TESTING THE EFFECTS OF ORAL INTERVENTIONS ON THE COVARIANCE OF EXCHANGE RATES IN A STATE-OF-THE-ART COMPUTATIONAL ENVIRONMENT

A Master's Thesis

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July 2009

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The Institute of Economics and Social Sciences
of
Bilkent University

by

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In Partial Fulfillment of the Requirements For the Degree
of
MASTER OF SCIENCE

in

THE DEPARTMENT OF
MANAGEMENT
BILKENT UNIVERSITY
ANKARA

July 2009

I certify that I have read this thesis and have found that it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science in Management.

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ABSTRACT

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In the last decade, both Federal Reserve System (FED) and European Central Bank (ECB) abandoned direct market interventions and relied on communication as their main policy tool to affect exchange rates. This paper investigates the impacts of officials' statements (oral intervention) on the covariance of the EUR/USD and JPY/USD. Using generalized autoregressive conditional heteroscedasticity (GARCH) model's diagonal vector error correction (DVEC) representation, we find that strengthening oral interventions in US and Japan decrease while in Eurozone increase the covariance between EUR/USD and JPY/USD. Also reversely, weakening oral interventions in US and Japan increase while in Eurozone decrease the covariance. Since oral interventions are explanatory variables of the conditional covariance structure of G3 currencies (USD, EUR and JPY), ignoring oral interventions may cause errors in foreign exchange (forex) covariance forecasts. During the estimation procedure, we use a different approach than the commonly practiced in the literature. We solve the resulting optimization problem from maximum likelihood estimation (MLE) of DVEC model in two steps: first by genetic algorithm (GA) and then by sequential quadratic programming (SQP) algorithm. Furthermore, to land at a better local optimal, the experiments are conducted in NEOS Servers[1]. Comparing our results with those of benchmark S+ GARCH module (a commercial software), we find that our approach yields much higher objective value than the benchmark does. Hence, we conclude that our computational methodology provides substantial improvement to in-sample forex covariance forecasting. Our results have applications in portfolio management as well.

Keywords: Central Bank Interventions, Constrained Nonlinear programming, Multivariate GARCH, Conditional Correlations.

[1] Highly specialized optimization problem solving environment in Argonne National Laboratory, USA.

ÖZET

SÖZLÜ MÜDEHALELERİN PARA BİRİMLERİNİN BİRLİKTE DEĞİŞİMLERİNE ETKİSİNİN İLERİ BİLGİSAYAR ORTAMINDA TEST EDİLMESİ

ÇAŞKURLU, TOLGA

Yüksek Lisans, İşletme Bölümü

Tez Yöneticisi: Doç. Dr. Aslıhan Altay Salih

Temmuz 2009

Son 10 sene içerisinde hem Amerika Birleşik Devletleri Merkez Bankası (FED) hem de Avrupa Merkez Bankası (ECB) piyasalara direkt alım satım müdehaleleri yerine, üst düzey yöneticilerle sözlü müdaheleleri tercih etmişlerdir. Bu çalışmada, Amerika, Japonya ve Avrupa'daki sözlü müdahelelerin EUR/USD ve JPY/USD birlikte değişimlerine (kovaryans) etkisi araştırılmaktadır. Sonuç olarak, Amerika ve Japonya'dan yapılan güçlendirici müdehalelerin birlikte değişimi azalttığı, zayıflatıcı müdehalelerin artırdığı; Avrupa'dan yapılan güçlendirici müdehalelerin birlikte değişimi artırdığı, zayıflatıcı müdehalelerin azalttığı gözlenmiştir. Hesaplamalar genelleştirilmiş özbağlanımlı, şartlı, değişken hata varyansı (GARCH) methodolojisi ile yapılmıştır. GARCH modellerinin çözümleri için olabilirlik artırma (MLE) temel alınmıştır. Literatürden farklı olarak, MLE'den oluşan problem BHHH algoritmaları yerine, SQP algoritmaları ile çözülmüş ve Amerika'daki NEOS servis sağlayıcısındaki özel bilgisayarlarda testler yapılmıştır. Sonuçlarımız, temel fonskiyon değeri bakımından, ticari yazılım olan S+ dilinin GARCH paketinden daha üstündür. Bu çalışmanın sonuçları, kısa zamanlı portföylerde kullanılabilir niteliktedir.

Anahtar Kelimeler: Merkez Bankası Müdehaleleri, Kısıtlamalı Doğrusal Olmayan Programlama, Çok Değişkenli GARCH, Şartlı Doğrusal Bağıntı (Korelasyon)

ACKNOWLEDGMENTS

I would like to thank my supervisor Assoc. Prof. Aslıhan Altay Salih for her guidance during my M.S Studies. She was always with me whenever I needed advice, which extended beyond academic studies. I will always be honored to be one of her students.

I would like to thank Asst. Prof. Sabri Öncü for being an enthusiastic instructor and mentor. His permanent support helped me a lot in the completion of the thesis and my academic life. I will always be indebted to him.

I would also like to thank Prof. Hakan Berument for not only being a great econometrics instructor but also for being an excellent career advisor.

I would also like to thank all jury members for reading and giving valuable comments throughout this thesis.

Last but not least, I would like to thank my family. They are so special for me that I really cannot find the exact words to express my love and gratitude. I also would like to thank my ex-girl friend Damla Şentürk for her encouragements and support in my undergraduate and first year of my M.S studies. I also would like to thank my friends. They were really more than great. Finally, I would like to thank TÜBİTAK for the financial support they provided for my graduate study.

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CHAPTER 1

INTRODUCTION

Forecasting the covariance is at the heart of many financial applications such as hedging, value-at risk measures or mean/variance optimization. To have better out-of-sample covariance forecasts, statistical methods such as rolling covariance, realized covariance, implied covariance or Multivariate GARCH (MGARCH) models are commonly used. However, to improve the relevance of the statistical models, factors that can affect the second moments of the series have to be incorporated to these models.

Beine (2004) considered Central Bank Interventions (CBIs) as an explanatory variable of the covariance structure. He found that at least concerted official CBIs are explanatory variables of the covariance dynamics of EUR/USD and JPY/USD. However, as discussed in Fratzscher (2006), in the last decade, FED and ECB relinquished direct CBIs and relied on communication to influence the exchange rates. One of the main reasons of central banks abandoning CBIs is its unexpected consequences. As discussed in Sarno and Taylor (2001), central banks' ultimate aim is to decrease the volatility of the exchange rates while not altering its level. However, there are empirical studies that show that interventions can influence the exchange rate level.[1] Since CBIs are affecting the capital market mechanism by changing the level and

[1] Aguilar and Nydalh (2001), Fratzscher (2006), Payne and Vitale (2003)

since central banks are staking their own capital, central banks hesitated to conduct interventions in the last decade. In addition, although central banks can not change the interest rate or other macroeconomic instruments very frequently to affect the exchange rate volatility, they can canalize the markets in the desired direction by oral interventions. Hence, assessing the effects of communication (oral intervention) on the covariance of EUR/USD and JPY/USD will contribute to the literature.

In this thesis, we investigate the extent the G3 economies officials' statements influence the covariance of EUR/USD and JPY/USD in MGARCH framework. We find that strengthening oral interventions in US and Japan decrease while in Eurozone increase the covariance between EUR/USD and JPY/USD. Also reversely, weakening oral interventions in US and Japan increase while in Eurozone decrease the covariance. In other words, from our results it can be inferred that ignoring the oral interventions in the covariance dynamics may underestimate/overestimate forex covariance forecasts.

Our second contribution to the finance literature is on the methodology side. In this study, during the estimation of the MGARCH models, we used recent advances in numerical optimization algorithms, software and state-of-art computing environment. To see whether the computational framework is important in MGARCH estimation, we compared our results with those of S+ language GARCH module, a commercial software commonly used by academicians and practitioners. We wrote the software in AMPL (A Mathematical Programming Language) and solved the problem in NEOS servers with SNOPT (Sparse Nonlinear OPTimizer) solver, which uses SQP (Sequential Quadratic Programming) algorithm. The benchmark software S+ GARCH module uses BHHH (Berndt, Hall, Hall, and Hausman) algorithm to solve the same problem. For the same maximization problem, higher objective value is obtained. Hence, we conclude that, at least for this data, also computational framework is important in covariance forecasting.

In the remaining part of the introduction section, we will first explain the econometric approaches used for covariance forecasting in the literature. Then, we will review some computational approaches on the same issue. After this methodological motivation, we will discuss the inadequacies in statistical methods and explain in detail the importance of assessing the oral intervention influence on the forex covariance forecasting.

We will firstly summarize the econometric approaches that are used for covariance forecasting and explain the underlying reasons of the difficulties that lead us to use more complicated computational techniques. Most of the econometrics approaches for the covariance and correlation forecasting is on the MGARCH framework. The first MGARCH representation was the VEC (Vector Error Correction) model of Bollerslev, Engle and Wooldridge (1988). Although this model had superior out-of sample forecasting results than the previously used models such as rolling covariance model, it had an important drawback: the resulting optimization problem from the maximum likelihood estimation (MLE) of the VEC model was highly nonlinear and non-convex. Since the global optimum of non-convex nonlinear programming problems that have many nonlinear equality constraints may not be found accurately, researchers were had to make a trade-off between estimation intractability and practical applicability. To decrease the time complexity of the problem, Bollerslev et.al. (1988) proposed Diagonal-VEC (DVEC) model which is a nested version of the VEC model. Two years later, Bollerslev (1990) introduced a new representation, CCC (Constant Conditional Correlation) GARCH, which assumes constant correlation for the underlying time series. Although CCC representation has reduced the time complexity of the problem by imposing artificial restrictions on the variables, some researches such as Bera and Kim (1996) and Tse (2000) have shown that correlations in some of the national stock markets for certain periods are in fact time varying. This fact gave rise to new econometric approaches that capture the ways the covariances and correlations evolve over time. Since constant correlation seemed to be quite restrictive in practice, researchers tried to explore some other representations that have less time complexity but at the same time have less prior assumptions on the variables to be estimated. One of these representations is BEKK (Baba, Engle, Kraft, Kroner) model of Engle and Kroner (1995), which eliminates the positive definiteness constraint (except initial matrix) by inserting restrictions on the variance and covariance equations. Similarly, Kawakatsu (2006)'s Matrix Exponential GARCH (MEXGARCH) model removed the positive definiteness constraint and any other restrictions on the variables. However, estimating the matrix exponential of the covariance matrix in every iteration increased computational complexity of the model. In addition to these new MGARCH representations, some researches modified these models by adding asymmetric terms to the variance and covariance equations. For example, Kroner and Ng (1998) modified BEKK representation by adding asymmetric terms to the covariance equation. Similarly, Goeij and Marquering (2004) developed asymmetric VEC model. There are many other representations and extensions. Silvennoinen et. al (2007) provides a detailed survey.

Although these MGARCH representations made important contributions to the literature, for forecasting the correlation, none of them has attracted as much interest as the DCC (Dynamic Conditional Correlation) GARCH model of Engle (2002) did. The power of the DCC comes from the low time complexity compared with that of other MGARCH models. The problem is separated into volatility and correlation parts in DCC representation and each part is solved separately. Since it doesn't try to estimate the conditional variance, it solves a smaller problem than other MGARCH models do. Hence, as shown in Engle (2002), DCC model outperforms the competing models in correlation forecasting. We use the DCC model in our correlation analysis.

Another direction to statistically enhance the volatility and covariance forecasts is the usage of different computational techniques. To calculate MGARCH variables, literature generally uses Maximum Likelihood Estimation (MLE), which pre-assumes a known distribution for the residuals. However, in practice these errors may be coming from a distribution that doesn't have any well defined moment generating function. So, to relieve this assumption, some researches used machine learning algorithms, which make non-parametric or semi-parametric estimation, to have conditional variance forecasts[2]. Besides the usage of machine learning algorithms, there is limited research on the applications of new computational (including optimization) algorithms and environments on the solution of MGARCH models. One example is Salih et.al (2003), which introduces a new MGARCH representation and solves the underlying MLE with SNOPT (SQP algorithm) solver instead of the commonly used BHHH algorithm. Although their model has a better in-sample forecasting capability than that of the competing models, they don't attribute the source of the superiority solely to the new representation or to the optimization solver. Also, they do not employ any standard initialization algorithm for the variables that will be estimated. In this paper, for our data, we test whether optimization algorithm and computing environment to solve the MLE of a specific MGARCH representation is important in terms of in-sample forecasting. To do this, we use two step procedure: In the first step, we solve the resulting optimization problem from MLE of DVEC model by Genetic Algorithms (GA), a stochastic global optimization algorithm. In the second step, using optimum points from the first step as the initial points for the variables to be estimated, we resolve the DVEC optimization problem by SNOPT solver (SQP algorithm), a local optimization algorithm, in NEOS

[2] To name a few, Schittenkopf et al.(2000) compared neural network and GARCH forecasts on DAX data and found that for some certain periods, volatility predictions from neural network are superior to GARCH predictions. Perez-Cruz et.al. (2003) employed support vector machine (SVM), another machine learning algorithm, to forecast the conditional variances of S&P100, FTSE100 and NIKKEI indexes and found that SVM outperforms the MLE of GARCH models.

servers. With the same data series, we then estimate DVEC model by S+ GARCH module, which uses BHHH algorithm. We find that solving the same DVEC optimization problem with SNOPT solver in NEOS Servers instead of the commonly used S+GARCH module yields higher objective value. In other words, it means that our results produce better in-sample covariance forecasts than the traditional approach does.

