An Investigation into Exchange Rate Dynamics, Adjustment Mechanisms and Monetary Policy

By

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Summary

Chapter 1 uses monthly frequency data to recover the preferred anchor currencies for a global set of currencies. For a smaller sample of currencies, the Chapter uses a Markov-switching process to examine how exchange rates evolve over time. The anchor currency regressions reveal that there is a strong preference for the USD and EUR, with the EUR dominant in Western Europe and the USD dominant in the rest of the world. The GBP and JPY still form part of the anchor currency basket, but their significance seems to have declined over time. There is also evidence of 1:1 parity for some currencies, especially with the USD. The Markov-switching results indicate that the model is able to decompose the currency behaviour of eight currencies into appreciating and depreciating regimes and identify the key turning points in the exchange rate series, especially the 2008/2009 crisis period. However, the Markov model was not able to capture the Engel and Hamilton (1990) long swings phenomenon, except for the Swiss Franc.

Chapter 2, still using monthly frequency data, investigates the extent to which there was currency value parity right before the introduction of the Euro. By testing for the existence of Purchasing Power Parity (PPP) using the French Franc and Deutsche Mark as reference currencies, and using data on the real exchange rate, nominal exchange rate and price differential, the results reveal that, to a greater extent, there was indeed currency value convergence for some countries. The weak-form test (a co-integration test) for PPP reveals that the long-run speeds of adjustment for all currencies in the sample are less than 1% per month and that deviations from PPP may be permanent too.

Chapter 3 attempts to examine the transmission mechanism/channels of the European Central Bank (ECB) Unconventional Monetary Policy (UMP), both domestic and international spill-over effects by employing a Global Vector Autoregressive (GVAR) model. Generally, ECB UMP effects show encouraging and positive responses from economies within the Euro Area region while international spill-over effects are mixed, probably due to the varying nature of the monetary policy regimes deployed in the different countries, especially the emerging economies.

Chapter 4 uses the science of a single hidden layer perceptron Artificial Neural Network (ANN) structure to forecast daily, weekly and monthly exchange rate data on CHF/EUR, GBP/EUR and USD/EUR. The results show good accuracy of the model as evidenced by the low Mean Absolute Error (MAE) and Root Mean Square Error (RMSE), especially for the daily

frequency data. Furthermore, the ANN performs best in out-of-sample predictions for the CHF/EUR currency pair for daily and weekly predictions, and best for the GBP/EUR pair when it comes to monthly frequency data. The USD/EUR pair proves more difficult to model, performing worst, especially in the validation period. The non-linear nature of the ANN model goes a long way in learning and capturing complex movements in the exchange rates.

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Chapter 1: Recovering Anchor Currencies and Decomposing Exchange Rate Behaviour into Component Regimes

Abstract

Exchange rate regimes have evolved substantially over the years, right from the Gold Standard to the Bretton Woods era and post-Bretton Woods periods. The post-Bretton Woods era has seen the emergence of currency unions and a whole range of hybrid and sophisticated exchange rate regimes. This study attempts to recover the preferred anchor currencies of different countries and further uses a Markov-switching process to decompose exchange rate behaviour into component regimes. The regression-based results reveal the preferred anchor currencies while the Markov-switching results indicate that the model is able to decompose the currency behaviour of eight currencies into appreciating and depreciating regimes. Furthermore, the Markov results identify the key turning points in the exchange rate series, especially the 2008/2009 crisis period.

Key Words: *Exchange rate regime, anchor currency, Markov process*

1.1 Introduction

This study applied an anchor currency regression-based model and a Markov regime switching model to monthly exchange rate time series over the period 2000-2019, with the aim of finding out how particular currencies behave towards major anchor currencies. The study was able to breakdown exchange rate behaviour into two competing regimes identified as appreciation and depreciation periods. The anchor currency regression model was applied to 70 currencies. The identified anchor currencies are the US Dollar, Euro, British Pound and Japanese Yen. The findings revealed that there is a major preference for particular anchors in different regions with the Euro dominant in Europe, Oceania and parts of Africa. In parts of West Africa, the preference is a peg to the Euro. The US Dollar is the preferred anchor in the Americas, Asia, and other parts of Africa. Of great importance is the fact that Middle East and Caribbean currencies have perfect pegs to the US Dollar and are consequently exactly tracking the variations in the US Dollar. However, even though there is a preferred anchor, several countries also prefer basket currency pegs. The Markov regime switching model was applied to four advanced and four emerging economy currencies. Findings indicate that the model performs well, and the switching probabilities capture key turning points in the exchange rate time series. The model is not able to capture the long swings exchange rate phenomenon.

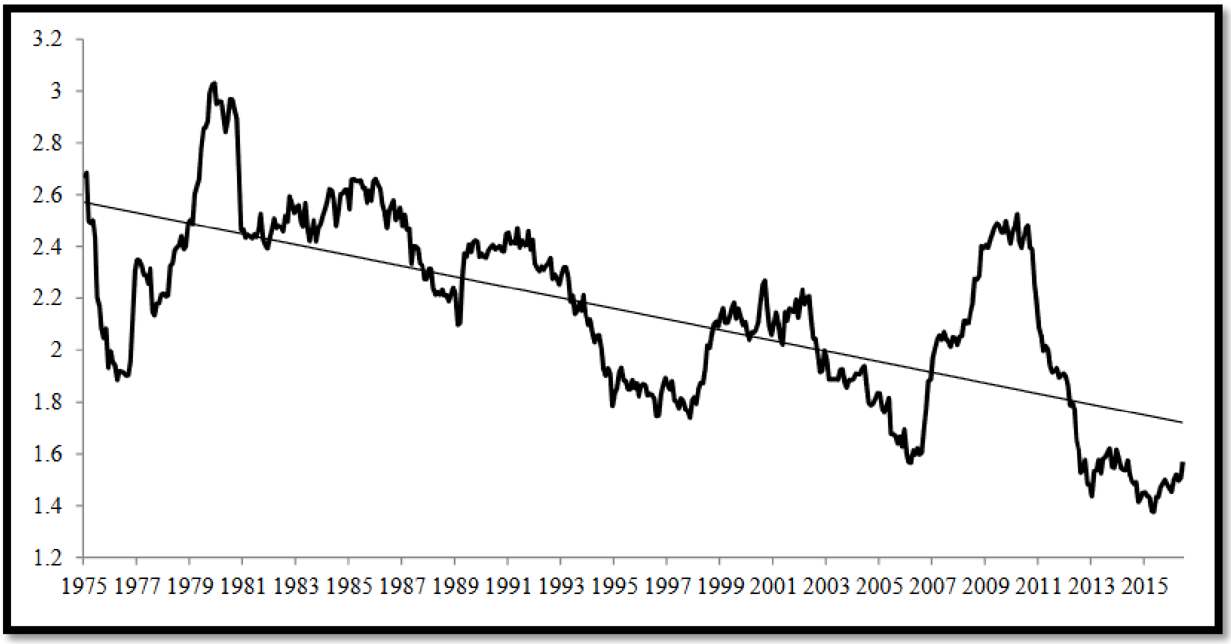
Section 1.2 gives a survey of various perspectives and literature on exchange rate behaviour and regime classifications, section 1.3 discusses the models and data used, section 1.4 gives a discussion of the results and section 1.5 gives a conclusion to the study.

As stated by Svensson (1992), the exchange rate as conventionally defined is the domestic price of foreign exchange or currency, that is, the number of domestic currency units per foreign currency unit. Generally, exchange rate regimes can be classified as fixed, floating, and managed floating. Researchers have developed techniques that characterize the regimes based on certain variables and clustering the candidates for a certain regime accordingly. Studies have resulted in classifications of up to ten or even more exchange rate regimes. See Reinhart and Rogoff (2004). It is the responsibility of the monetary authorities to deploy an exchange rate regime policy or mechanism that may seek to maintain an exchange rate or allow it more flexibility as and when they deem fit. The exchange rate regime employed by a country has macroeconomic effects on the economy through inflation, price, capital flows, economic growth, and several other variables. Ghosh et al. (1997) shows that inflation is lower and more stable under the pegged regime. Some studies have linked the fixed exchange rate regime and/or monetary union to more growth, trade, and less exchange rate volatility. Furthermore, Ghosh et al. (2015) show that macroeconomic vulnerabilities are significantly greater under less flexible regimes including hard pegs compared to floats. This is only a highlight of how important the regime employed by a country is for the economy.

In the integrated and globalised world of today, economies are intertwined. The risk of financial and currency crises is high, and consequently monetary policy management must consider effects of currency attacks and shocks coming from external sources. Ohno (1999) states that financial markets operate through expectations whose dynamics are not very well understood, and further adds that the financial markets are vulnerable to herding, over-borrowing, bubbles, reversals, and contagion. This has come into surface as evidenced by the 2007-2009 global financial crisis. Exchange rates remain a pillar of macroeconomic stability and avoiding mis-valuation of a currency is an important step. Mis-valuation is often a predictor of an impending currency attack. Where, a mis-valuation implies a country's exchange rate is not reflective of the true state of the economy. For instance, a strong currency should be represented by a strong economy and a weak currency should reflect a weak economy, not the other way around. The strength of an economy may be represented by stable and improved macroeconomic indicators like inflation and interest rates, the standard of living, unemployment, and current account position.

