchange rates.

The second finding of the first essay is that the shift of monetary policy did not lead to significant changes in the overall volatility of the exchange rate. According to this result, one would conclude that the implementation of unconventional policy does not impact the stability of the foreign exchange market. The above findings are based on the analysis of daily data, perhaps only summarizing overall exchange rate behavior on a daily basis and missing out on other important impacts. Foreign exchange rates, however, are changing all the time, second by second, and responding to all varieties of information. Hence, in order to further investigate this topic, I continue to examine exchange rates using intraday data.

In the second essay, concentrating on the 25 minutes around US monetary policy announcements, I find that exchange rate volatility increases around announcements relative to the non-announcement period. During the 25 minutes around announcements, exchange rate returns are most volatile during the contemporaneous period, which is five minute immediately after the announcements. In addition, the increases in the volatility around announcement are greater under unconventional monetary policy regime relative to conventional monetary policy regime, especially with respect to the contemporaneous period.

According to the findings in the second essay, US monetary policy announcements might be an essential source of systematic risk to market participants. When a monetary policy announcement is made to the public, market participants quickly respond to it, thus leading to higher volatility of the foreign exchange market. Moreover, unconventional monetary policy announcements contribute to even higher volatility of the foreign exchange market relative to conventional monetary policy during the announcement period. This may result from the fact that market participants respond more strongly to announcements during the unconventional monetary policy regime period.

The third essay explores the impacts of monetary policy announcements on exchange rate volatility of the Mexican peso, a currency that is representative of emerging market currencies, against the US dollar. While incorporating monetary policy announcement from both the US and Mexico, I find that US monetary policy announcements have greater impacts on the volatility relative to Mexican monetary policy announcements, although both of them lead to significant increase in the volatility around announcements. Furthermore, the increase in volatility resulting from the US announcements last for all the pre-announcement, contemporaneous and post-announcement periods, while the Mexican announcements cause an increase over only the first

two periods. In other words, the impact of US monetary policy tends to be more persistent than Mexican monetary policy with respect to peso/dollar volatility.

While the peso/dollar volatility responds to both US and Mexican monetary policy announcements, it is found that US announcements are more important with respect to the significance of its impact on exchange rate volatility, while Mexican announcements are less influential. It can be concluded that the US, as the largest and most advanced economy in the world, has a dominant influence on the foreign exchange market relative to Mexico, an emerging market economy. Therefore, Mexican market participants and policy makers need to keep a close watch on the systematic risk caused by the monetary policy announcements originated from both countries.

This dissertation sheds light on the relationship between monetary policy and foreign exchange market and provides important implications for policy makers and market participants. First, it helps policy makers assess the effects of conventional and unconventional monetary policy on exchange rate levels and the stability of the foreign exchange market. Second, it demonstrates that monetary policy announcements could be a crucial source of systematic risk which market participant should pay attention to. Third, this dissertation also provides other central banks with important information to proceed in their implementation of unconventional monetary policy. Fourth, this research provides evidence of the different roles US central bank and emerging market central banks are playing in the financial markets. Finally, one can get some insights into how exchange rate behavior may be affected by unconventional monetary policy when the central bank implements another round of new policy in the non-expansionary or even contractionary policy phase.

Future study regarding this topic can be conducted in three ways. First, while the second essay in this dissertation only compares the magnitude of the impacts of the two monetary policy announcement, future research can also compare the duration of the impacts, in other word, how long the impacts last after an announcement is made. This can explain how long it takes the market participants to react to and digest the monetary policy announcements. Second, since the Fed announced raising the Federal funds rate on December 16, 2015, it can be considered as an official termination of the unconventional monetary policy at this stage. It is important to know how this change may impact the foreign exchange market. Third, given that the US is not the only country that implemented unconventional monetary policy after the financial crisis, it is of importance to study similarities and differences of the policy and their impacts on other countries.