Although econometric and computational approaches yield some covariance forecasts, as discussed in Beine (2004), incorporating some explanatory variables will improve the relevance of these methodologies. Therefore, the financial variables that have relevance with the second order conditional moments of the exchange rates have to be considered as the explanatory variables of covariance structure. There are many papers [3] that investigate the impacts of Central Banks Interventions (CBIs) on the volatility of exchange rates. However, to the best of our knowledge, there exists only one study Beine (2004), which investigates the effects of CBIs on the covariance of the exchange rates. He finds that at least coordinated official CBIs are explanatory variables of the covariance of EUR/USD and JPY/USD series. Although Beine (2004) paper was a milestone paper in portfolio optimization, as commented in Fratzscher (2006), in the last decade both FED and ECB abandoned direct central bank interventions and relied on communication (oral intervention) to affect exchange rates. Fratzscher (2006) finds that oral interventions decrease the volatilities of EUR/USD and JPY/USD series in %90 significance level. Since oral interventions have impact on the second order moments of the exchange rates and since in the last decade oral interventions are conducted as substitute for CBIs, oral intervention is a good candidate instead of the official CBIs to use as an explanatory variable for the covariance of EUR/USD and JPY/USD . In this thesis, we use the method-

[3] To name a few: Ballie and Osterberg (1997), Beine and Laurent (2003), Brander, Grech and Stix (2006), Dominguez (1998), Edison, Cashin, and Liang (2003), Fatum and Hutchison (2003) and Humpage (1999).

ology of Beine (2004) and the data of Fratzscher (2006) to assess the effects of official statements (oral interventions) on the covariance of EUR/USD and JPY/USD.

Our study contributes literature in two ways: Firstly, to our knowledge, it is the first study that investigates the effects of oral interventions on the covariance and correlation of exchange rates. Also, the statistical tests in section 4.3.1 show that incorporating oral intervention dummy variables enhance the in-sample forex variance and covariance forecasts. Since daily currency trading is more than $3.2 trillion and since variance and covariance of foreign exchanges is an input for the minimum variance portfolios, we believe that our study is important for academic purposes as well as for the practitioners who are dealing with currency trading and portfolio optimization. Our second contribution is on the computational methodology of MLE of GARCH models. It is the first study that investigates whether in-sample forecasts of MLE of the same GARCH representation can be statistically enhanced by only computational algorithms and environments. We find that employing GA and SQP algorithms in NEOS Servers consecutively, instead of the commonly used BHHH algorithm, brings tremendous improvement in forex forecasting. We argue that also our second contribution is important for both academicians and practitioners[4].

This thesis is organized as follows. Section 2 presents a literature review on the interventions and their effects on the forex volatility and covariance. Section 3 presents the data and methodology employed in this thesis. Section 4 explains the estimation and empirical results in detail. Section 5 makes an application of our results in daily currency portfolios. Section 6 concludes.

[4]Software used in the estimation of this paper can be found at `http://www.bilkent.edu.tr/~caskurlu/Thesis`

CHAPTER 2

LITERATURE REVIEW

2.1 History of Direct Central Bank Interventions

Official exchange rate intervention (direct central bank intervention) occurs when the underlying central bank buys or sells foreign currency against its own currency. The stated and intended aim and efficiency of these interventions have been the subject of the academic literature in the past 40 years[1]. Actually, debates on the interventions start with the collapse of Bretton Woods System in 1973, which forced each country to adopt a monetary policy that maintains the exchange rate of its currency within a fixed value − plus or minus one percent in terms of gold. After this monetary regime shift, the 1970s economy experienced floating exchange rates. The new system came with a shortcoming: volatility, which is one of the sources of the financial risk for the international traders and investors. As discussed in Sarno and Taylor (2001), the high volatility of forex parities of the major industrialized countries led the authorities to a consensus about the stabilization of the parities

[1] Ballie and Osterberg (1997); Beine and Laurent (2003); Brander, Grech and Stix (2001);Edison, Cashin, and Liang (2003); Fatum and Hutchison (2003b); Humpage (1999); Neely (2005); Sarno and Taylor (2001) and Schwartz(2000) provide detailed survey of this literature.

by intervening the markets. However, during 1980s, in a period where capital could move faster than 1970s, Reagan administration and many economists viewed interventions as costly and inefficient operations that have negligible effects on the markets due to high volume of assets traded − a result that is just the opposite of the official's intention. However, in 1980s, the dollar was so aggressively overvalued (%50 in nominal terms) that all G5 economy leaders and many academicians agreed on the importance of intervention again. In Plaza meetings (Plaza Hotel in New York in September 1985) G5 leaders decided to make concerted intervention to depreciate the dollar. However, unexpected and stationary decline of U.S dollar in late 1980s forced G7 leaders to make one more meeting (Louvre in Paris in February 1987) about the stabilization of the range of U.S price [2]. After the Plaza and Louvre meetings, there have been frequent interventions until 1996. These unilateral and coordinated interventions with coordinated monetary policy meetings were the fundamentals of the Exchange Rate Mechanism (ERM) of the European Monetary System (EMS). The last interventions of the Euro zone and USA were the coordinated intervention of the G7 economy in September 2000. However, Bank of Japan (BoJ) continued to make direct interventions in the forex markets until 16 March 2004 [3].

There are two mechanisms of direct central bank interventions: sterilized and non-sterilized operations. An official intervention is called sterilized when the central bank takes action to offset a change in the domestic-based foreign asset holdings. If the central bank only exchanges domestic currency but does not buy/sell domestic assets, then this operation is a non-sterilized operation. The main purpose of a sterilized intervention is to affect exchange rate while keeping the money supply and interest rates unaffected. Many central banks may choose to make sterilized operations for different purposes. For example,

[2] They decided to make a coordinated intervention though they didn't publicize the reasonable price range.

[3] The dates and amounts of BoJ official interventions can be reached at http://www.mof.go.jp/english/$e1c021$.htm

one central bank monetary policy may be targeting to slowly increase the interest rate to prevent the boost of the inflation while depreciating domestic currency to provide traders an advantage on international markets. Hence, central bank makes a sterilized intervention because a direct forex intervention of this central bank to depreciate the domestic currency would increase the money supply, resulting a higher inflation − the opposite of the central bank's intention. Parallel to its monetary policy, this central bank offsets the effects of intervention in the forex market by a transaction in the domestic bond market.

As discussed in Sarno and Taylor(2001), in theory, these sterilized and non-sterilized operations can affect the exchange rates through three channels: The portfolio balance channel, the signalling channel and co-ordination channel.

The portfolio balance channel is generally investigated under portfolio balance model (PBM), which implicitly assumes that domestic and foreign assets aren't perfect substitutes for the investors. According to this model, since the sterilized interventions do not affect the money supply, they don't cause a change in interest rates. However, the buy/sell of the domestic assets changes the composition of the international traders' portfolios, affecting indirectly the spot exchange rates. Dominguez and Frankel (1993) presents empirical evidence that interventions affect the exchange rates through portfolio balance channel. However, as Sarno and Taylor (2001) claims, for two reasons portfolio balance channel can less thought to be the one of the channels for interventions effecting forex dynamics. First, in the last decades financial markets are integrated so rapidly that financial assets of different countries became better substitutes. Second, in recent years forex market volume so much increased that liquidity is not a big problem for asset substitution. [4]

One of the other channels that is thought to effect the level exchange rates

[4] For more information on PBM model, one can refer to Branson (1983) and Dooley and Isard (1983).

is the signalling channel. This channel was initiated by the influential work of Mussa (1981), which states that the central banks convey some private information to the public by intervening in the forex markets. According to this hypothesis, central banks might have access to data (or information) that public doesn't have or might have in the future. Therefore, if there is an asymmetric information between the central bank and the public about the dynamics of the economy, investors may alter their expectations in the direction of the authorities' view. There are some empirical studies that support the validity of the signalling channel. Lewis (1995) finds that FED interventions can be used to predict the U.S monetary parameters. In a follow up paper, Kaminsky and Lewis (1996) show that forex interventions can be used to predict future monetary policies but the sign inferred from the signaling hypothesis can be opposite when the interventions are followed by inconsistent movements in monetary policy. In another paper, Bonser-Neal et al. (1998) concludes that exchange rates immediately react to central bank interventions. Although there is a vast literature in support of the signalling channel, one of the questions that arises is: Why don't central banks simply relieve information about the economy instead of directly intervening in the markets? Aguliar (2000) argues that intervention on the markets is a more credible operation since the authorities stake their own capital as well. Therefore, the intervention may be seen as an indicator of the strength of the authorities view about the economy. However, if the authorities are so sure about the fundamentals of the economy, then why some of the interventions were kept secret still seems to be an open question.

The last channel that is thought to effect the exchange rates is the coordination channel, which operates as a coordination device between the authorities and investors and may change the dynamics of the exchange rates. Although both portfolio channel and signalling channel imply that interventions affect the exchange rates immediately (assuming efficiency of the markets), co-ordination channel suggests that the interventions (actual or oral) are incorporated into asset prices overtime. There are many studies that investigate the long lasting effect of the interventions on the asset prices and find compelling evidence in favor of co-ordination channel. For example, Andersen et. al (2003) shows that macroeconomic news affects the volatility of the exchange rates to a greater extent initially but then the effects become quite persistent in time. Also, Evans and Lyons (2005) finds that macroeconomic news arrivals cause subsequent changes in trading of the major end-user participants such as hedge funds, mutual funds, and non-financial corporations and that these induced changes remain significant for days. They conclude that forex markets are not responding to macroeconomic news instantaneously.

2.2 Impact of Direct Intervention, Macroeconomic News and Oral Interventions on the Volatility and Covariance of the Foreign Exchanges

Since the volatility of the exchange rates is quite important for the risk management of the portfolios and for the stability of international trading, there are various studies that investigate the factors that affect the volatilities of the forex markets. Literature generally considers three factors that can have impact on the volatility: Direct Central Bank Interventions (CBIs), macroeconomic news and officials' statements (oral interventions).

The researches tested the effects of CBIs on the forex markets generally in either time series or event study framework. In time series models, many authors chose GARCH framework to assess the impact of the interventions. To name some of these papers, Dominguez (1998) investigates the effect of interventions on USD/DM and USD/JPY in 1977-1994 by using univariate

GARCH models. He documents that the interventions are positively correlated with the level of volatility. Ballie and Osterberg (1997) uses martingale-GARCH model and shows that interventions in 1985-1990 had no significant effect on the level and volatility of the USD/DM exchange rate. Beine and Laurent (2003) uses ARFIMA/FIGARCH to model the major exchange rates volatility. They assign a time-varying jump probability to central bank interventions and find that coordinated or unilateral interventions produce a jump in the forex return process and cause an increase in the volatility. Brander et.al (2006) examines the effects of central bank interventions of six European countries by EGARCH model and MS-ARCH model. The results from EGARCH model show that interventions influence the conditional mean in only one case and present mixed results (both increasing and decreasing) for the volatilities. They conclude that both EGARCH and MS-ARCH models do not find consistent effects on volatility and mean equations.[5]

Although GARCH framework is one of the most commonly used approach for examining the effects of CBIs, some researchers discusses the reliability of this methodology when the data include sporadic and intense intervention periods. As an alternative to GARCH models, these studies suggested to use event study approach, which investigates only the intervention periods with suitable time windows. However, as discussed in Neely (2005), selection of the "suitable" time window jeopardizes the reliability of this approach. Short window may not be covering the whole effect, while long windows may be increasing the danger of omitting important variables. Still, there are many papers using this methodology. To list some of the representatives of these event studies: Edison, Cashin, and Liang (2003) investigates the effect of intervention operations on mean and volatility of Australian dollar/ US dollar in 1997-2001 period. They find that intervention have quite modest impact on both level and volatility of Australian dollar. Fatum and Hutchison

[5]Neely (2005), Sarno and Taylor (2001) and Schwartz(2000) provide detailed survey of this literature.