The main variables used in exchange rate classification are the exchange rate volatility, reserve volatility, interest rates and the behaviour of the exchange rate towards an anchor or reference currency. The more advanced economies, especially those practising the inflation targeting mechanism, have witnessed a drop in the exchange rate volatility over the years as opposed to the emerging market economies that have experienced more volatility and have more intervention in the markets. This is mainly attributed to fundamental institutional differences pointed out by Mishkin (2004) and Calvo and Mishkin (2003).

Figure 1.1: The declining volatility of the US Dollar-Deutsche Mark/Euro exchange rate



Source: Ilzetzki et al. 2017

Empirical studies in exchange rate regime classifications show a clear discrepancy in the de facto and de jure regimes. See Calvo and Reinhart (2002). This discrepancy between the de facto exchange rate regimes, the regimes that countries actually follow and the de jure exchange rate regimes, the regimes that countries claim to officially follow and report to the International Monetary Fund (IMF) and other similar institutions, can be very misleading and pervasive according to Frankel and Wei (2008).

Ilzetzki et al. (2017) in their classification study of 194 countries (or territories) using monthly data on core exchange rate and inflation over the period 1946 to 2016, find that 80% of all countries covered are biased towards a less flexible exchange rate arrangement. They add that almost 40% of all countries under the inflation targeting framework adopt somewhat limited flexibility arrangements like crawling pegs. Hence, it is not right to assume that all inflation targeting countries adopt a floating regime. This is a re-enforcement of the same finding by Mishkin (2004). There is accordingly a markedly lower incidence of bi-polar or corner solutions; there is instead a marked increase in the adoption of intermediate regimes. Ilzetzki et al. (2017) further state that the evolving inconsistencies between the de facto and de jure exchange rate regimes have forced the IMF to move from a de jure classification that it focused on in the 1990s to an additional classification to include a de facto one as well to avoid misalignment of monetary policy and economic decisions.

1.2 Literature Review

1.2.1 Brief history of the international monetary system

Winton, a research-based investment management company in a 2017 article provides a detailed history of the modern international monetary system, some of which is presented herein.

Classical Gold Standard (1870-1914)

Before the 1870s, most monetary systems were based on a bimetallic standard. Only Britain was on the Gold Standard. By using gold as its trading currency, Britain forced her trading partners like Germany and the US to adopt this metallic standard currency form. By 1900, a good number of countries had adopted gold as a form of exchange with only a few sticking to silver. Bordo (2003) adds that by 1900 most nations had switched away from silver and bimetallic standards and adhered to the Gold Standard. Fiat money and floating was considered to be a radical departure from fiscal and monetary stability, and was only acceptable in case of global emergencies like wars and financial crises. Countries like Spain and Austria-Hungary that adopted fiat money and permanently floated were viewed with disfavour. Over this period, central banks were willing to convert paper currencies into a pre-determined amount of gold, thus, ensuring stable exchange rates in terms of gold. A country could not simply alter its money supply without experiencing gold flows since currencies were backed by gold. Sir John Swanwick Bradbury, a British Economist and an official of the Treasury in the 20th century put it, the Gold Standard was knave-proof and characterized by low interest rates, price stability and increased world trade.

The collapse of the Gold Standard in 1914 was mainly due to World War I (1914-1918), countries needed a source to finance their war debts and gold was an inconvenience. In addition, this was a scarce metal. Governments resolved to printing more money and issuing bonds. In 1925, Britain and other advanced economies returned to the Gold Standard, but this did not last long. Britain returned to the Gold Standard at the pre-war parity in order to please its creditors and this left the Pound 10% overvalued against the US Dollar due to the inflation gap since 1914. In 1931, Britain abandoned the Gold Standard again and several countries followed suit.

Bretton Woods (1945-1971)

The agreement at Bretton Woods introduced a new era in monetary policy management. This resulted in the creation of the International Monetary Fund, the World Bank, and the international gold-exchange standard. This was seen as an opportunity to correct the mistakes that led to the Great Depression of the 1930s and to help rebuild after World War II (1939-1945). During this era, several countries pegged their currencies to the US Dollar at specified parities. The US Dollar in turn was convertible into gold at a fixed rate of $35/oz; this characteristic defined the fixed exchange rate regime period preceding the 1970s. This only applied to US Dollars held by central banks and governments, not private persons. Central banks had to intervene in markets to fix their exchange rates against the Dollar, which in turn was pegged to gold. According to Bordo (2003), the agreement allowed narrow bands of 2.5% around parity and the right to change parity in the event of a fundamental misalignment, therefore, *fixed but adjustable*. It was supposed to combine the advantages of the Gold Standard (sound money) with those of floating (flexibility and independence). The system was purposely meant to overcome the weaknesses characterized by the classical Gold Standard. Several nations had difficulties in finding parities consistent with their balance of payment positions, setting the stage for the collapse of the Bretton Woods. In addition, the re-alignment of parities led to crises in the early years of the Bretton Woods system. The IMF was responsible for bailing out countries with balance of payments crises.

Demise of the Bretton Woods (1971-1973)

Like all economic systems, the Bretton Woods System had its weaknesses, some of which led to its demise. The US was at the centre of the Bretton Woods System given its large influence and dominance in international trade, gold stock and global finance. This influence inclined the US to run chronic trade deficits that are still present today. Several countries were angered by this and threatened to liquidate their Dollar reserve balances into gold. In addition, the US was characterized by high inflation rates in the 1960s due to the expansionary fiscal policy, something that many European countries feared would be imported into their economies. This was caused by the *Dollar fight* where a number of countries, especially in Western Europe, were converting their Dollars into gold. For fear of depletion of American gold, President Nixon closed the US Federal Reserve's gold window, effectively suspending the commitment to provide gold to foreign central banks at any rate. Darby et al. (1983) state that the increasing US monetary growth led to rising inflation, which spread to the rest of the world through growing US balance of payments deficits. This led to growing balance of payments surpluses in Germany and other countries. The German monetary authorities (and other surplus countries) attempted to sterilise the inflows but were eventually unsuccessful, leading to growing inflationary pressure. Despres et al. (1966) argue that the growing US balance of payments deficit was of no great concern because the rest of the world voluntarily held Dollar balances, thus, the Bretton Woods System could have continued in operation.

According to Kawai and Akiyama (1998) in their account of the evolution of exchange rates, before the suspension of the convertibility of the US Dollar to gold by President Richard Nixon in 1971, exchange rate fluctuations of most IMF member countries had been limited to ±1% around par values set in terms of gold or the US Dollar. After the Nixon shock, these countries moved towards the floating exchange rate regime. The year 1973 saw the European Community countries sever the link between their currencies and the US Dollar. Some countries feared the risk of the true floating regime era and decided to maintain a peg or a managed float to the currencies of major industrialised economies. Western Europe countries limited their exchange rate fluctuations within margins of ±2.25% with each other and a band of ±4.5% against the Dollar. This was referred to as the 'snake regime', eventually forming the European Monetary System[1] in 1979.[2] This saw the emergence of the Deutsche Mark as the dominant currency in Europe and many countries began to mimic the monetary policies of the Bundesbank. Germany, being the most stable and developed economy in the region made this inevitable; other countries in the region anchored their inflation rates to that of Germany, which was the lowest in Europe. The French Franc also had considerable influence coupled with its CFA zone prevalently in West and Central Africa. Eventually these two blocks (French Franc and Deutsche Mark) merged to form the Euro Area in 1999.

In the 1970s, the numeraire or reference currency, the US Dollar, was connected or linked to the supply and value of gold. Today, the numeraire is connected to the supply of US goods and services, in general terms, the performance and the value that the globe attaches to the US economy (fiat currency). There have been outcries from nations both in emerging and advanced economies for a return to the Gold Standard based currency, a time of exchange rate stability and capital mobility, at the expense of monetary independence. The return to the Gold Standard has been supported by Alan Greenspan who served as the Chair of the US Federal Reserve from 1987-2006. In his words, "we did very well in the 1870-1914 period with an international Gold Standard". He argues that the Gold Standard restricts the amount of money that is produced, and this helps control inflation. It takes a lot for a shift in the international monetary

[1] The European Monetary Fund was also established to provide credit to members experiencing balance of payment problems.
[2] See Kawai and Akiyama (1998), The Role of Nominal Anchor Currencies in Exchange Rate Arrangements, the paper covers the evolution of exchange rate arrangements of almost all countries in the world over the period 1970-1996.

system, sometimes a serious financial crisis or even a world war. However, it is hard to predict when the next shift shall come, and so, we wait.

1.2.2 Classification of exchange rate regimes

Frankel (1992) pioneered a technique aimed at recovering the weights assigned to currencies in order to determine whether a regime is fixed or floating. This technique has been used and extended by a number of researchers over the years and still remains a strong model to date.

Levy-Yeyati and Sturzenegger (2005) in their paper, Deeds vs. Words, covering all IMF-reporting countries over the period 1974-2000 revealed that pure floats are associated with minor nominal exchange rate volatility and that there has been an increase in the number of dirty floats[3] over the years. Their findings support the *fear of floating* phenomenon. They point out that countries that appear to behave according to a de jure regime during tranquil times may be tempted to change their course of action once the regime is under stress. Levy-Yeyati and Sturzenegger (2016) extend their earlier studies through 2014 to cover the financial crisis period and increase the sample size; they report that there was a growth in the number of floaters over the financial crisis period. Pegs remained the preferred regime for low-income countries. Also, the number of countries which run a fixed regime without stating that they do (fear of pegging) has increased remarkably. Their findings further revealed that fixed regimes are characterized by relatively low nominal exchange rate volatility (with an average absolute change of 0.60% per month as opposed to 1.59% in the case of floats), and high volatility in reserves (19.15% against 5.66% for floats).

Calvo and Reinhart (2002) use monthly data over the period 1970-1999 for 39 countries across all continents trying to compare what countries say and what they do, focussing on whether countries that claim to float are indeed doing so, and whether countries are moving further towards corner solutions as they say. Analysing the behaviour of exchange rates, foreign exchange reserves and interest rates, they find that these countries had a volatility of these variables somewhat similar to those with a pegged regime. They show that the volatility in these variables of de jure floaters differs to a much greater extent from true floaters. Concluding

[3] In the words of Levy-Yeyati and Sturzenegger (2016), flexible exchange rates are characterized by little intervention in the exchange rate markets together with unlimited volatility of the nominal exchange rate. Conversely, a fixed exchange rate regime occurs when the exchange rate does not move while reserves are allowed to fluctuate. Under a crawling peg, changes in the nominal exchange rates occur with stable increments (i.e., low volatility in the rate of change of the exchange rate) while active intervention keeps the exchange rate along that path. Finally, a dirty float should be associated to the case in which volatility is relatively high across all variables, with intervention only partially smoothing exchange rate fluctuations.

that countries that say they allow their exchange rate to float mostly do not, there seems to be an epidemic case of *fear of floating*. Schnabl (2003) tries to replicate the technique identified by Calvo and Reinhart (2002) on Central and Eastern Europe countries with some augmentations. Findings revealed that all the four[4] countries in the study classified as fixed regimes show very low exchange rate volatility against the Euro and Dollar, particularly the Euro. And, among the de jure floaters, three[5] countries pegged their currencies to the Euro.

Reinhart and Rogoff (2004), in a classification covering 153 countries over the period 1946-2001, consider exchange rates in parallel markets. They develop an algorithm; in what they call a natural classification algorithm, allowing for up to fourteen categories of exchange rate regimes ranging from a strict peg to a dysfunctional freely falling or hyper-float. Some of their findings revealed that de facto floating was common during the early years of the Bretton Woods era of fixed exchange rate regimes. Many de jure floats of the post-1980s turned out to be de facto pegs, crawling pegs or narrow bands to an anchor currency. Important to note in their findings, 53% of the countries listed in the IMF classification as managed floats turned out to be de facto pegs, crawls, or narrow bands to an anchor. Their famous classification has been used by many researchers in the areas of macroeconomics and finance.

According to Frankel (1999), most countries classified by the IMF as fixed regimes have in fact had re-alignments and most of those listed as floaters in fact intervene in the foreign exchange markets frequently.

Shambaugh (2004)[6] while examining the effect of the fixed regime on monetary autonomy using a sample of over 100 developing and industrial countries from 1973 through 2000, creating a de facto coding system that focusses on the volatility of the exchange rate, and dividing countries into pegs and non-pegs, reports that his classification technique disagrees with the reported IMF de jure status about 12% of the time. He finds that most countries that claim to float do so to some degree and some are mislabelled.

Ghosh et al. (1997) in their investigation of whether the regime matters for macroeconomic performance, argue that the de jure classification captures the formal commitment of the central bank to intervene in the foreign exchange market while the de facto classification obviously has the advantage that it captures actual behaviour. They therefore adopt a technique that

[4] Bulgaria, Estonia, Lithuania, and Latvia.
[5] The Czech Republic, Slovenia, and Slovakia.
[6] See also Klein and Shambaugh (2010), Exchange Rate Regimes in the Modern Era.

combines the de jure and de facto classifications in their study. They define a pegged regime as one with frequent and infrequent adjusters, the former being defined as regimes with more than one change per year in either parity or, for basket pegs, in the weights. They divide the regimes into three; pegged, intermediate and floating. They further find that a pegged regime is associated with lower inflation.

Kawai and Akiyama (1998) examine officially reported and empirically observed exchange rate arrangements of more than 100 countries over the period 1970-1996 and find that most countries, especially in Asia, Latin America and the Middle East, attempt to peg their exchange rates particularly to the US Dollar, forming somewhat a *Dollar block*. The researchers further report that the role played by the Japanese Yen remains rather less significant.

Ilzetzki et al. (2017) in a comprehensive study of 194 countries over the period 1946-2016 state that the often-cited post-Bretton Woods transition from fixed to floating exchange rate regimes is overstated and emphasise that regimes with limited flexibility remain preferred and in the majority. The US Dollar still scores as the world's dominant anchor currency[7], and by a very large margin, with a much wider use today than 70 years ago, and the global role of the Euro[8] seems to have stalled[9], maybe for now. Some scholars argue that the world is headed towards a multi-polar system, especially with the rise of China in the global economy. This will undermine the influence of the US Dollar and increase the weight of the Chinese Renminbi. Eichengreen (2011) re-iterates that it is very likely that the Euro will be the anchor currency in Europe, the US Dollar in the Americas, leaving the emerging Renminbi anchoring in Asia, a role that the Japanese Yen has failed to take on to date. It is difficult to quantitatively disaggregate the influence of the Chinese Renminbi on its own since it has had a long history of being pegged to the US Dollar.

1.2.3 The choice of the exchange rate regime

The choice of an exchange rate regime may depend on several factors, such as the level of development of a country. Advanced economies have the capacity to defend their exchange

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[7] Its role has even expanded further after the collapse of the Ruble zone, the Ruble zone emerged after the collapse of the Soviet Union in December 1999. The countries that emerged formed some kind of currency union where they all used the Ruble as their primary currency. The influence of the US Dollar has expanded further to the Middle East over the years.

[8] Ilzetzki et al. (2017) also state in their paper that from the early 1980s until the introduction of the Euro, the German Deutsche Mark sphere expanded, first in Western Europe and later in the East. The Euro inherited the German Deutsche Mark and French Franc zones (the French Franc zone included the current eight West African states that use the West African CFA Franc currency that was tightly pegged to the French Franc).

[9] There seems to be a declining share of Europe in the world output today, weakening the role of the Euro.

rates against speculative attacks. Obstfeld and Rogoff (1995) add that if their commitment to use those resources lacks credibility with markets, the costs to the broader economy of defending a regime against speculative attacks could be very high. A major disadvantage of this regime (fixed regime) is that the central bank loses control of domestic money supply, and as a consequence, monetary independence, and cannot use monetary policy for stabilisation purposes in case of economic shocks. See Obstfeld and Rogoff (1995) for a detailed discussion.

Frankel (1999) classifies regimes as; Fixed arrangements (currency unions, currency boards and truly fixed arrangements), Intermediate arrangements (adjustable pegs, crawling pegs, basket pegs and target zones) and Floats (managed and free floats). Managed floats are also known as dirty floats, defined as a readiness to intervene in the foreign exchange market without defending any particular parity and most intervention is intended to lean against the wind; buying the currency when it is rising and selling when it is falling.

A number of countries, especially emerging market economies, are within the intermediate regimes like target zones and crawling pegs. According to Bordo (2003), exchange rate regimes have evolved a lot over the past 100 years; the advanced economies seem to get it right while the emerging markets try to emulate and may get the choice right occasionally. The regimes range from pure floats to the hard pegs of currency boards, dollarization, and currency unions.

Of course, the regime employed by a country would also depend heavily on macroeconomic variables like inflation rates, reserves, financial market development and the general macroeconomic direction desired by the monetary authorities.

According to the IMF Annual Report on Exchange Arrangements and Exchange Restrictions 2017, the de jure regimes are classified as indicated below.

No separate legal tender: The currency of another country may circulate as the sole legal tender. Some countries have become dollarized, substituting their currencies with the US Dollar, these include Ecuador and El Salvador in Latin America and Zimbabwe in Africa. This form of arrangement involves the complete surrender of a nation's monetary policy independence. Currency unions for this matter are classified based on the arrangement governing the joint currency. The Euro, for example, is classified as a floating currency.

Currency Board: A currency board arrangement is a monetary arrangement based on an explicit legislative commitment to exchange domestic currency for a specified foreign currency at a fixed exchange rate, combined with restrictions on the issuing authority to ensure the fulfilment of its legal obligation. This implies that domestic currency is usually fully backed by foreign assets, eliminating traditional central bank functions such as monetary control and lender-of-last-resort, and leaving little scope for discretionary monetary policy. According to Chang and Velasco (2000), under a currency board, the amount of base money in circulation is always exactly equal to the foreign reserves of the central bank. Therefore, there cannot be a balance of payments crisis. For instance, a Peso central bank will stand ready to exchange Dollars for Pesos at a fixed exchange rate and, in addition, it is committed not to create or destroy Pesos in any other way.

Conventional Peg: The country formally pegs its currency at a fixed rate to another currency or basket of currencies, where the basket is formed, for example, from the currencies of major trading or financial partners and weights reflect the geographic distribution of trade, services, or capital flows. The anchor currency or basket weights are public or notified to the IMF. The country authorities stand ready to maintain the fixed parity through direct intervention (that is, via sale or purchase of foreign exchange in the market) or indirect intervention (for example, via exchange rate related use of interest rate policy, imposition of foreign exchange regulations, exercise of moral suasion that constrains foreign exchange activity, or intervention by other public institutions). There is no commitment to irrevocably keep the parity. The exchange rate may fluctuate within narrow margins of less than ±1 percent around a central rate or the maximum and minimum value of the spot market exchange rate must remain within a narrow margin of 2 percent for at least six months.