(2003) focuses on the effects of Bundesbank and FED direct interventions on DEM/USD series. They identify separate intervention 'episodes' and then analyze their subsequent effects on volatility. They find that interventions have effects in the short run. Humpage (1999) uses a logit model and suggests that coordinated intervention has a higher probability of success than unilateral interventions and the probability of success increases with the dollar amount used in the intervention. [6]

Second factor that prior researchers generally accepted as one of the key determinants of the forex mean and volatility process is the macroeconomic news. For example, Ito and Roley (1987) investigates the impacts of Japan and US macroeconomic news on the JPY/USD and find that US-based news significantly effect the parity while Japan news has no such effect. Ederington and Lee (1993) uses high frequency data to examine the impacts of the 19 types of macroeconomic news on the volatility of USD/DEM. They conclude that merchandize trade, employment, retail sales, the producer index and GNP news have influence over the exchange rate volatility. Goodhart et. al. (1993) assesses the importance of US trade figures and UK interest rise on the GBP/USD. They find that these news changed the time-series behavior of the exchange rate. DeGenarro and Shrieves (1997) examines the impact of market activity and macroeconomic news on the volatility of JPY/USD. They show that both news and private information are important determinants of volatility. Andersen and Bollerslev(1998) tries to characterize the volatility of DEM/USD using three factors that effect the exchange rate volatility: intraday activity patterns, macroeconomic announcements and volatility persistence (ARCH) effects. They conclude that although announcement have significant effects, they have less explanatory power than the other two factors.

During 1980-1996 period, major central banks employed many direct in-

[6] For a complete list of this literature, again you can refer to Neely (2005).

terventions on the forex markets. However, especially in the last decade, authorities relied on communication to affect the exchange rates. Although, as mentioned above, there is considerable number of papers that investigate the effects of CBIs and macroeconomic news on the exchange rates, there is limited research on the impacts of the officials' statements on the forex markets. Two exceptions are Fratzscher (2006) and Jansen and De Haan (2005). Fratzscher (2006) investigates the effects of both CBIs and G3 economies' (US, Japan, Euro zone) authorities' statements that appeared on *Reuters News* about the forex. To test the effects, he uses univariate GARCH framework and incorporates CBIs, oral interventions, interest rate differentials and day-of the week as explanatory variables of the model. He finds that all of the CBIs have an increasing effect on the volatility. However, EURO zone oral interventions have a decreasing effect on the volatility of EUR/USD and both US and Japan oral interventions decrease the volatility of JPY/USD. He attributes the different impacts of CBIs and oral interventions to the market certainty. He claims that since major CBIs are conducted secretly, investors possess hesitations about the desired levels of the exchange rates. However, with oral interventions, investors have much more information about the economy and they do not overreact to events in the forex market. The other oral intervention study, Jansen and De Haan (2005) examines the effects of officials' statements about the monetary policy and the external value of the EUR in univariate GARCH framework. They conclude that in some cases the statements of ECB officials influence the level of the EUR/USD. These effects on the level are not permanent; statements don't have significant effects over the two day period after the statement. Furthermore, the statements to appreciate EUR against other currencies are generally not successful. These comments to strengthen EUR increase the volatility of EUR/USD.

CHAPTER 3

DATA AND METHODOLOGY

3.1 Data

In our analysis, we use the statements of USA, Japan and Euro zone officials about the exchange rates for 1996-2003 period.[1] Actually, it is quite difficult to know which news reaches to the investors in a timely fashion. Therefore, we accept the *Reuters News* as the benchmark and assume that the officials' statements that appeared on *Reuters News* are read by the investors on the news release day. Since *Reuters News* is one of the most reliable and comprehensive data service and since it makes the news accessible in a short time after the statement, our assumptions are quite reasonable in practice.

As explained in Fratzscher (2006), the first step in gathering the statements is the identification of the policy makers in the underlying countries or zones. In USA, exchange rate policy has been controlled by the US Treasury Department and FED. Therefore, the statements of Treasury Secretary, Deputy Secretary and Federal Open Market Committee (FOMC) members are included in our analysis. In Euro area, exchange rate policy lies in the realm of respective central banks. Therefore, for the 1996-1998 period, statements of the Bundesbank Zentralbankrat members and for the 1999-2003

[1] I would like to thank Marcel Fratzscher (ECB Research Department) for kindly providing the data that he used in Fratzscher (2006)

period, statements of ECB Governing Council Members are taken into account. In Japan, the authority about the exchange rates is the Ministry of Finance. However, Bank of Japan's (BoJ) members make regular announcements about the exchange rate. Hence, the data covers the statements of the Finance Minister, Vice Finance Minister for International Affairs, BoJ's governor and two deputy governors. The distribution of the officials' statements (oral interventions) in 1996-1999 and 1999-2003 periods are presented in Table 3.1.

After the the officials are determined, the search is conducted by the key terms a) "exchange rate" and b) the name of the official. Since the macroeconomic announcements that occurred on the days of monetary policy meetings or testimonies to central banks may have a dominant effect on that day, the statements on these days were ignored to get the pure effect of oral intervention.

After listing all of news, it is classified into three categories in terms of their content and meaning. If an official statement is interpreted as in favor of appreciation of domestic currency, then it is accepted as "strengthening"; whereas if interpreted as in favor of depreciation of domestic currency, then marked as "weakening". Some of the strengthening and weakening statement examples of the data can be found in Fratzscher (2008). There are also some statements that are difficult to categorize as "strengthening" or "weakening". In our thesis, we treat "ambiguous" statements as deviations from the predominant foreign exchange policy. Therefore, "ambiguous" news are counted as "weakening" in USA and Euro zone, whereas it is counted as "strengthening" in Japan. After the classification, all news are represented by the indicators. The dummy variable for the days that "strengthening" and "weakening" news arrived are marked by 1 and -1 respectively and the dummy variable for the days in which no news arrived are given value 0.

	USA	Euro Area	Japan
1996-1999			
Strengthen	25	15	2
Weaken	5	0	8
1999-2003			
Strengthen	76	61	16
Weaken	10	18	51

Table 3.1: Number of Official Statements. Source: *Reuters News*

3.2 Advances in Forecasting Volatility and Correlation

For forecasting the volatility, the most common approaches are realized volatility, which requires high frequency data, implied volatility, which requires option data and Generalized Autoregressive Conditional Heteroscedasticity (GARCH) models. As explained in Chapter 2, for the investigation of the impacts of central bank interventions on the volatility components, generally GARCH models are used. Since we have daily data and since our time series show GARCH effects, we also employed GARCH framework. In the remaining of this chapter, we will explain the basics and different multivariate representations of GARCH models.

The analysis of time series dynamics of economic data is usually based on observations of relevant processes, e.g., the behavior of short and long-term interest rates, rate of inflation, stock prices, etc. Therefore, an observed time series is viewed as a realization of a stochastic process. The random variables in the stochastic process may be unidimensional, leading to univariate econometric models, or multidimensional, in which case multivariate models are appropriate. For univariate models, we adopt the following notation:

$$Y_t = \phi_1 Y_{t-1} + \phi_2 Y_{t-2} + \ldots + \phi_m Y_{t-m} + \varepsilon_t$$

where $Y_t \in \Re^1$, $\varepsilon \in \Re^1$ and ε is a weak white noise satisfying the martingale difference sequence condition:

$$E(\varepsilon_t | \underline{\varepsilon_{t-1}}) = 0$$

where the notation $E(.)$ denotes mathematical expectation and $\underline{\varepsilon_{t-1}} = \{\varepsilon_{t-1}, \varepsilon_{t-2}, \ldots\}$ represents the vector of past values. When the error term ε_t is a multivariate process of dimension n, for all $t = 1, \ldots, T$ we have $Y_t \in \Re^n$ and $\varepsilon_t \in \Re^n$ with components Y_{lt} and $\varepsilon_{lt}, l = 1, \ldots, n$, respectively. We denote the components of the $n \times n$ conditional variance-covariance matrix $H_t = E(\varepsilon_t \varepsilon_t^T | \underline{\varepsilon_{t-1}})$ by $h_{ij,t}$ where $i, j = 1, ...n$.

3.2.1 Multivariate GARCH Models

As discussed in Bauwens et. al(2003), it is now widely accepted that volatilities move together over time across financial assets and markets. Taking the co-movement account through a multivariate modeling framework leads to more realistic empirical models than working with separate univariate models. In addition, multivariate framework provides us the covariance and correlation of the financial assets, which are critical inputs for value-at risk measures, mean/variance optimization or hedging. Although there are various multivariate GARCH (MGARCH) representations, we will explain the most commonly used representations in this thesis. For a more comprehensive MGARCH representations, you can refer to Silvennoinen et. al (2007).

3.2.2 Vec and Diagonal Vec Model (DVEC)

The first attempt to MGARCH models was Bollerslev et.al (1988)'s Vec representation. In this model, the conditional covariance is represented as a linear function of the cross products of errors, and lagged values of all the elements of H_t. Assuming errors are normally distributed, Vec model can be formulated as the following optimization problem:

$$\max -\frac{TN}{2}\log(2\pi) - \frac{1}{2}\sum_{t=1}^{T}(\log|H_t| + \varepsilon_t' H_t^{-1}\varepsilon_t)$$

$$s.t$$

$$vech(H_t) = vech(C) + \sum_{i=1}^{q}(A_i vech(\varepsilon_{t-i}\varepsilon_{t-i}') + \sum_{j=1}^{p}(B_j vech(H_{t-j})$$

$$H_t \geqslant 0$$

where vech(.) is the operator that stacks the lower triangle and diagonal elements of an $N \times N$ matrix, where N is the number of time series, to a $N(N+1)/2 \times 1$ vector and "$\geqslant 0$" denotes the positive definite matrix. The Vec model is very intuitive and easy to understand because it estimates the covariances as a geometrically declining weighted average of past cross products of the error terms. The major weakness of this model is the number of parameters to be estimated. For example, the simplest Vec(1,1) model has to estimate $N(N+1)(N(N+1)+1)/2$ parameters. In addition to large number of parameters, positive definiteness condition of the Vec model requires strong restrictions on the variable set. For the matrix representation of Vec (1,1):

$$H_t = C + (I_n \otimes \varepsilon_{t-1}')A(I_n \otimes \varepsilon_{t-1}) + E_{t-2}[(I_n \otimes \varepsilon_{t-1}')G(I_n \otimes \varepsilon_{t-1})]$$

is the sufficient conditions for the positive definiteness is : $C \geqslant 0$, $A \geqslant 0$, $G \geqslant 0$, where I_n is the nxn identity matrix. To ease the optimization problem, the positive definiteness constraint is generally not imposed, but instead checked after the estimation procedure. Because of the optimization difficulties in Vec model, Bollerslev et.al (1988) also proposes the Diagonal Vec model, where

A_i and B_j are assumed to be diagonal matrices. For GARCH(1,1) process the entries of the H_t can be written as

$$h_{ijt} = c_{ij} + a_{ij}\varepsilon_{i,t-1}\varepsilon_{j,t-1} + b_{ij}h_{ij,t-1}$$

and in matrix notation it can be characterized as follows:

$$H_t = C + A \odot (\varepsilon_{t-1}\varepsilon'_{t-1}) + B \odot H_{t-1}$$

where $\odot$ represents the Hadamard products. In DVEC specification the number of parameters to be estimated reduces to $N(N+5)/2$. Despite the decreased number of parameters, restrictions on semi-definiteness on C, A, B and initial matrix H_0 still remain.

3.2.3 BEKK Model

Engle and Kroner (1995) suggests BEKK (Baba, Engle, Kraft, Kroner) model to eliminate the hard restrictions of VEC representation on positive definiteness of H_t. Although this model is a special case of the VEC, it is generally preferred to VEC model since it has very low number of parameters to be estimated while it is sufficiently general. Assuming errors are normally distributed, BEKK model can be formulated as the following optimization problem:

$$\max \qquad -\frac{TN}{2}\log(2\pi) - \frac{1}{2}\sum_{t=1}^{T}(\log|H_t| + \varepsilon'_t H_t^{-1}\varepsilon_t)$$

$$s.t$$

$$H_t = C'C + B'H_{t-1}B + A'\varepsilon_{t-1}\varepsilon'_{t-1}A$$

where A, B and C are $N \times N$matrices with C symmetric and positive definite. In BEKK model, $H_o \geqslant 0$ is sufficient condition for the positive definiteness of conditional covariance matrix. While BEKK makes progress on restrictions of H_t, compared with DVEC model,it increases the number of parameters to be estimated. From a numerical optimization point of view, the BEKK model also increases the nonlinearity of the constraints by utilizing a higher-order polynomial representation.