Stabilized Arrangement: This entails a spot market exchange rate that remains within a margin of 2 percent for six months or more (with the exception of a specified number of outliers or step adjustments) and is not floating. The required margin of stability can be met either with respect to a single currency or a basket of currencies, where the anchor currency or the basket is ascertained or confirmed using statistical techniques. Classification as a stabilized arrangement requires that the statistical criteria are met and that the exchange rate remains stable as a result of official action (including structural market rigidities). The classification does not imply a policy commitment on the part of the country authorities.

Crawling Peg: The currency rate is adjusted in small amounts at a fixed rate or in response to changes in selected quantitative indicators, such as past inflation differentials vis-à-vis major trading partners or differentials between the inflation target and expected inflation in major trading partners. The rate of crawl can be set to generate inflation-adjusted changes in the exchange rate (backward looking) or set at a predetermined fixed rate and/or below the projected inflation differentials (forward looking). The rules and parameters of the arrangement are public or notified to the IMF. Obstfeld and Rogoff (1995) state that the crawling peg is common among high-inflation developing countries in which the government announces a schedule of small, discrete devaluations in order to prevent inflation differentials from cumulating, thereby necessitating a single large devaluation.

Crawl-like Arrangement: The exchange rate must remain within a narrow margin of 2 percent relative to a statistically identified trend for six months or more (except for a specified number of outliers) and the exchange rate arrangement cannot be considered as floating. Normally, a minimum rate of change greater than allowed under a stabilized (peg-like) arrangement is required. However, an arrangement will be considered crawl-like with an annualized rate of change of at least 1 percent, provided that the exchange rate appreciates or depreciates in a sufficiently monotonic and continuous manner.

Pegged exchange rate within horizontal bands: This involves the confirmation of the country authorities' de jure exchange rate arrangement. The value of the currency is maintained within certain margins of fluctuation of at least ±1 percent around a fixed central rate, or the margin between the maximum and minimum value of the exchange rate. It includes arrangements of countries in the ERM of the European Monetary System (EMS), which was replaced with the ERM II on January 1, 1999, for those countries with margins of fluctuation wider than ±1 percent. The central rate and width of the band are public or notified to the IMF.

Other managed arrangement: This category is a residual and is used when the exchange rate arrangement does not meet the criteria for any of the other categories. Arrangements characterized by frequent shifts in policies may fall into this category.

Floating: A floating exchange rate is largely market determined, without an ascertainable or predictable path for the rate. In particular, an exchange rate that satisfies the statistical criteria for a stabilized or a crawl-like arrangement will be classified as such unless it is clear that the stability of the exchange rate is not the result of official actions. Foreign exchange market intervention may be either direct or indirect, and such intervention serves to moderate the rate of change and prevent undue fluctuations in the exchange rate, but policies targeting a specific level of the exchange rate are incompatible with floating. Indicators for managing the rate are broadly judgmental (for example, balance of payments position, international reserves, and parallel market developments). Floating arrangements may exhibit more or less exchange rate volatility, depending on the size of the shocks affecting the economy.

Free Floating: A floating exchange rate can be classified as free floating if intervention occurs only exceptionally and aims to address disorderly market conditions and if the authorities have provided information or data confirming that intervention has been limited to at most three instances in the previous six months, each lasting no more than three business days. If the information or data required are not available to the IMF, the arrangement will be classified as floating. Detailed data on intervention or official foreign exchange transactions will not be requested routinely from member countries, but only when other information available to the IMF is insufficient to resolve uncertainties about the appropriate classification.

Also, according to the IMF, the monetary policy frameworks employed by central banks are as follows.

Exchange rate anchor: The monetary authority buys or sells foreign exchange to maintain the exchange rate at its predetermined level or within a range. The exchange rate, thus, serves as the nominal anchor or intermediate target of monetary policy. These frameworks are associated with exchange rate arrangements with no separate legal tender, currency board arrangements, pegs (or stabilized arrangements) with or without bands, crawling pegs (or crawl-like arrangements), and other managed arrangements. Common anchor currencies include the US Dollar, Euro or a composite consisting of two or more currencies as an anchor.

Monetary aggregate target: The intermediate target of monetary policy is a monetary aggregate such as M0, M1, or M2, although the country may also set targets for inflation. The central bank may use a quantity (central bank reserves or base money) or price variable (policy rate) as an operational target.

Inflation targeting framework: This involves the public announcement of numerical targets for inflation, with an institutional commitment by the monetary authority to achieve these targets, typically over a medium-term horizon. Additional key features normally include increased communication with the public and the markets about the plans and objectives of monetary policymakers and increased accountability of the central bank for achieving its inflation objectives. Monetary policy decisions are often guided by the deviation of forecasts of future inflation from the announced inflation target, with the inflation forecast acting (implicitly or explicitly) as the intermediate target of monetary policy.

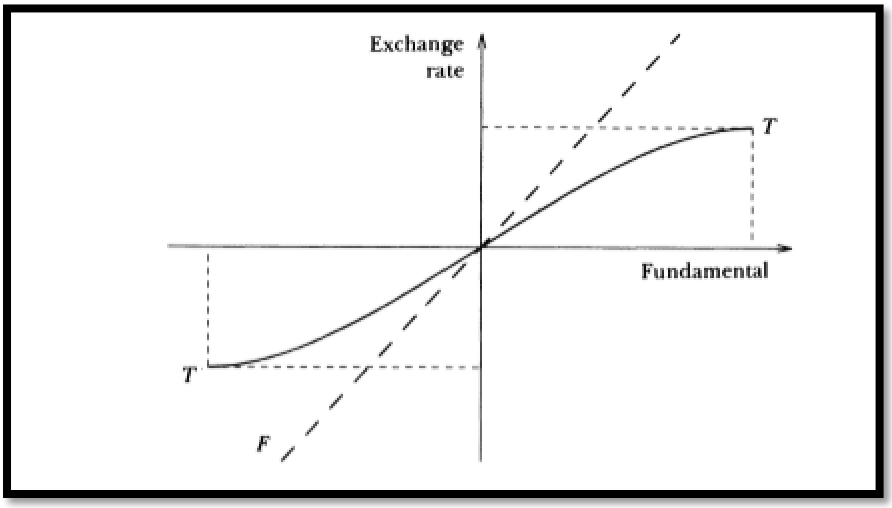
1.2.4 Within the band regimes

Krugman (1991)[10], using a basic monetary model, developed an elegant fundamental model of exchange rate behaviour under a target zone exchange rate regime. The main result shows that the expectation that monetary policy will be adjusted to limit exchange rate fluctuation affects the exchange rate behaviour even when the exchange rate lies inside the target zone, and is therefore not being defended actively. Most scholars have provided a modification or an extension of this model one way or the other. A target zone should not be confused with a fixed exchange rate regime; a target zone may allow the exchange rate to fluctuate around a fairly wide predetermined reference rate. It could be 10% or any other reasonable rate on either side of the central rate. It is argued that countries may adopt a target zone regime since it does not require a lot of monetary policy action compared to the strictly pegged regime whose defence is a full-time job.

The Krugman (1991) model is based on two critical assumptions; the target zone is perfectly credible; market agents believe the lower and upper edges of the band will remain fixed forever and the exchange rate will forever stay within the band. Secondly, the exchange rate is defended with minimal interventions by the monetary authorities, money supply remains constant and no interventions as long as the exchange rate remains within the band. These assumptions are reiterated by Svensson (1992).

[10] The basic model is, $s = m + v + \gamma E[ds]/dt$; where s is the log of the nominal exchange rate, m the domestic money supply, v represents the velocity shocks and the last term is the expected rate of depreciation. The two fundamentals in the equation are money supply and the velocity shift. Velocity is assumed to be a Brownian motion without drift, that is, the realised sample paths are continuous over time with no discrete jumps. This implies that the free-float exchange rates behave like random walks. It should be noted that m is shifted only in order to defend the target zone, therefore preventing s from exceeding some predetermined maximum value. Svensson (1992) gives a detailed explanation.