3.2.4 DCC Model

This model proposed by Engle (2002) eliminates the complexity of MGARCH models by dividing the problem into two subproblems: volatility estimation and correlation estimation. In the first step, n individual asset volatilities are calculated using univariate GARCH problems in the folowing manner where $l = 1, ..n$, $P \in \Re^1$ and $Q \in \Re^1$:

$$h_{l,t} = c_i + \sum_{i=1}^{P} a_{l,i}\varepsilon^2_{l,t-p} + \sum_{j=1}^{Q} b_{lq}h_{l,t-j}$$

and in the second step, using the estimated volatilities in the first step, standardized residuals are calculated and put into equation system to get the time-varying correlations.

In this model, multivariate conditional covariance is represented as:

$$H_t = D_t R_t D_t$$

where H_t represents the conditional variance matrix, D_t is the $(n \times n)$ diagonal matrix of time-varying standard deviations from the univariate GARCH estimation and R_t is the $(n \times n)$ time-varying correlation. Assuming the errors, ε_t, has the property $\varepsilon_t|\Im_{t-1} \sim N(0, H_t), where \Im_{t-1}$ represents all the information up to time (t-1), the log-likelihood function can be written as:

$$
\begin{aligned}
L &= -\tfrac{1}{2}\sum_{t=1}^{T} n\log(2\pi) + \log|H_t| + \varepsilon_t' H_t^{-1}\varepsilon_t \\
L &= -\tfrac{1}{2}\sum_{t=1}^{T} n\log(2\pi) + \log|D_t R_t D_t| + \varepsilon_t' D_t^{-1} R_t^{-1} D_t^{-1}\varepsilon_t \\
L &= -\tfrac{1}{2}\sum_{t=1}^{T} n\log(2\pi) + 2\log|D_t| + \log|R_t| + u_t R_t^{-1} D_t^{-1} r_t \\
L &= -\tfrac{1}{2}\sum_{t=1}^{T} n\log(2\pi) + 2\log|D_t| + \varepsilon_t' D_t^{-1} D_t^{-1}\varepsilon_t - u_t' u_t + \log|R_t| + u_t' R_t^{-1} u_t \\
L &= L_v + L_c \\
L_v &= -\tfrac{1}{2}\sum_{t=1}^{T} n\log(2\pi) + 2\log|D_t| + \varepsilon_t' D_t^{-1} D_t^{-1}\varepsilon_t \\
L_c &= -\tfrac{1}{2}\sum_{t=1}^{T} -u_t' u + \log|R_t| + u_t' R_t^{-1} u_t
\end{aligned}
$$

where $u_{i,t}$ is the standardized residuals and calculated as $u_{i,t} = \varepsilon_{i,t}/\sqrt{h_{ii,t}}$. In the second part of the estimation, we will use L_c as the objective function and R_t matrix will be the constraints. The evolution of DCC is given by the following equation:

$$Q_t = (1 - \alpha - \beta)\overline{Q} + \alpha u_{t-1} u_{t-1}' + \beta Q_{t-1}$$

in which Q_t is the $(n \times n)$ time-varying covariance matrix of u_t, $\overline{Q} = E[u_t u_t']$ is the $(n \times n)$ unconditional matrix of u_t. We can transform the covariance matrix into correlation matrix as:

$$R_t = (diag(Q_t))^{-1/2} Q_t (diag(Q_t))^{-1/2}$$

where $(diag(Q_t))^{-1/2} = diag(1/\sqrt{q_{11,t}}, ..., 1/\sqrt{q_{nn,t}})$. Simply the correlation can be calculated by $\rho_{ij,t} = q_{ij,t}/\sqrt{q_{ii,t} q_{jj,t}}$.

3.3 Computational Issues

One of the most common ways of estimating GARCH-volatility is the Maximum Likelihood Estimation (MLE) method. In MLE of GARCH representations, the resulting optimization problems are nonlinearly constrained non-convex nonlinear programming problems. This type of the problems is the hardest problems in operations research literature. For problems containing huge number of variables of this type, it may not be possible to find the global optimal. When the optimization solvers are not able to find the global optimal, they present Karush-Kuhn-Tucker (KKT) points as the solution. Since the KKT points are only necessary but not sufficient conditions to be the optimal, the algorithms employed in the solvers determine the accuracy of the experiment. Furthermore, the local optimization algorithms start to search for the optimal from a fixed point and if the starting point is far away from the mathematical global optimal then local optimal solvers may not be successful to locate the global optimal. Hence, also the initial points can be very crucial in the estimation procedure.

For GARCH optimization problems, beginning by the Bollerslev et. al (1988), it is quite standard to use BHHH algorithm for GARCH estimation. In Salih et. al (2003), a new GARCH representation was introduced and volatility was estimated by SNOPT solver. Although the model had a better in-sample forecasting capability than that of the competing models, the source of the superiority was not attributed solely to new representation or to the solver. Also, they didn't employ any standard initialization algorithm for the variables to be estimated. In this paper, we employ two step estimation: In the first step, we employ Genetic Algorithm (GA), which is a stochastic global optimization solver, to solve the resulting optimization problem of GARCH models. Although GA's results are not mathematical global optimal, its results are accepted as fair initial variables to start with. In the second step, the optimal values of GA are accepted as initial values and problem is resolved with SNOPT solver in NEOS Servers (Figure 3.1 sketches the estimation method). In the first part of the paper, we use DVEC model to investigate

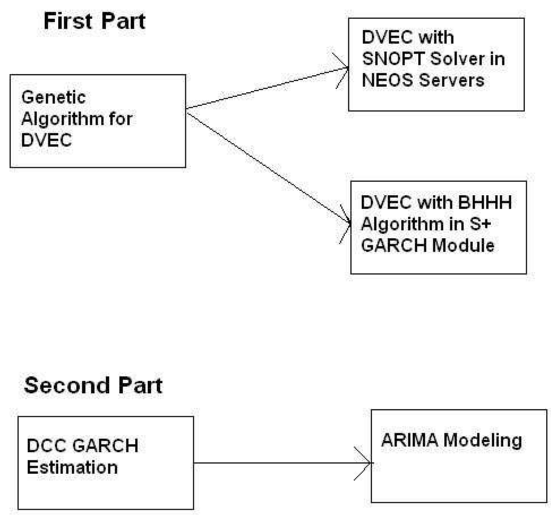

Figure 3.1: Estimation Methods

the effects of oral intervention on the covariance dynamics of the exchange rates. In the second part, we examine the effect of these intervention on the correlation structure of these series.

3.3.1 Genetic Algorithm

Genetic Algorithm (GA) was initiated by Holland (1975). It is generally used to solve large-scale optimization problems that are not well suited for deterministic optimization algorithms, including problems in which the objective function is highly nonlinear, discontinuous, non-differentiable or stochastic. In principle, GA simulates the evolutionary process of species that sexually reproduce. In this system, the new candidates for the solution are generated with a mechanism called crossover which combines part of the genes of each parent and then makes a random mutation. The new individual will have higher probability to survive, if it inherits good characteristics from its parents.

As Gilli and Winker (2007) indicate, the algorithm of GA can be summarized as follows: In this algorithm, firstly a set of solution is chosen. Then in the for loop, random individuals from the set is picked, applied crossover and also mutated. This fitness of this child and parent population is compared by the survive function. After a pre-specified number of generation, the algorithm stops.

Input: Initial Population

Output: Neighborhood solution

Generate initial population of solutions);

while *stopping criteria has not reached* **do**

  Select X' ⊂ X (mating pool), initialize X"=∅ (set of children)

  for *i=1:n* **do**

    Select individuals x^a and x^b at random from X' ;

    Apply crossover to x^a and x^b to produce x^{child};

    Randomly mutate produced child x^{child};

    X" = X" ∪ x^{child} ;

  end

  X = survive(X', X");

end

Algorithm 1: Pseudo-Code for Genetic Algorithm

3.3.2 SNOPT Solver

As indicated in Gill et.al (2002), SNOPT is a general-purpose system for constrained optimization. It minimizes a linear or nonlinear function subject to bounds on the variables and sparse linear or nonlinear constraints. It is suitable for large-scale linear and quadratic programming and for linearly constrained optimization, as well as for general nonlinear programs. SNOPT generally finds solutions that are locally optimal. However, local optima are often global optimal, and discontinuities in the function gradients can often be tolerated if they are not too close to an optimum. Unknown gradients are estimated by finite differences. SNOPT employs the sequential quadratic programming (SQP) algorithm. In this algorithm, search directions are obtained from QP subproblems that minimize a quadratic model of the Lagrangian function subject to linearized constraints and an augmented Lagrangian merit function is reduced along each search direction to ensure convergence from any starting point. SQP algorithms perform two different methodologies for Equality Constrained Quadratic Problems (ECQP) and Inequality Constrained Quadratic Problems (ICQP). However, understanding the ECQP is essential for ICQP.

3.3.3 Equality Constrained Quadratic Problem (ECQP)

ECQP is the reduction of the equality constrained NLP to a quadratic problem in the SQP algorithms. A basic equality constrained NLP can be represented as:

$$\min f(x)$$
$$s.t \quad h(x) = 0$$

where $f(x)$ and $h(x)$ can be nonlinear functions of x. In DVEC representation, $f(x) and h(x)$ refers to objective function and constraint indicated in section 4.2.1. KKT conditions for general equality constrained NLP problem can be derived as:

$$\begin{pmatrix} \nabla_x \mathrm{L(x,}\lambda) \\ \nabla_\lambda \mathrm{L(x,}\lambda) \end{pmatrix} = \begin{pmatrix} \nabla \mathrm{f(x)} + \sum_{\mathrm{i=1}}^{\mathrm{m}} \lambda_{\mathrm{i}} \nabla h_{\mathrm{i}}\mathrm{(x)} \\ \mathrm{h(x)} \end{pmatrix} = 0$$

and

$$\mathrm{L(x,}\lambda) = \mathrm{f(x)} + \sum_{\mathrm{i=1}}^{\mathrm{m}} \lambda_{\mathrm{i}} h_{\mathrm{i}}\mathrm{(x)}$$

The main idea behind the SQP model is to model problem equality constrained problem (ECP) at a given point x_k by a quadratic programming subproblem and then use this solution for a more accurate approximation of x_{k+1}. For the sub-quadratic programming problem(QPS), objective function is the truncated second order Taylor series expansion of the Lagrangian function and the constraints are derived by the first order Taylor series expansion of the constraints in the original problem. The QPS is formulated as:

$$\min \ \nabla \mathrm{f}(\mathrm{x}^{(\mathrm{k})})'\Delta \mathrm{x} \ + \tfrac{1}{2}(\Delta \mathrm{x})' \ [\nabla_x^2 \mathrm{L}(\mathrm{x}^{(\mathrm{k})},\lambda^{(\mathrm{k})})] \ \Delta \mathrm{x}$$

$$\text{s.t} \quad \mathrm{h}(\mathrm{x}^{(\mathrm{k})}) \ + \ \nabla h(\mathrm{x}^{(\mathrm{k})})'\Delta \mathrm{x} = 0$$

where $\nabla_x^2 \mathrm{L}(\mathrm{x}^{(\mathrm{k})},\lambda^{(\mathrm{k})}) = \nabla^2 f(\mathrm{x}^{(\mathrm{k})}) + \sum_{i=1}^{m} \lambda_i \nabla^2 h_i(\mathrm{x}^{(\mathrm{k})})$

3.3.4 Inequality Constrained Quadratic Problem (ICQP)

The most general constrained NLP problem is

$$\begin{aligned} &\min \ \mathrm{f(x)} \\ &\text{s.t} \quad \mathrm{h_i}(x) = 0 \ \text{ for } \mathrm{i} \in \mathrm{E} \\ &\qquad\ \ \mathrm{h_i}(x) \geq 0 \ \text{ for } \mathrm{i} \in I \end{aligned}$$

where $f : R^n \to R$ and h_i: $R^n \to R^m$ are smooth functions. In general constrained nonlinear problems, only constraints that are satisfied as equalities affect the solution. So, a strategy for identifying constraints that will be active in the solution has to be developed. SNOPT chooses $\mathrm{Z} = \{\mathrm{i} : \mathrm{h_i(x)} = 0, \mathrm{i} \in \mathrm{I} \cup \mathrm{E}\}$ and then solve the equality constrained problem.

For the ICQP problem active set Z can be found while solving the quadratic problem :

$$\begin{aligned} &\min \ \nabla \mathrm{f}(\mathrm{x}^{(\mathrm{k})})' \ \Delta \mathrm{x} + \tfrac{1}{2}(\Delta \mathrm{x})' \ [\nabla_x^2 \mathrm{L}(\mathrm{x}^{(\mathrm{k})},\lambda^{(\mathrm{k})})] \, \Delta \mathrm{x} \\ &\text{s.t} \quad \mathrm{h_E}(\mathrm{x}^{(\mathrm{k})}) + \nabla h_E(\mathrm{x}^{(\mathrm{k})})' \, \Delta \mathrm{x} = 0 \\ &\qquad\ \ \mathrm{h_I}(\mathrm{x}^{(\mathrm{k})}) + \nabla h_I(\mathrm{x}^{(\mathrm{k})})' \, \Delta \mathrm{x} \geq 0 \end{aligned}$$

using linear approximations of the constraints. Then, $\mathrm{Z} = \{\mathrm{i} : \mathrm{h_i(x)} + \nabla h_i(\mathrm{x})'\Delta \mathrm{x} = 0\}$ is the active constraints in the sub quadratic problem. So, SNOPT takes the active set of problems as a prediction of the nonlinear constraints. At each iteration, it first picks constraints for Z and solves the ECQP. If the solution is infeasible in the remaining constraints ($\mathrm{R} = \mathrm{I}/\{\mathrm{Z} \cap \mathrm{E}\}$), then another set of constraints is picked for Z. Conversely, if the solution for the active constraints is also feasible for the inactive constraints, the solution is candidate for the ICQP problem.

Problem arises for the ICQP problem when a good positive definite approximation of the $\nabla_x^2 \mathrm{L}(\mathrm{x}^{(\mathrm{k})}, \lambda^{(\mathrm{k})})$ can't be found. Also, the length of the step can be an important issue in the estimation. To evaluate the progress in improving the objective function and feasibility SNOPT uses the below merit functions.

$$\varphi_1(x, \beta) = f(x) + \beta \left\| h(x) \right\|_1$$
$$\varphi_2(x, \beta) = f(x) + \tfrac{\beta}{2} \left\| h(x) \right\|_2^2$$

3.3.5 BHHH Algorithm

BHHH algorithm is the one of the most common method used for the GARCH model estimations. Although it is slower than the competing Newton-Raphson algorithm, since BHHH only requires first derivatives of the QML estimates (Newton-Raphson also requires second order), BHHH is less prone to error in terms of computation. In addition to that, BHHH algorithm structure allows for easy testing of some hypothesis like estimation of covariance of MLEs. In essence, BHHH takes advantage of the analytical properties of MLEs. Since, in MLEs, the matrix of second derivatives evaluated at θ_0 has the same expectation as the outer product of the gradient matrix:

$$\sum_{t=1}^{n} \frac{\partial l_t}{\partial \theta} \frac{\partial l_t}{\partial \theta'}$$

In this algorithm, a computationally economic way is used for the optimization. The search directions is found in the following manner:

$$d_r = (\sum_{t=1}^{n} \frac{\partial l_t}{\partial \theta} \frac{\partial l_t}{\partial \theta'})^{-1} \sum_{t=1}^{n} \frac{\partial l_t}{\partial \theta}|_{\theta=\theta^r}$$

3.3.6 NEOS Server

The NEOS Server, initiated by U.S Department of Energy and Northwestern University, is a collaborative project that represents the efforts of the optimization community by providing access to variety (over 50) of solvers for researchers. Optimization problems can be submitted in a programming language (Fortran, C), in a modeling language (AMPL, GAMS), or in some other data formats. One of the main advantages of the NEOS Server is to eliminate the need to purchase the optimization solvers. In NEOS, it is easy to upload the code and get the results from an e-mail account. Another advantage of the NEOS is getting rid of the necessity of providing auxiliary information for a solver. Especially, nonlinear problems (like GARCH model) often require derivatives and sparsity patterns.

CHAPTER 4

ESTIMATION AND EMPIRICAL RESULTS

4.1 Diagnostic Tests

To find a proper model to assess the covariance dynamics of the exchange rate series, we firstly investigate whether 1996-2003 period JPY/USD and EUR/USD series' residuals of conditional mean equations have autocorrelation and heteroscedasticity properties. For autocorrelation, we initially visually check the serial correlation of residuals and squared residuals. As seen in the Figure 4.1, although both EUR/USD and JPY/USD series don't have serial correlation in residuals, they have autocorrelation up to 20 lag in squared residuals. In addition to visual inspection of autocorrelation effects, we employ Ljung-Box test to statistically conclude about the autocorrelation properties of the two series. As shown in Table 4.1, Ljung-Box test confirms the visual inspection and finds that the series have no autocorrelation in residuals whereas they have significant autocorrelation in 5% level in squared residuals. For heteroscedasticity, we employ ARCH-LM test of Engle (1982). As seen in Table 4.1, there is significant heteroscedasticity in residuals of both series. As there is significant autocorrelation and heteroscedasticity, we conclude that there is enough evidence for using GARCH models to capture the time varying behavior of volatility and covariance. After we decided to use the GARCH model for estimation, we decide on the appropriate distribution for the maximum likelihood estimation (MLE). Since normal distribution is the simplest distribution to model, we check whether the residuals of the conditional mean comes from the normal distribution. As seen in Figure 4.2, visual inspection shows that there are some deviations from the normal distribution. Standard statistical tests conclude that residuals have fatter tail and a sharper central peak than the theoretical normal distribution. To deal with this issue, we will use Bollerslev-Wooldridge (1992) standard errors that are robust to non-normality.

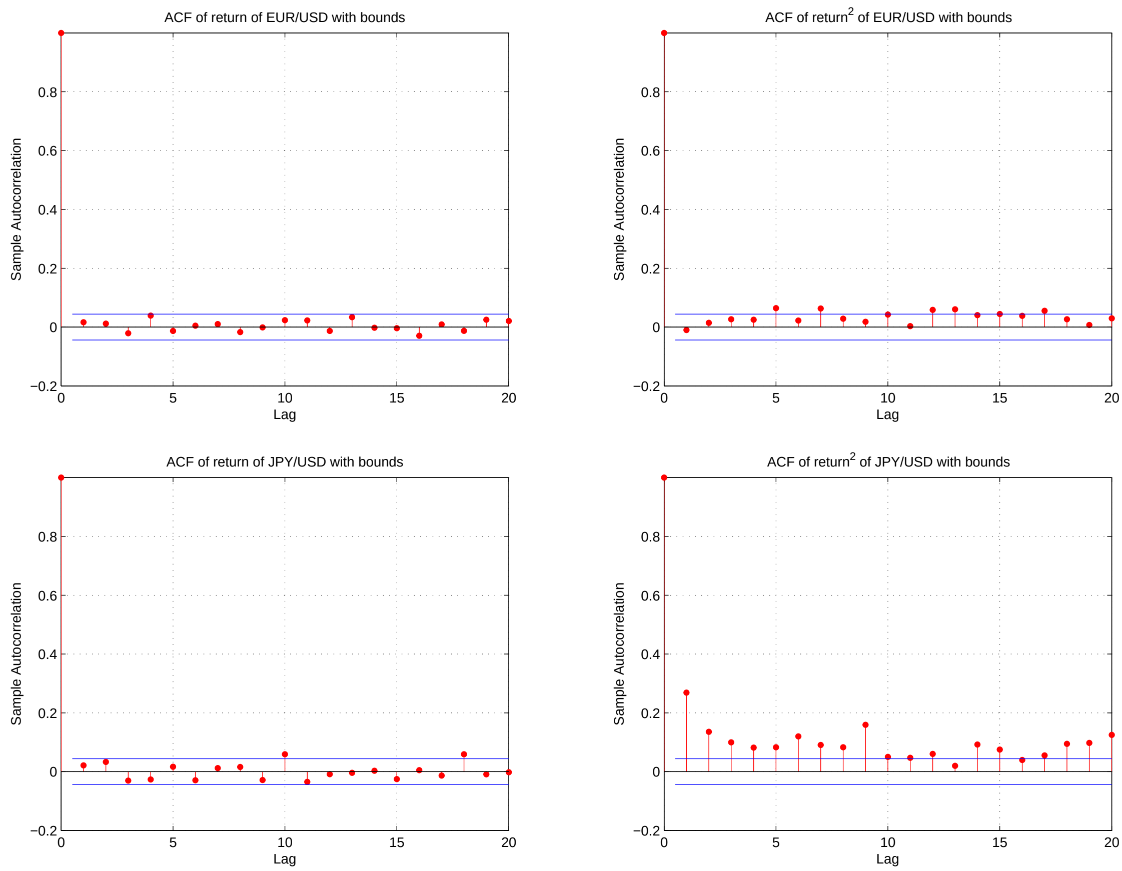

Figure 4.1: ACF of residuals and squared residuals of EUR/USD and JPY/USD

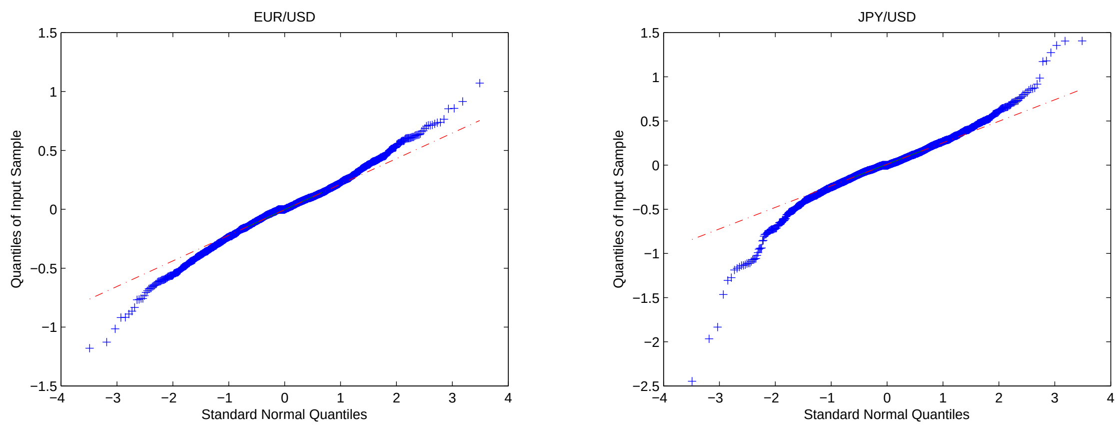

Figure 4.2: QQ-Plot of residuals

Diagnostic Test Results			
		EUR/USD	**JPY/USD**
Autocorrelation tests Ljung-Box(20)	Residuals Squared Residuals	15.5389 62.1083***	30.5791 476.7538***
Heteroskedasticity Test	ARCH (10) LM	105.32***	87.35***
Normality Test	Skewness Kurtosis Jarque-Bera	-0.1526*** 4.1156*** 114.65***	-0.6795*** 7.9745*** 227.91***

Table 4.1: Diagnostic Results

4.2 Econometric Methodology

Since diagnostics exhibit significant heteroscedasticity and autocorrelation, we can investigate the conditional covariance and correlation in GARCH framework. Although there are variety of GARCH representations, we chose specifically DVEC model for conditional covariance estimation. There are three main motivations for using DVEC model. Firslty, it has very few variables to estimate, making the estimated coefficients can be more accurate since we are making local optimization. Secondly, it is sufficiently successful for estimation of time series models despite having few variables and lastly, it is quite easy to incorporate dummy variables into covariance equation. In fact, we tried to use Asymmetric-DVEC (ADVEC) model of De Goeij et.al (2004) instead of DVEC since ADVEC takes into account also the asymmetric shocks. However, we had converge problems and we had to return to DVEC.

In the second part of the the thesis, we check our results of DVEC model by conditional correlation analysis. The most suitable GARCH representation for correlation estimation is DCC model of Engle(2002). We preferred DCC over other representations because it evaluates correlation with the simplicity of univariate GARCH estimation. However, DCC comes with a drawback: it is not straightforward to incorporate dummy variables into correlation structure. Therefore, in our analysis, we will assume that correlation forecasts of DCC model are true correlation values and will employ regression to see the effects of oral intervention in the correlation dynamics.

After deciding on the GARCH representation that we will employ in our analysis, we examined the appropriate computational framework that we will conduct our experiments. BHHH, a local optimization algorithm, is kind of standard methodology for the estimation of optimization problems resulting from GARCH representations. However, we wanted to assess whether SQP algorithm used in SNOPT solver can beat the performance of BHHH algorithm. Therefore, we solved optimization problems of DVEC representations by both BHHH and SQP local optimization algorithms. Before the estimation, we also use Genetic Algorithm (GA) to have good initial points to run the local optimization solvers. The motivation and details of the computational issues employed in the thesis can be found in section 3.3.