Figure 1.2: The Krugman model of exchange rate target zones

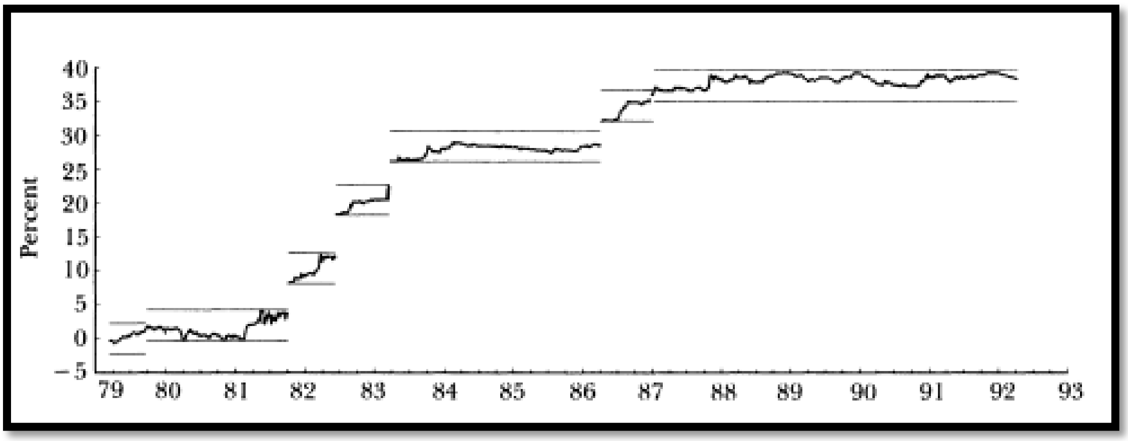


Source: Svensson (1992)

The model predicts the S-shape non-linear relationship between the exchange rate and its fundamental determinants as shown by the curve TT. The line F represents the equilibrium exchange rate in the free-floating regime. The assumption is that the exchange rate depends linearly on macroeconomic fundamental and the expected future value of a currency. Within the fundamental, there are two components, that is, velocity and domestic money supply where velocity is exogenous and stochastic while the money supply is changed or altered by the central bank from time to time to control and manage the exchange rate. As long as the exchange rate lies within the band, the money supply remains unchanged. The stochastic process is assumed to follow a Brownian motion without drift. The main results from the Krugman model are the *honeymoon* effect and *smooth pasting*. As revealed in literature by Svensson (1992), if the exchange rate is higher and closer to the upper edge of the exchange rate band, the probability that it will reach the upper edge is higher. Thus, the probability that there will be future intervention to reduce money supply and strengthen the currency is higher. The target zone exchange rate is less than the free-float exchange rate for a certain level of the fundamental. He further adds that the slope of the target zone exchange rate function is zero at the edges of the band, hence, the exchange rate at this point is insensitive to changes in the fundamental; this is *smooth pasting*. The *honeymoon* effect implies that a perfectly credible target zone has the stabilization effect and *smooth pasting* implies the exchange rate is a non-linear function of is fundamental determinants and insensitive to these fundamentals at the edge of the exchange rate band.

A further concept to the target zone literature is the time varying re-alignment risk which occurs when the exchange rate band is allowed to shift over a period. Bertola and Svensson (1993) pioneered interest in this area and were the first to present an exchange rate target zone model with time varying re-alignment risk. The introduction of time varying re-alignment risk changes the process by which the interest rate differentials are determined and the interpretation of interest rate differentials against exchange rate plots. The interest rate differential is now equal to the sum of the expected rate of currency depreciation within the band and the expected rate of re-alignment. The diagram below shows the log of the French Franc/Deutsche Mark exchange rate from the start of the European Monetary System in March 1973 through to 1992 with a band of ±2.25% around a central rate. There were re-alignment shifts in September 1979, October 1981, June 1982, March 1983, April 1986 and January 1987 with the Franc being devalued against the Mark, that is, the number of Francs per Mark increased.

Figure 1.3: Log French Franc/Deutsche Mark exchange rate



Source: Svensson (1992)

Hurley et al. (1993) in their study of the appropriate level of reserves required to defend an exchange rate target zone found that; for the case of Ireland, reserves were approximately optimal for most of the 1980s but significantly below optimal during 1989 and 1992. Furthermore, the researchers concluded that foreign exchange reserves should at least be kept above 25% of domestic credit.

1.2.5 Optimal currency area (OCA)

Frankel (1999) defines an optimum currency area as a region for which it is optimal to have its own currency and its own monetary policy. Mundell (1961) defines an OCA as a currency area for which the costs of relinquishing the exchange rate, an internal instrument of adjustment (within the area) are outweighed by the benefits of adopting a single currency or a fixed exchange rate regime. The registered success of the Eurozone has of recent re-ignited studies in the optimum currency area and its applicability. Fleming (1971) and Ricci (2008) stress that the similarity of pre-union inflation rates across countries may be considered as an important factor determining the OCA. Countries may have different Phillips curves[11] and therefore the act of imposing a unique level of inflation by adopting a common currency may automatically generate some costs. The OCA theory was fast put forward by Mundell (1961)[12] where he develops a simple two-entity model which could be regions or countries, initially at full employment and balance of payments equilibrium, and introduces asymmetric shocks to output and an adjustment mechanism. He asks the question; whether countries intending to form common markets and economic unions should allow each of their national currencies to fluctuate or form a single currency area. He argues that the subject of flexible exchange rates can be separated into two distinct questions. The first is whether a system of flexible exchange rates can work effectively and efficiently in the modern world economy. For this to be answered, it must be demonstrated that: (1) an international price system based on flexible exchange rates is dynamically stable after taking speculative demands into account; (2) the exchange rate changes necessary to eliminate normal disturbances to dynamic equilibrium are not so large as to cause violent and reversible shifts between export and import-competing industries; (3) the risks created by variable exchange rates can be covered at reasonable costs in the forward markets; (4) central banks will refrain from monopolistic speculation; (5) monetary discipline will be maintained by the unfavourable political consequences of continuing depreciation, as it is to some extent maintained today by threats to the levels of foreign exchange reserves; (6) reasonable protection of debtors and creditors can be assured to maintain an increasing flow of long-term capital movements and (7) wages and profits are not tied to a price index in which import goods are heavily weighted. The second question he answers is how the world should be divided into currency areas; the stabilization argument for flexible exchange rates is valid only if it is based on regional currency areas. If the world can be divided into regions within each of which there is factor mobility and between which there is factor immobility, then each of these regions should have a separate currency which fluctuates relative to all other currencies. This carries the argument for flexible exchange rates to its logical conclusion. However, if labour and capital are insufficiently mobile within a country then flexibility of the external price of the national currency cannot be expected to perform the stabilization function attributed to it, and one could expect varying rates of

[11] This econometric model describes the inverse relationship between inflation and unemployment; a decrease in unemployment correlates with higher rates of wage rises/inflation.
[12] The model was developed within the IS-LM-FE framework.

unemployment or inflation in the different regions. A key weakness of the Mundell (1961) model is that he assumed that economic agents did not incorporate expectations about future movements in the price level, interest rates, exchange rates and government policy.

Symmetry in business cycles has been put forward by some scholars as a condition for the OCA. Symmetry in the business cycle is defined as a positive co-movement between the two countries' output; the shocks or disturbances affect the countries in a much similar way, in other words, symmetric. The existence of highly correlated business cycles is a signal that the two countries can almost form an OCA with a common monetary policy. Asymmetric shocks on the other hand tend to come along with inflationary pressures for the country that has gained from this sort of shock, monetary expansion is still possible though. Asymmetric shocks are caused by differences in financial and tax systems, structural differences in labour markets and institutions. Shocks could come from shifts in demand as described in the model by Mundell (1961). It is important to note that the actions of monetary policy have an effect on the exchange rates if not handled carefully (appreciation and depreciation). In relation to this, Ricci (2008) states that the exchange rate between two areas is an effective instrument of short-run adjustment if the following conditions hold; (1) the two areas face asymmetric shocks, so that an adjustment of the relative price of the goods produced in the two countries is required; (2) domestic prices are not fully flexible, that is, prices do not adjust immediately to shocks (price stickiness); (3) pass-through[13] is not large, therefore a relative price change due to exchange rate change is not immediately neutralised by domestic price movements.

Bayoumi and Eichengreen (1998) in a study that takes into consideration the exchange rate regimes employed by the advanced economies find that the OCA variables[14] have an explanatory power towards the variations in exchange market pressures, and so, exchange rate behaviour. The OCA variables affect the bilateral exchange rates through market conditions and intervention, with asymmetric shocks being the main source of exchange market pressures, and proxies for deterioration in the transactions value of money due to floating provide the main motivation for intervention.

[13] This is a measure of how responsive international prices are to changes in exchange rates. If the degree of pass-through is large, then there is a high probability of transmission of inflation between countries.
[14] The variables that determine the regime employed by a country as predicted by the OCA are asymmetric output disturbances, trade linkages, the usefulness of money for domestic transactions, and the extent of labour mobility.

1.2.6 Why countries float or peg and anchor currencies

Levy-Yeyati and Sturzenegger (2005) findings support the fact that countries may declare a regime and behave differently in order to avoid speculative attacks[15] on their currencies. In this regard, fixers may declare a more flexible regime, the concept of *hidden pegs*. Their findings further reveal that intermediate regimes like crawling pegs and bands have reduced in number over the years. Furthermore, they find that de facto floats are characterized by small amounts of exchange rate variability, so, a large number of these countries intervene in the markets in order to maintain a certain exchange rate. This is in opposition to the textbook definition of a floating regime, confirming the concept of *fear of floating* introduced by Calvo and Reinhart (2002).

Ilzetzki et al. (2017) emphasize that the reserve currency composition is a good indicator of whether a country may be inclined to intervening in the markets to defend its exchange rate value against the currency whose share of the reserve composition is higher. For instance, if the Euro takes a bigger share of the reserve composition in relation to other currencies, this country is likely to choose the Euro as an anchor. The historical colonial relationship between two countries may also play a part when it comes to choosing an anchor currency. By default, emerging economies, to a greater extent, peg their currencies to that of their colonial masters. Countries facing macroeconomic instabilities like high inflation rates tend to choose as an anchor the currency of a country whose performance they want to mimic. Pegging to a low-inflation currency has the advantage of reducing domestic inflationary pressures.

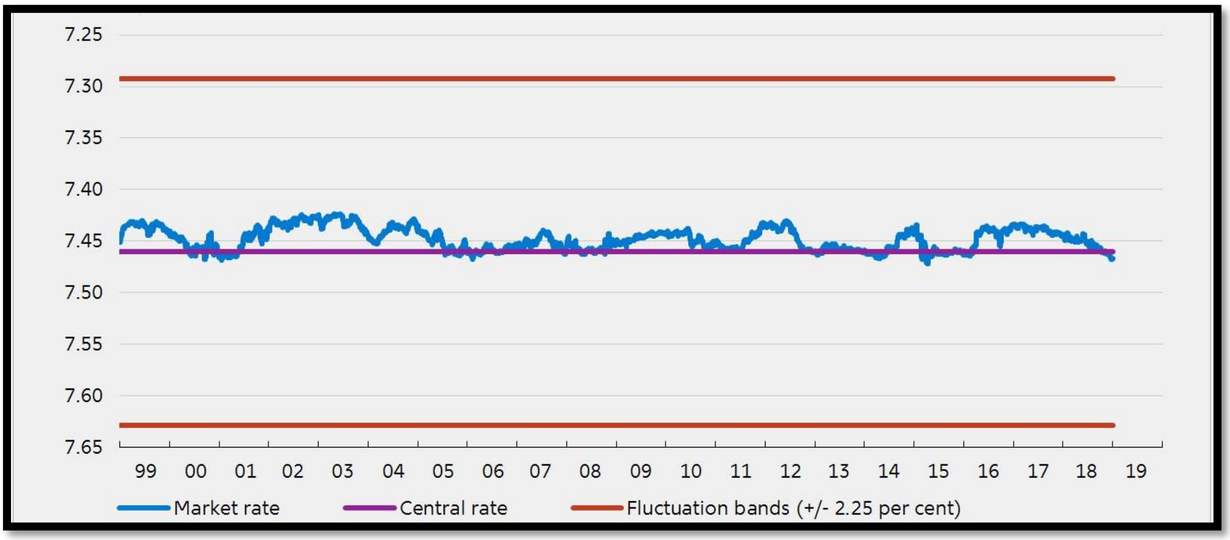
Many scholars have argued that a fixed exchange rate regime is associated with less exchange rate volatility, and as a result, likely to increase trade. A country whose foreign trade is mostly with Eurozone countries and invoices in Euros is likely to deploy the Euro as an anchor currency. Mussa (1986) argues that the real exchange rates show greater volatility under floating regimes than they do under the fixed regime. Kenen and Rodrik (1986) argue that the volatility of the real exchange rate depresses trade, and so, a fixed regime is pro-trade. Aristotelous (2001) contradicts this result and reveals that the regime employed by a country has no effect on the export volume. Bacchetta and Van Wincoop (2000) introduce a new

[15] In what is referred to as Black Wednesday in Britain, George Soros, a currency trader, made an estimated $1 billion in profit after a timely and brave bet against the Sterling and Bank of England in 1992. When Britain joined the ERM, the rate was set at 2.95 DM per Sterling, allowing a flexibility of about 6% on either side. The economy was not doing well compared to the German economy with the inflation rate three times that of Germany, setting the stage for a burst period. Traders took advantage of this and started short selling the Sterling. This forced Britain to withdraw from the ERM because the Sterling value fell below the lower limit specified by the ERM.

perspective altogether, adding that, adopting a fixed regime does not necessarily lead to more trade, the volume of trade will depend on how the regime is implemented. Rose (2000) argues that countries in a currency union trade more with each other than they do with countries outside a union, approximately 3.35 times more with each other. This finding is further supported by Adam and Cobham (2007).

Under The Maastricht Treaty signed in 1992 by members of the European Community to further European integration, countries within the union and candidates to adopt[16] the Euro currency are required to peg their currencies to the Euro over a band for a period of at least 2 years. This pegging enables the EU to gain a credible mechanism for evaluating potential Eurozone members. The Danish Krone is the only currency in the ERM II stage, hence, pegging its exchange rate to the Euro. According to the European Central Bank, the Danish Krone fluctuates within a band of ±2.25% against the Euro. However, the standard ERM II fluctuation band is ±15%. This inconsistency is simply because of the existence of an already high degree of convergence of the Danish Krone against the Euro.

Figure 1.4: Exchange rate of the Krone/Euro



Source: *Danmarks Nationalbank*

[16] Other criterion to adopt the Euro as a sole currency include among others; countries are required to maintain their public debt as a percentage of GDP and GDP growth at 60% and 3% respectively, hold nominal long-term interest rate in the preceding year that did not exceed 2% of the three most stable price-stable members, and run an inflation rate over the preceding year that did not exceed that of the three lowest inflation member states by more than 1.5%. These are all outlined in the Stability and Growth Pact (SGP). These conditions were agreed upon by all the European Union member states.

Several countries have foreign currency denominated debt in anchor currencies like the US Dollar and Euro, thus, find it wise to peg to these currencies and avoid destabilising fluctuations while they service their foreign debt.

Theoretical grounding reveals that the floating exchange rate regime acts as a shock absorber to internal and foreign macroeconomic shocks, enabling the economy to adjust accordingly by adjusting interest rates, this, with the assumption of capital mobility. These could include inflationary shocks, financial crises, commodity price shocks and business cycles with booms and depressions (output or unemployment shocks). Fixed exchange rate regimes are linked to financial crises since the monetary authorities must constantly defend the exchange rate regime which may not be possible at times due to inadequate reserves and underdeveloped capital markets. This was evident during the Asian financial crisis of 1997, the Mexican crisis of 1995, and the Russian crisis of 1997. McKinnon (2000) uses high frequency (daily) data to test for the weight of the Dollar versus the Yen and notes in his study that by keying to the Dollar, the macroeconomic policies of the Asian crisis economies[17] were loosely tied to each other. Some of the countries affected by the 1997 crisis[18] subsequently switched to an inflation targeting monetary framework regime that is primarily characterized by a floating exchange rate regime. Baig (2001) in a study examining the daily exchange rate behaviour of 5 East Asian currencies before, during and after the Asian crisis of 1997 found that these countries maintained a de facto peg to the US Dollar over the pre-crisis period, however, he adds that this result may not be reliable given that the results from the regressions of de jure floaters or the control group exhibited large and significant coefficients similar to those of the Asian crisis countries. Mishkin (2004) points out that countries employing inflation targeting as a monetary policy framework are not necessarily targeting only inflation but the exchange rate as well thereby intervening in the foreign exchange markets to defend a regime, an act that contradicts the inflation targeting model.

The pegged system, especially to a recognised and stable anchor currency like the US Dollar, is a good practise to attract foreign investors. Investors can evaluate their returns on investment over time easily with less fluctuations.

[17] The crisis economies were Indonesia, Korea, Malaysia, Philippines, and Thailand. It is important to note that the economies of Hong Kong, Singapore and Taiwan pegged their currencies to the Dollar but were not hit hard by the 1997 Asian crisis.

[18] Ohno (1999) states that many Asian countries were priced out of international competition by pegging their currencies to the US Dollar which appreciated greatly during 1995-1997. This meant that some currencies were overvalued in the period leading up to the Asian crisis of 1997.

1.2.7 Regimes and crises

According to Calvo and Mishkin (2003), countries often choose an intermediate path when it comes to exchange rate regimes; that is, an exchange rate is often stabilized by the central bank, but might sometimes shift, often known as a "soft peg." However, in the aftermath of the macroeconomic crisis across East Asia over the period 1997–1998, a view emerged that this exchange rate regime was in part responsible for the depth of the macroeconomic crisis. The governments of Thailand, Malaysia, South Korea, and other nations in that region had kept exchange rates fixed, closely following the US Dollar. Frankel (1999) argues that, contrary to what is always claimed that Mexico, Thailand, Indonesia, Korea, Russia or Brazil formally pegged their currencies to the US Dollar when their crises hit, they actually were following varieties of bands, baskets, and crawling pegs. This remains open to debate as other scholars have found a rather different result.

Chang and Velasco (2000) provide a detailed and impressive model of the relationship between financial fragility and the exchange rate regime, comparing currency boards, fixed rates, and flexible rates, with and without a lender of last resort. They note that under a currency board, the exchange rate is fixed, and the central bank does not issue domestic credit, and therefore these economies are vulnerable to bank runs and not currency crises. A fixed exchange rate regime is more prone to bank runs, exchange rate crises and balance of payments crises. A flexible exchange rate system implements the social optimum and eliminates runs, provided the exchange rate and credit policies of the central bank are appropriately designed. They argue that the abilities of the currency boards have been observed in the successes registered by Hong Kong and Argentina over turbulent periods in the recent past when financial institutions came under intense pressures globally.

Aghion et al. (2001), while developing a model of currency crises driven by the interplay between the credit constraints of private domestic firms and the existence of nominal price rigidities and examining the impact of various shocks including expectations shocks, argue that currency crises can occur under both the fixed and flexible exchange rate regimes since the primary source of the currency crisis is identified as the deteriorating balance sheet of private firms. They add that an initial regime may be able to maintain a stable exchange rate when the economy is hit by small shocks, however, if the shock is large, then the initial regime has little influence in preventing a currency crisis. The regime employed ultimately becomes irrelevant.

Haile and Pozo (2006), using a broad sample of 35 countries, test whether the exchange rate regime employed by a country has an impact on the vulnerability of the countries to a currency crisis using an Extreme Value Theory[19] technique. They construct an exchange market pressure index and a Hill Estimator/Tail Index to identify exchange market crises. The index is constructed as the weighted average of nominal exchange rate depreciation, change in domestic and foreign interest rates differential, and decrease in foreign exchange reserves. In their words, 'we find that the actual or de facto exchange regime plays no role in determining currency crisis periods. Fundamentals and contagion instead appear to be the main determinants of currency crises. We find, however, that while the de facto exchange regime fails to explain currency crises, the declared exchange regime does play a role with declared pegs increasing the likelihood that a nation experiences a currency crisis. Our results are consistent with the idea that soft pegs are easy targets for speculators and as such have a higher probability of resulting in a currency crisis with the peg turning into a float.'