4.2.1 DVEC Analysis

In the first part of the estimation, we will use DVEC representation to investigate the effects of oral interventions on the conditional covariance structure of EUR/USD and JPY/USD. To see the effects, we will put dummy variables on the covariance equation and assess whether they are significant at 5% level.

We will solve the optimization problem resulting from DVEC representation both with SNOPT solver in NEOS server and with BHHH algorithm in S+ language in a PC. Hence, we will be able to compare the performances of these two environments and choose the appropriate computation environment for our analysis.

The resulting optimization problem of bivariate DVEC representation can be written as:

$$
\begin{aligned}
&\max \quad -0.5 * \sum_{t=1}^{T} (\log(h_{11,t}h_{22,t} - h_{12,t}^2) + \tfrac{\varepsilon_{1,t}^2 h_{22,t} + \varepsilon_{2,t}^2 h_{11,t} - 2\varepsilon_{1,t}\varepsilon_{2,t}h_{12,t}}{h_{11,t}h_{22,t} - h_{12,t}^2}) \\
&s.t \\
&h_{11,t} = \mu_1 + \alpha_1 \varepsilon_{1,t-1}^2 + \beta_1 h_{11,t-1} + \lambda_{USvar} OI_{US,t-1} + \lambda_{EUvar} OI_{EU,t-1} \\
&h_{12,t} = \mu_2 + \alpha_2 \varepsilon_{1,t-1}\varepsilon_{2,t-1} + \beta_2 h_{12,t-1} + \lambda_{UScov} OI_{US,t-1} + \lambda_{EUcov} OI_{EU,t-1} + \lambda_{JPcov} OI_{JP,t-1} \\
&h_{22,t} = \mu_3 + \alpha_3 \varepsilon_{2,t-1}^2 + \beta_3 h_{11,t-1} + \lambda_{USvar2} OI_{US,t-1} + \lambda_{JPvar} OI_{JP,t-1} \\
&y_{1,t} = \eta_1 + \lambda_{USmean} OI_{US,t-1} + \lambda_{EUmean} OI_{EU,t-1} + \varepsilon_{1,t} \\
&y_{1,t} = \eta_2 + \lambda_{USmean2} OI_{US,t-1} + \lambda_{JPmean} OI_{JP,t-1} + \varepsilon_{2,t}
\end{aligned}
$$

where $OI_{US,t-1}, OI_{EU,t-1}$ and $OI_{JP,t-1}$ indicates the oral intervention dummies of US, Eurozone and Japan officials respectively. As can be seen in the objective function, during the estimation process, we employed Gaussian-maximum likelihood. The main motivations for Gaussian assumptions are: Firstly, the optimization problem is easier to implement and has less number of variables to be estimated than have the alternative models such as t-distribution and generalized hyperbolic distribution. Secondly, following Weiss (1986) and Bollerslev et.al (1992), when the normality assumption is violated but the first two conditional moments are specified, under suitable regularity conditions, QMLE estimates of L(θ) will be asymptotically normal and consistent. Hence, in our estimation we use robust standard errors of Bollerslev and Wooldridge (1992) for the MLEs. Robust Bollerslev-Wooldridge asymptotic covariance matrix for the MLEs is written as:

$$V(\theta) = \frac{1}{n}(\frac{1}{n}\sum_{i=1}^{n}\Upsilon_t)^{-1}(\frac{1}{n}\sum_{i=1}^{n}\frac{\partial l_t}{\partial \theta}\frac{\partial l_t}{\partial \theta'})\frac{1}{n}(\frac{1}{n}\sum_{i=1}^{n}\Upsilon_t)$$

where Fischer information matrix is:

$$\Upsilon_t = (\nabla\varepsilon_t)' H_t^{-1}(\nabla\varepsilon_t) + \frac{1}{2}(\nabla H_t)'(H_t^{-1} \otimes H_t^{-1})(\nabla H_t).$$

4.2.2 DCC Analysis

In this part, we check our results from DVEC analysis via correlation analysis and use DCC model of Engle(2002). The main reason to use DCC is that it gives the advantage to model correlations by the simplicity of estimating univariate GARCH model (see section 3.2.4 for details). Since we examine the conditional correlation of EUR/USD and JPY/USD series; we use the bivariate DCC formulated as follows:

$$\max \quad \tfrac{1}{2}\sum_{t=1}^{T}\left[\log(1 - \tfrac{q_{21,t}^2}{q_{11,t}q_{22,t}}) - \frac{2u_{1,t}u_{2,t}\frac{q_{21,t}^2}{q_{11,t}q_{22,t}} - u_{1,t}^2 - u_{2,t}^2}{1 - \frac{q_{21,t}^2}{q_{11,t}q_{22,t}}} + u_{1,t}^2 + u_{2,t}^2\right]$$

$s.t$

$$q_{11,t} = (1-\alpha-\beta)\bar{q}_{11,t} + \alpha u_{1,t-1}^2 + \beta q_{11,t-1}$$
$$q_{21,t} = (1-\alpha-\beta)\bar{q}_{21,t} + \alpha u_{1,t}u_{2,t} + \beta q_{21,t-1}$$
$$q_{22,t} = (1-\alpha-\beta)\bar{q}_{22,t} + \alpha u_{2,t-1}^2 + \beta q_{22,t-1}$$

Hence, the conditional correlation between these two series is:

$$\rho_{12,t} = \frac{(1-\alpha-\beta)\bar{q}_{12} + \alpha u_{1,t-1}u_{2,t-1} + \beta q_{12,t-1}}{\sqrt{(1-\alpha-\beta)\bar{q}_{11} + \alpha u_{1,t-1}^2 + \beta q_{11,t-1}}\sqrt{(1-\alpha-\beta)\bar{q}_{22} + \alpha u_{2,t-1}^2 + \beta q_{22,t-1}}}$$

where $u_{1,t-1}$ and $u_{2,t-1}$ represents the standardized residuals of the EUR/USD and JPY/USD series; and $\bar{q}_{11}, \bar{q}_{21}, \bar{q}_{22}$ stands for the unconditional correlations of the standardized residuals.

To test the effects of the oral interventions on the correlation dynamics, it would be better to be able to estimate the conditional correlation with the incorporation of the oral intervention dummy variables. However, in DCC model, it is not trivial to place dummy variables on the correlation structure. Therefore, in our experiments, we assume that DCC correlation results are true correlation values and we will employ regression analysis (using MLE) to investigate the impact of the oral intervention on the correlation structure. As can be seen in Figure 4.6, ARIMA(0,1,0) model seems a good model to trace the correlation series. With the inclusion of the exogenous variables, our model takes the following form:

$$Y_t - \varphi Y_{t-1} = \mu + \lambda_1 OI_{US,t-1} + \lambda_2 OI_{EU,t-1} + \lambda_3 OI_{JP,t-1} + \varepsilon_t$$

We will assess the statistical significance of λ_1, λ_2 and λ_3 in %95 level and conclude whether oral interventions of USA, EU zone and Japan officials have influence on the conditional correlation of EUR/USD and JPY/USD.

4.3 Test Results

4.3.1 DVEC Analysis

In the first part of the thesis, we investigate the effects of US, Euro zone and Japan officials' statements on the mean, variance and covariance dynamics of EUR/USD and JPY/USD. To show whether official interventions have significant effects, we estimated with and without intervention dummy variables. First and second column of Table 4.2 shows the results for these two estimations. The estimation without dummy variable yields the objective value 1508.07 and the estimation with intervention dummy variables yields 1519.34. Using these objective values, Likelihood-Ratio test (LR-test) concludes that incorporating intervention dummies to the mean, variance and covariance equation results in a better fit of the model in % 95 significance level. As seen in the second column of Table 4.2, the interventions do not significantly affect the mean levels. However, strengthening/weakening US oral interventions increase/decrease the volatility of both EUR/USD and JPY/USD in % 99 significance level. Strengthening/weakening Euro-zone interventions decrease/increase the volatility of EUR/USD in % 95 significance level while strengthening/weakening Japan interventions increase/decrease JPY/USD volatility in % 99 significance level. The interventions also have explanatory effect in the covariance. Strengthening/weakening US oral interventions decrease/increase the covariance in % 95 significance level, strengthening/weakening Japan interventions decrease/increase in % 99 significance level while strengthening/weakening EU interventions increase/decrease in % 99 significance level. Therefore, not including the US and Japan oral interventions during forecasting the covariance of these two exchange rate series results in overestimation of covariance while not including the EU interventions yields underestimation. Figure 4.4 depicts the covariance forecasts of DVEC module with and without intervention dummy variables.

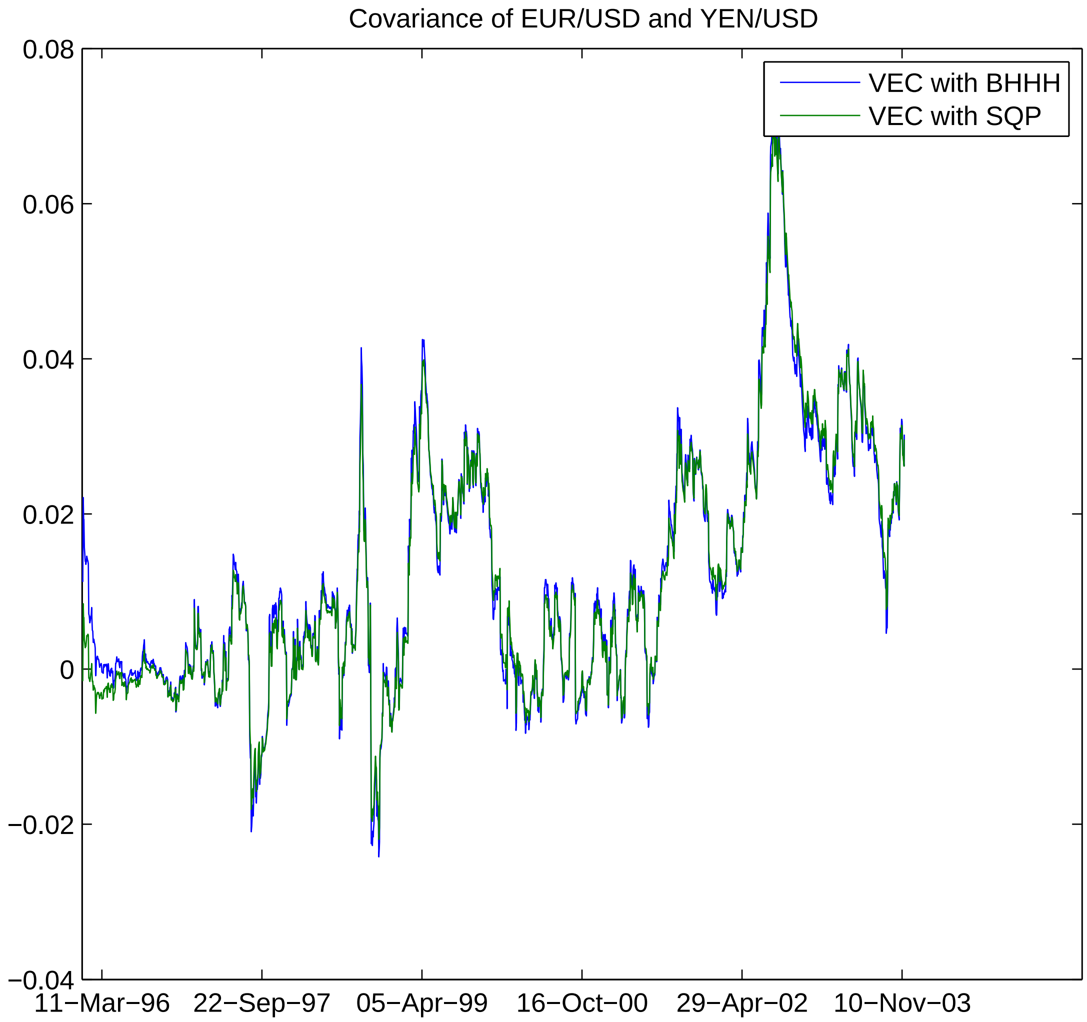

Figure 4.3: Covariance of EUR/USD and JPY/USD with BHHH and SQP

Third column of Table 4.2 shows the estimation results of DVEC model in S+ Language GARCH module (commercial software) that uses BHHH algorithm. Comparing the objective values of first column and third column, we see that solving the optimization problem of DVEC representation in NEOS servers by SNOPT solver (SQP algorithm) produces considerably better results than solving in a personal computer (PC) by S+ GARCH module (BHHH algorithm) does. Figure 4.3 exhibits the covariance estimation of DVEC model by S+ GARCH module (BHHH) and SNOPT Solver (SQP).

Parameter	DVEC(SQP)	DVEC(SQP) with Dummy	DVEC(BHHH)
μ_1	0.000294	0.000107	0.000516
	(0.000037)	(0.000021)	(0.000191)
μ_2	0.000037	0.000047	0.000054
	(0.000002)	(0.000002)	(0.000048)
μ_3	0.000702	0.000640	0.000877
	(0.000044)	(0.000023)	(0.000197)
α_1	0.014994	0.011246	0.020827
	(0.000259)	(0.003996)	(0.004204)
α_2	0.020701	0.015666	0.023611
	(0.000380)	(0.002157)	(0.003640)
α_3	0.027294	0.023613	0.030292
	(0.000528)	(0.004727)	(0.003623)
β_1	0.980933	0.986300	0.971332
	(0.011714)	(0.008638)	(0.006473)
β_2	0.977590	0.980612	0.973409
	(0.005625)	(0.003890)	(0.004358)
β_3	0.965155	0.968612	0.960294
	(0.008046)	(0.004870)	(0.004991)
λ_{USmean}	$-$	0.010870	$-$
		(0.028651)	
λ_{EUmean}	$-$	-0.041990	$-$
		(0.145291)	
$\lambda_{USmean2}$	$-$	0.016170	$-$
		(0.013993)	
λ_{JPmean}	$-$	0.020095	$-$
		(0.061256)	
λ_{USvar}	$-$	$0.002169***$	$-$
		(0.000094)	
λ_{EUvar}	$-$	$-0.000999**$	$-$
		(0.000403)	
λ_{USvar2}	$-$	$0.002230***$	$-$
		(0.000102)	
λ_{JPvar}	$-$	$0.004542***$	$-$
		(0.000903)	
λ_{UScov}	$-$	$-0.000118**$	$-$
		(0.000051)	
λ_{EUcov}	$-$	$0.000229***$	$-$
		(0.000020)	
λ_{JPcov}	$-$	$-0.000424***$	$-$
		(0.000031)	
$Log-likelihood$	1508.07	1519.34	-384.75
$LR-test$		$22.54**$	

Notes: a) Numbers in parenthesis are the standard deviation of the MLE estimates. b) ***,**,* indicate %99, %95 and %90 statistical significance levels respectively. c) LR-test is the value of the likelihood ratio test of models with no dummies versus with dummies in mean, variance and covariance.

Table 4.2: DVEC Estimation Results

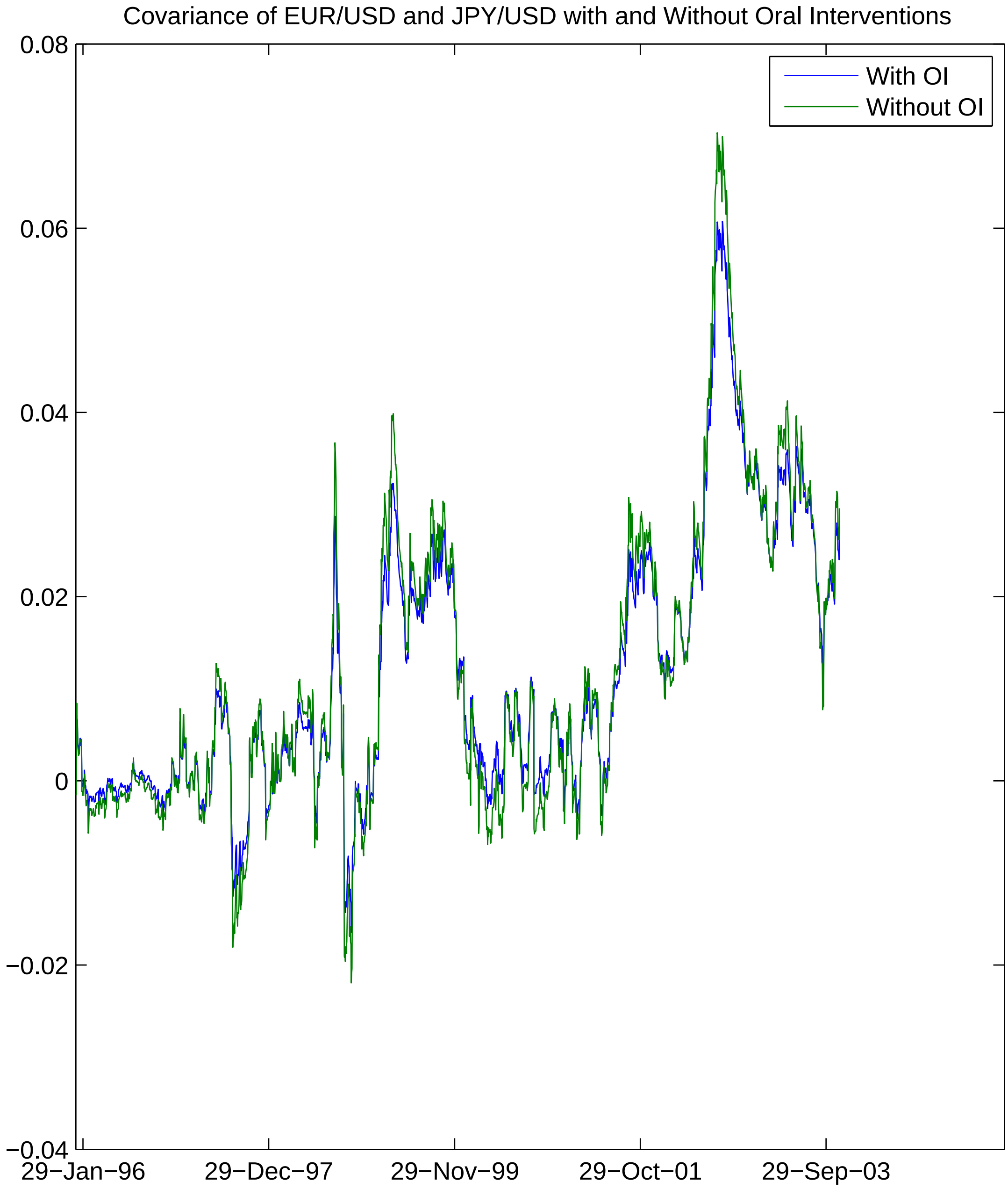

Figure 4.4: Covariance of EUR/USD and JPY/USD with DVEC(SQP)

Parameter	DCC(BHHH)
c_1	0.001381
	(0.000002)
a_1	0.028889
	(0.000115)
b_1	0.950742
	(0.000953)
c_2	0.001718
	(0.000004)
a_2	0.047839
	(0.000774)
b_2	0.934819
	(0.002250)
α	0.014288
	(0.000011)
β	0.984114
	(0.000014)
$Log - likelihood$	-390.705016

Table 4.3: DCC Estimation Results

4.3.2 DCC Analysis

In the second part of the thesis, we assess whether oral interventions have impacts on the correlation of EUR/USD and JPY/USD series. Using DCC model of Engel (2002), we first calculate the conditional correlation of these series and assume that it is the "true" correlation process. Figure 4.5 exhibits the conditional correlation graph and Table 4.3 shows DCC coefficients. Then, we regress the intervention dummy variables on the correlation series. Table 4.4 shows the dummy variable values for this regression. Assuming volatility of forex constant for a moment, the results of DCC model confirms the results of DVEC model. Strengthening/weakening US and Japan officials' statements decrease/incerase the correlation in %99 and %95 significance level respectively, whereas strengthening/weakening EU-zone officials' statements increase/decrease the correlation in %99 significance level.

Parameter	Coefficients
μ	0.197219 (0.134231)
φ	0.997618 (0.001591)
$\lambda_1(USDummy)$	-0.000201 (0.000962)
$\lambda_2(EUDummy)$	0.000639 (0.001107)
$\lambda_3(JPDummy)$	$-0.003002**$ (0.001189)