Calvo and Mishkin (2003) state that one danger of a hard exchange rate peg is the risk of being locked into a misaligned exchange rate, defined as a sizeable difference between its actual level and the one which fundamentals would dictate. They further note that neither the fixed nor the freely floating regimes has an unblemished record with regard to crises and that no exchange rate regime can prevent macroeconomic turbulence. The choice of the regime should be chosen to match the characteristics of the economy in question. The researchers state in their paper that the regime chosen is of second-order importance. Of primary importance is the need for reforms; more regulation for the financial sector, fiscal constraint and developing a predictable monetary policy and more trade openness. These reforms will help emerging market economies be more immune to currency crises.

1.2.8 The testing, estimation, and classification models

Frankel (1992), Frankel and Wei (1994), Ohno (1999) and McKinnon (2000) use a technique that recovers the weights that countries assign to certain anchor currencies or currency baskets containing currencies that countries may claim to peg to. If the weight assigned to an anchor currency is close to one, then a peg or fixed regime is identified. In all studies, the researchers find that the coefficients estimated for the Asian economies are close to one for the US Dollar,

[19] Extreme Value Theory (EVT) is useful in dealing with the statistical modelling of rare or extreme events. It has widely been used in other disciplines like engineering, earth sciences, traffic prediction and biology. For instance, it can be used to estimate the probability that an earthquake or flood may occur over a specified period of time, say a 50-year period.

indicating a close peg. Ohno (1999) extends and/or modifies this technique by incorporating the real effective exchange rate, constructing multiple currency baskets containing currencies of three industrial blocks, that is, Yen, US Dollar and Euro. He adds that there is a high risk associated with using high frequency data when evaluating exchange rate performance. His simulations reveal that there were no risky pre-crisis exchange rate misalignments among the worst hit countries of the 1997 Asian crisis.

As earlier stated, Calvo and Reinhart (2002) test for the de facto exchange rate regimes using three criteria; monthly percentage exchange rate changes, monthly percentage changes of official foreign reserves and monthly absolute changes in nominal short-term interest rates, estimating the probability that a variable falls within a predetermined bound that defines a certain exchange rate regime. For instance, if a bound is set at 2.5%, then the probability that the monthly exchange rate change falls within the 2.5% band will be greatest for the fixed regime and lowest for the freely floating regime. They follow the same procedure to examine the behaviour of reserves and interest rates that are used by governments as monetary policy tools.

Levy-Yeyati and Sturzenegger (2005, 2016) define exchange rate regimes according to the behaviour of three variables; changes in the nominal exchange rate, volatility of these changes and the volatility of international reserves[20]. Fixed exchange rate regimes are characterized by more changes in international reserves aimed at reducing the volatility in the nominal exchange rate, and flexible regimes are characterized by substantial volatility in nominal rates with relatively stable reserves. The researchers develop clusters, the clusters with high volatility of reserves and low volatility of nominal exchange rate are fixers while those with low volatility in international reserves and substantial volatility in the nominal exchange rate identify as flexible. They note that reserves are notoriously hard to measure and there is a large difference between changes in reserves[21] and interventions. Their approach uses a cluster analysis to identify the exchange rate regimes based on the classification variables. This is a multivariate approach used to identify homogeneous observations, according to similarities between data points along certain identified dimensions.

[20] Their incorporation of the behaviour of reserves goes a step further from the Reinhart and Rogoff (2004) study that classifies regimes based on the degree of exchange rate variability.

[21] Reserves may change due to expenditure on foreign assets, foreign aid or purchase of certain plant and equipment by governments, like arms.

Ilzetzki et al. (2017)[22] stress that any classification algorithm must simultaneously determine both an anchor currency, if any, and its degree of fixity or flexibility. They go ahead and develop an anchor or reference currency classification algorithm, emphasizing that this can prove to be a heavy task given that there is a great degree of flexibility in exchange rates globally and some anchor or reference currencies may not be declared by monetary authorities.

Frankel and Wei (2008) propose an extension to the original regression-based technique that incorporates an exchange market pressure variable, defined as a percentage increase in the value of the currency plus the percentage increase in reserves. This answers the question as to what extent the authorities allow the increase in international demand for a currency to show up as an appreciation in the currency and to what extent as an increase in reserves.

[22] This is an extension of the Reinhart and Rogoff (2004) classification that introduces classification based on the anchor/reference currencies, inflation targeting cases and treatment criteria for Eurozone countries.

1.3 Models and Data

1.3.1 Anchor currency regressions

The regression equation below is used to investigate or recover the weights that monetary authorities in a country may attach to the three main global anchor currencies.

$$\Delta Ln(\frac{LCY}{CHF})_t = \beta_1 + \beta_2 \Delta Ln(\frac{USD}{CHF})_t + \beta_3 \Delta Ln(\frac{EUR}{CHF})_t + \beta_4 \Delta Ln(\frac{JPY}{CHF})_t + \beta_5 \Delta Ln(\frac{GBP}{CHF})_t + \varepsilon_t$$

Where LCY is the domestic currency of the country under study, USD is the US Dollar, EUR is the Euro, JPY is the Japanese Yen, GBP is the British Pound, and finally, CHF is the Swiss Franc, the numeraire. The technique aims to recover the weights, βs, that are assigned by each country to the potential anchor currencies. That is, it aims to decompose the variation in each domestic currency due to the variation in the chosen anchor currencies. A β close to one and statistically significant shows a sign of pegging, and a β close to zero and not significant is a sign of a floating regime.

It is tempting to use the Chinese Renminbi as a possible anchor currency in the Equation above given its recent inclusion to the Special Drawing Rights (SDR)[23] basket and increased share in global GDP, however, this will not be a good idea given that it has for a long period of time been known to be pegged to the US Dollar. This would obscure or confound, to a great extent, the integrity of the findings of this study.

The Swiss Franc is chosen as a numeraire currency to express the value of all currencies in terms of a common currency. The Swiss Franc is the preferred choice because it is a freely floating currency of an advanced economy. In addition, the volume of trade between Switzerland and the countries chosen in the sample is quite minimal. A significant volume of trade would encourage pegging to reduce the exchange rate risk associated with exchange rate fluctuations.

[23] SDR refers to an international type of monetary reserve currency created by the IMF in 1969 that operates as a supplement to existing money reserves of member countries. It was created as a result of concerns raised about the limitations of gold and the US Dollar as the sole means of settling international accounts. The SDR generally reflects the importance of a currency in the world's trading and financial system. There are weights attached to each of the 5 currencies included in the SDR basket, with the US Dollar having the highest, and the British Pound the least at the time of writing this document.

Furthermore, the Swiss Franc is considered a haven[24] currency. The stability of the Swiss government, sound macroeconomic stability and developed financial system makes it a good candidate as a numeraire. To a greater extent, Switzerland is legally independent of the European Union, this shields the country from negative shocks and pressures from the EU and Euro Area. However, the currency periodically faces an upward pressure due to increased demand given that it is a haven; this could result in an overvalued currency.

1.3.2 Markov regime switching models

The Autoregressive (AR) version of the Markov process is chosen since it allows a smooth transition from one regime to another. This model is essentially trying to describe the intervention behaviour of the central bank. It is also appropriate when the exchange rates exhibit long swings in one direction. This discussion closely follows the work of Hamilton (1989), Hamilton (1990), Engel and Hamilton (1990), Hamilton (1994) and Kim (1994). The Markov-switching regression models, chains and estimation procedure are described below.

Take a simple process of y_t, in this case, y_t is the log of the nominal exchange rate at time t, with $t = 1,2, \dots T$, and described by 2 states as below.

$$State\ 1: y_t = \mu_1 + \Phi y_{t-1} + \varepsilon_t$$

$$State\ 2: y_t = \mu_2 + \Phi y_{t-1} + \varepsilon_t \qquad (1)$$

μ_1 and μ_2 are the intercepts in the respective states that are unobservable, Φ is the AR term that allows for smooth transition between states, and ε_t, a white noise error with variance σ^2. The 2 states are essentially modelling shifts in μ. It is possible to express the above model as;

$$y_t = s_t\mu_1 + (1 - s_t)\mu_2 + \Phi y_{t-1} + \varepsilon_t \qquad (2)$$

s_t is 1 if the process is in state 1 and 0 otherwise.

Allowing the intercept to depend on the state that the process is in, up to k states, the model can be expressed as;

$$y_t = \mu_{s_t} + \Phi y_{t-1} + \varepsilon_t \qquad (3)$$

$\mu_{s_t} = \mu_1$ if $s_t = 1$, $\mu_{s_t} = \mu_2$ if $s_t = 2$ and $\mu_{s_t} = \mu_k$ if $s_t = k$.

[24] A haven is an investment that usually retains or increases in value during times of market turbulence, and thus, limit an investor's exposure to losses in times of market downturns and high volatility periods, including crises. Other haven investments include gold, treasury bills and cash, just to mention but a few.

Equation 4 below describes a MSDR (Markov-Switching Dynamic Regression) process that allows the intercept to switch across 2 states, as in Krolzig (2013).