Table 4.4: Regression Results for Correlation Series

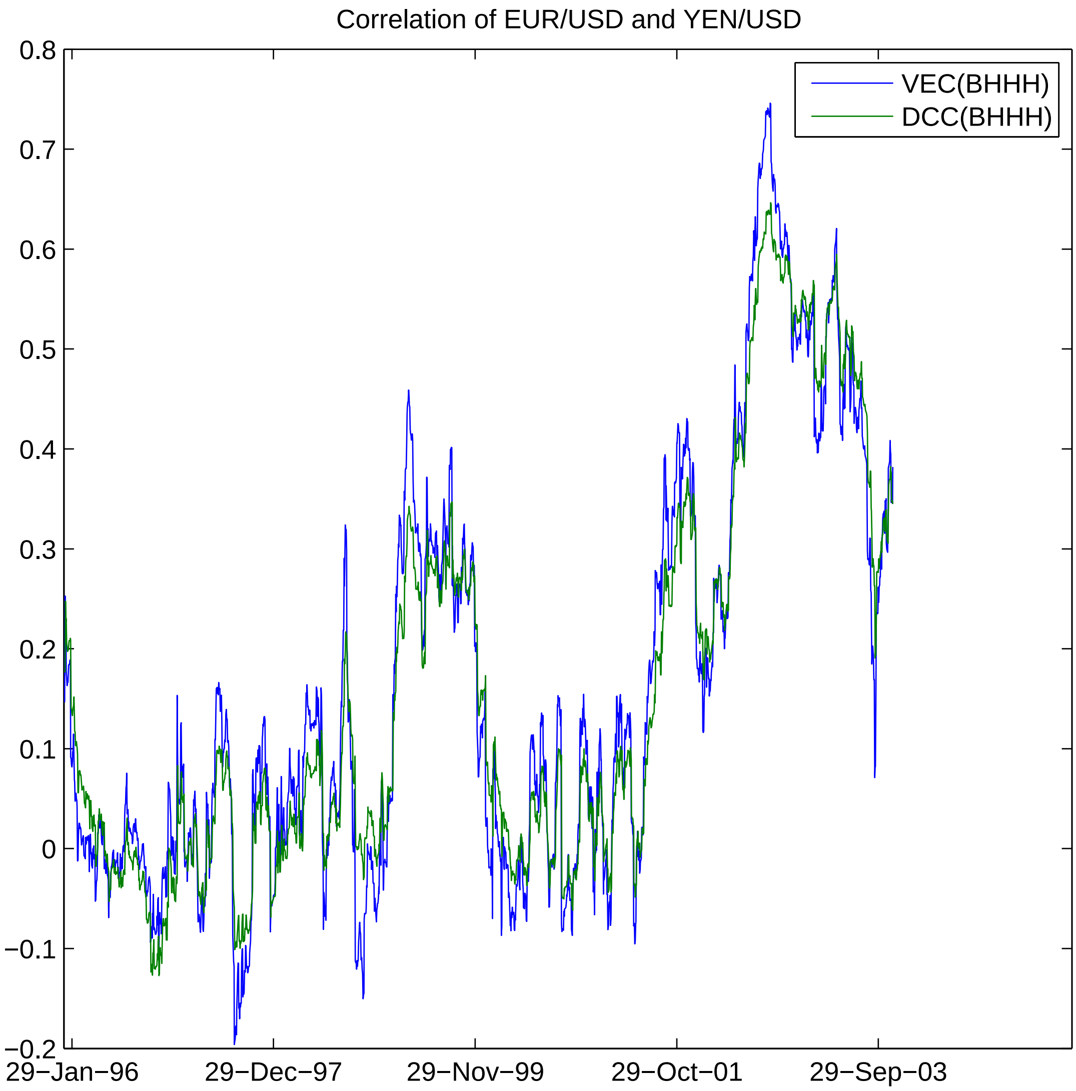

Figure 4.5: Correlation between EUR/USD and JPY/USD

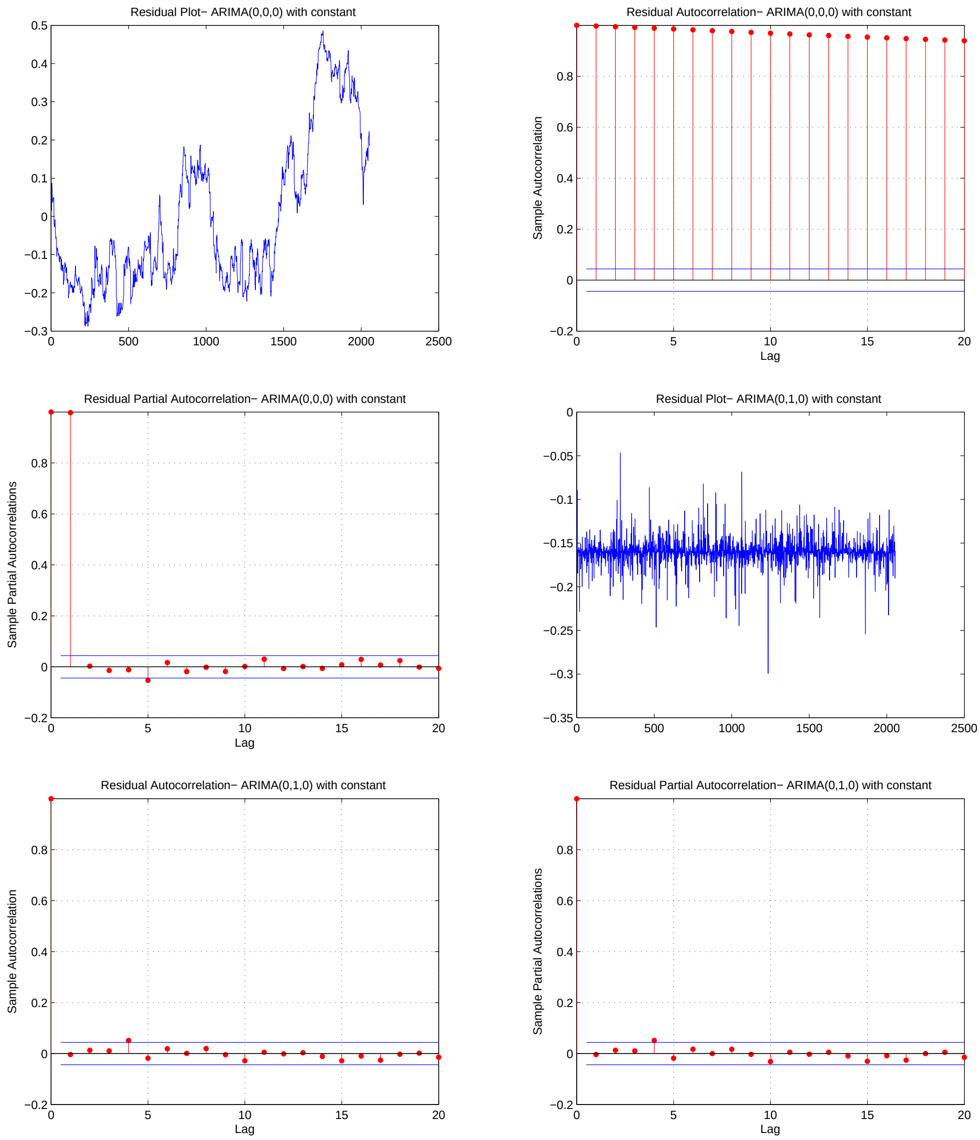

Figure 4.6: ACF and PACF of DCC Correlation Residuals

CHAPTER 5

APPLICATION

In this part, we will demonstrate an example to show that our results can have important applications in short run portfolio management. To illustrate, assume that the variances and covariance of EUR/USD and JPY/USD are at their unconditional level. In 1996-2003 period, EUR/USD has a daily unconditional variance of 0.0651, JPY/USD of 0.0976 and these two series have unconditional covariance of 0.01172. Hence, these two series have unconditional correlation 0.147. Now suppose that both US and Japan officials have made speeches that appeared on Reuters News- the timetable of oral interventions and portfolio update is shown in Figure 5.1. Using Table 4.2, we recalculate EUR/USD volatility as 0.06726 and JPY/USD volatility as 0.104372. Therefore, taking into account the oral interventions only on the volatility components, we find that our new correlation forecast becomes 0.140. However, since we showed that the oral interventions have also affect on the covariance, we adjust our results to the change in the covariance. Our new covariance forecast becomes 0.001117, making the correlation forecast 0.133.

Change in the correlation has direct impact on the portfolio management. Similar to Beine (2004) analysis, consider an investor who tries to have global minimum variance portfolio of foreign exchanges. Since oral interventions do not systematically effect the level and expected return of the currencies is zero, the optimal vector of portfolio weight (ω) is:

$$\omega = \frac{H^{-1}i}{i'H^{-1}i}$$

where H is the variance-covariance matrix of returns and i' is the vector of ones. The variance (risk) of this portfolio (σ) is calculated as:

$$\sigma = \frac{1}{i'H^{-1}i}$$

For simplicity, assume that this investor will have only EUR and JPY in his portfolio and the variances and covariance are at its unconditional level as above. There are three situations to consider:

- If the investor doesn't take into account the oral interventions, then his portfolio allocation will be %61.67 EUR and %38.33 JPY with a portfolio variance %4.46.
- If the investor take into account the oral interventions only on the volatility components, then his portfolio allocation will be %62.52 EUR and %37.48 JPY with a portfolio variance %4.64.
- If the investor take into account the oral interventions both on the volatility and covariance, then his portfolio allocation will be %62.43 EUR and %37.57 JPY with a portfolio variance %4.62.

We conclude that using the oral interventions as an explanatory variable changes the optimal forex allocation and portfolio variance. In our example, we see that usage of oral intervention changed the optimal forex allocation up to %1 of total assets. Furthermore, taking into account the effect of oral interventions on the covariance revised the asset allocation up to %0.1. These small changes in allocation are important for practitioners considering the size of forex markets. According to Bank of International Settlements survey

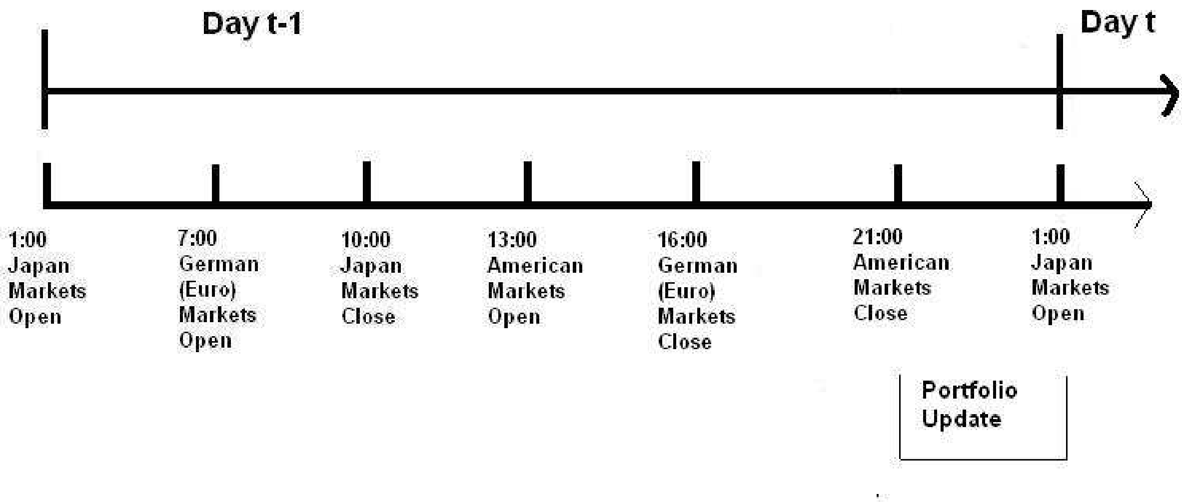

Figure 5.1: Timing of oral interventions and Portfolio Balancing

(2007), daily global turnover in total forex market is \$3.98 trillion and it consists of \$70 billion daily exchange between JPY and EUR. In addition to asset allocation, the effect of oral interventions on the variance and covariance are important for the portfolio variance. In our example, we saw that ignoring US and Japan oral interventions to the covariance led underestimated portfolio variance, which is an input for Value at Risk (VaR) analysis. Conversely, not incorporating EU interventions would lead overestimated portfolio variance.

CHAPTER 6

CONCLUSIONS

In this paper, we investigated two things: Firstly, whether the official statements of US, Euro zone and Japan officials have impact on the variance and conditional covariance of EUR/USD and JPY/USD series in 1996-2003 period. Consecutively, if they have statistically significant influence, whether they provide statistical improvement in variance and covariance forecasting of these exchange rate series. Secondly, for GARCH estimation, we examined whether the recent advances in computational algorithms and environments yield statistically better in-sample variance and covariance forecasts (in terms of objective function value) than those of the commercial software S+ GARCH module.

We found that for the 1996-2003 period, oral interventions do not affect the level of exchange rates. However, the strengthening statements of the USA and Japan policy makers decrease the covariance of EUR/USD and JPY/USD respectively in %95 and %99 significance levels; while the strengthening statements of Euro-zone increase it in %99 significance levels. For weakening statements, the signs of the effects on the covariance are just opposite. In variance analysis, the situation is a little bit different. The strengthening oral interventions of US and Japan increase the volatility of JPY/USD in %99 significance level, while strengthening Euro zone oral interventions decrease EUR/USD volatility in %99 significance level. Again, for weakening statements, the signs of the effects on the volatility are just opposite. As a supporting statistical analysis, LR tests show that oral interventions significantly improve the estimation. Hence, official statements can be used as explanatory variables for the variance and covariance dynamics of EUR/USD and JPY/USD series. In this respect, using these statements as dummy variables yield us better in-sample variance and covariance forecasts. To test our conclusions in DVEC covariance estimation, we also employ DCC correlation analysis. Assuming constant variances, the results of the correlation is quite in line with the results of the covariance analysis: strengthening/weakening US and Japan officials' statements decrease/increase the correlation while those of Euro-zone increase/decrease it.

The second result of this study is about the computation of MLE of GARCH models. The resulting optimization problem of MLE of GARCH models is non-linear non-convex non-linearly constrained optimization problems. Since, it is quite difficult to find the global optimal for these optimization problem, literature used local optimization solvers. The standard algorithm that are used in commercial softwares such as S+GARCH and GAUSS-FANPAC modules is BHHH algorithm. In this paper, for GARCH estimation we use SNOPT solver which use SQP algorithms and solve the problem in NEOS Servers. As depicted in Table 4.2, SNOPT solver solves the problem better in terms of objective value. Hence, instead of using the standard commercial softwares, following our computational methodology provide us statistically better forecasts. However, there is one drawback of our computational approach. The computational time depends on the number of tasks in the queue of NEOS server. If there are a few number of tasks in the queue, we get the results in approximately in 5-6 minutes. But if there are a lot of tasks in the queue, the required time depends the completion of the previous tasks (Generally not more than 30 minutes).

Variance and covariance forecasts of exchange rates are widely used in many applications such as short-run portfolios or risk management of assets. Hence, statistically superior forecasts are quite important for both academicians and practitioners. In this thesis, we show that, as depicted in Figures 4.4, including the oral interventions to the covariance dynamics and using our computational methodology yield portfolios different from what is found without using them.

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APPENDIX

APPENDIX A

Caveats

Although we believe that our study is important for academicians and practitioners, we have some limitations in our thesis. These inadequacies can be investigated in three categories: estimation, data and model limitations. Some of these limitations are due to insufficiencies of today's optimization algorithms and computer technology while some of the them are left for future studies to overcome.

A.1 Estimation Limitations

- Since we are trying to solve the GARCH model with MLE, we have to assume a distribution for the error terms. In our analysis, we assume that errors are normally distributed because of its easiness in estimation. It would be a better choice to use a more general distribution such as multivariate generalized hyperbolic distribution (GHD), which turns into normal and t-distribution in special forms. However, we had convergence problems with GHD as well as with t-distribution. Hence, we had to assume normal distribution for the error terms.

- Since the resulting optimization problem from the MLE of multivariate GARCH models are nonlinearly constrained non-convex nonlinear programming problems, by today's optimization algorithms and computers, it is difficult to solve this type of problems. Hence, similar to what commercial softwares such as S+ GARCH module and GAUSS Fanpac package do, we solve the problem with local optimization solvers. Therefore, we don't claim that our solution is global optimal.

A.2 Data Limitations

- The data is categorized as strengthening, weakening or ambiguous. However, this classification is limited by the judgement of the classifier. For example, although officials' intended aim is to strengthen to domestic currency, classifier may interpret the statement as a weakening or ambiguous statement.

- The data include only the statements of the predetermined officials (listed in section 3.1). However, some other officials statements may also have an effect on the exchange rate level, volatility and covariance.
- Our data don't include officials' comments on monetary policy that may have effect on the forex markets.
- For the 1996-1999 period, Deutsche Mark and Deutsche officials' statements were accepted as the representatives of Euro and Euro-zone officials' comments.

A.3 Model Limitations

- The model assumes that the only factor that can have effect on the level of the forex level is the oral interventions. However, some other macroeconomic variables such as interest rate differentials or inflation may have affect on the level.
- The model assumes that all strengthening and weakening statements influence the exchange rate level, volatility and covariance symmetrically.