The conditional density of y_t is dependent only on the realisation of the current state that the process is in, s_t. The conditional density is;

$$f(y_t|s_t = i, y_{t-1};\ \boldsymbol{\theta}) \tag{4}$$

$\boldsymbol{\theta}$ is a representation of a vector of parameters. Given that there are k states, then it follows that there are k conditional densities as shown below.

$$\tau_t = \begin{bmatrix} f(y_t|s_t = 1;\ y_{t-1};\ \boldsymbol{\theta}) \\ f(y_t|s_t = 2;\ y_{t-1};\ \boldsymbol{\theta}) \\ \vdots \\ f(y_t|s_t = k;\ y_{t-1};\ \boldsymbol{\theta}) \end{bmatrix} \tag{5}$$

τ_t is therefore a $k \times 1$ vector of conditional densities.

The transition probabilities can be represented by a $k \times k$ matrix as;

$$\boldsymbol{P} = \begin{bmatrix} p_{11} & p_{21} & \cdots & p_{k1} \\ p_{12} & p_{22} & \cdots & p_{k2} \\ \vdots & \vdots & \cdots & \vdots \\ p_{1k} & p_{2k} & \cdots & p_{kk} \end{bmatrix} \tag{6}$$

With columns summing up to 1, that is, $\sum_{j=1}^{k} p_{ij} = 1$.

The transition probabilities in functional form are expressed as;

$$p_{ij} = \frac{\exp(-q_{ij})}{1 + \exp(-q_{i1}) + \exp(-q_{i2}) + \cdots + \exp(-q_{i,k-1})} \tag{7}$$

For $j \in (1, 2, \ldots, k-1)$.

To normalise p_{ik}, the restriction below is imposed. Please note the difference in the numerator.

$$p_{ik} = \frac{1}{1 + \exp(-q_{i1}) + \exp(-q_{i2}) + \cdots + \exp(-q_{i,k-1})} \tag{8}$$

Of particular interest is a model that allows gradual adjustment between states. This can be done using a MS-AR (Markov-Switching Autoregressive) model.

$$y_t = \mu_{s_t} + \Phi(y_{t-1} - \mu_{s_{t-1}}) + \varepsilon_t \qquad (9)$$

Notice that, in this case, the current value of y_t depends on the value of its switching mean in the current state and its lagged value.

A MS-AR model with k number of states/regimes with covariates included will be of the form;

$$y_t = \mu_{s_t} + \boldsymbol{X}_t\boldsymbol{\alpha} + \boldsymbol{Z}_t\boldsymbol{\beta}_{s_t} + \sum_{i=1}^{k} \Phi_{i,s_t}(y_{t-i} - \mu_{s_{t-i}} - \boldsymbol{X}_{t-i}\boldsymbol{\alpha} - \boldsymbol{Z}_{t-i}\boldsymbol{\beta}_{s_{t-i}}) + \varepsilon_{s_t} \qquad (10)$$

y_t is the dependent variable at time t, μ_{s_t} is the state dependent intercept, $\boldsymbol{X}_t$ are covariates whose coefficients α are state-invariant, $\boldsymbol{Z}_t$ are covariates whose coefficients, β_{s_t}, are state-dependent, Φ_{i,s_t} is the i^{th} AR term in state s_t, $\mu_{s_{t-i}}$ is the intercept corresponding to the state that the process was in at period $t-i$, $\boldsymbol{\beta}_{s_{t-i}}$ is the coefficient vector on $\boldsymbol{Z}_{t-i}$ corresponding to the state that the process was in at period $t-i$ and ε_{s_t} iid $N(0, \sigma_{s_t}^2)$.

Now, again consider a 2-state/regime process, and in both regimes, y_t follows a normal distribution. The transition probabilities can be denoted as shown below. The implication of this is that the probability of regime 1 occurring at time t depends solely on the regime at time $t-1$.

$$p_{ij} = Pr(s_t = j | s_{t-1} = i) \qquad (11)$$

With $i, j = 1,2$.

The transition probabilities in a 2×2 matrix can be expressed as;

$$P = \begin{bmatrix} p_{11} & p_{12} \\ p_{21} & p_{22} \end{bmatrix} \qquad (12)$$

Where the transitional probabilities may be calculated as;

$$p[s_t = 1 | s_{t-1} = 1] = p_{11}$$
$$p[s_t = 2 | s_{t-1} = 1] = p_{12} = 1 - p_{11}$$
$$p[s_t = 2 | s_{t-1} = 2] = p_{22}$$

$$p[s_t = 1|s_{t-1} = 2] = p_{21} = 1 - p_{22} \tag{13}$$

p_{11} is the probability that the series is in state 1 at time $t-1$ and remains in state 1 at time t, p_{12} is the probability that the series is in state 1 at time $t-1$ and transitions to state 2 at time t, p_{22} is the probability that the series is in state 2 at time $t-1$ and remains in state 2 at time t and p_{21} is the probability that the series is in state 2 at time $t-1$ and transitions to state 1 at time t.

The expected duration in a state is computed as;

$$ED = \frac{1}{1 - p_{ij}} \tag{14}$$

Since the states are latent, then it follows that one can never know for sure which regime prevailed at a certain time as the states remain unobservable. To draw meaningful inference about the progression of y_t over time, then state probabilities and other $\boldsymbol{\theta}$ parameters will need to be estimated using maximum likelihood.

$$\boldsymbol{\theta} = [\mu_1, \mu_2, \Phi_1, \Phi_2, \sigma_1^2, \sigma_2^2, p_{11}, p_{22}]' \tag{15}$$

$$\xi_{jt} = Pr(s_t = j|\Omega_t; \boldsymbol{\theta}) \tag{16}$$

Where $j = 1{,}2$ and $\Omega_t = (y_t, y_{t-1}, \dots, y_1, y_0)$ are observations at time t.

For $t = 1,2, \dots, T$, inference is performed iteratively with step t accepting as input values in Equation 17 below and producing as output Equation 16.

$$\xi_{i,t-1} = Pr(s_{t-1} = i|\Omega_{t-1}; \boldsymbol{\theta}) \tag{17}$$

For $i = 1{,}2$. Note the differences in the subscripts.

The density of y_t conditional on s_t is given by;

$$\eta_{jt} = f(y_t|s_t = j, \Omega_{t-1}; \boldsymbol{\theta}) = \frac{1}{\sigma_{s_t}\sqrt{2\pi}} \exp\left(-\frac{1}{2\sigma_{s_t}^2}\left[y_t - \mu_{s_t}\right]^2\right) \tag{18}$$

The conditional density of the t^{th}observation can be computed from;

$$f(y_t|\Omega_{t-1}; \boldsymbol{\theta}) = \sum_{i=1}^{2}\sum_{j=1}^{2} p_{ij}\xi_{i,t-1}\eta_{jt} \tag{19}$$

Giving an output of;

$$\xi_{jt} = \frac{\sum_{i=1}^{2} p_{ij}\xi_{i,t-1}\eta_{jt}}{f(y_t|\Omega_{t-1};\boldsymbol{\theta})} \quad (20)$$

The execution of this iteration leads to the evaluation of the sample conditional log likelihood in Equation 21 below.

$$Logf(y_1, y_2, \dots, y_T|y_0;\boldsymbol{\theta}) = \sum_{t=1}^{T} logf(y_t|\Omega_{t-1};\boldsymbol{\theta}) \quad (21)$$

An estimate of $\boldsymbol{\theta}$ can be obtained by maximising Equation 21 above.

The smoothed probabilities are computed using an algorithm developed by Kim (1994). This recursion is called the Kim-smoother.

$$\xi_{t|T} = \xi_{t|t} \odot \left[\boldsymbol{P}'(\xi_{t+1|T}(\div)\xi_{t+1|t})\right] \quad (22)$$

$\odot$ indicates element-by-element multiplication.

The expectation maximisation algorithm for obtaining maximum likelihood estimates of parameters for processes subject to discrete shifts developed by Hamilton (1990) is applied to the likelihood function in Equation 21.

1.3.3 Data

Monthly nominal exchange rate data per CHF on 70 countries to best represent the globe was collected. The sample period was 2000-2019 and the data was collected from the IMF-IFS database. The countries in the sample are;

Europe; Albania, Armenia, Bulgaria, Czech Republic, Denmark, Hungary, Iceland, Norway, Poland, Romania, Russia, Sweden, Turkey, and Ukraine.

Americas; Argentina, Aruba, Barbados, Bahamas, Brazil, Canada, Chile, Colombia, Jamaica, and Mexico

Middle East, South and East Asia; Bahrain, China, Hong Kong, India, Israel, Malaysia, Oman, Philippines, Qatar, Saudi Arabia, Singapore, South Korea, Thailand, and United Arab Emirates.

Oceania; Australia, Fiji, and New Zealand.

Africa; Algeria, Benin, Burkina Faso, Cameroon, Central African Republic, Chad, Congo, Côte d'Ivoire, Egypt, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Ghana, Guinea-Bissau, Kenya, Mali, Morocco, Niger, Nigeria, Rwanda, Senegal, Seychelles, South Africa, Tanzania, Togo, Tunisia, Uganda and Zambia.

After applying the anchor currency regressions discussed in section 1.3.1 and getting a good feel of how the different currencies behave according to the anchors, a smaller sample comprising of the log exchange rate per US Dollar of 4 advanced economies (UK, Euro Area, Switzerland and Canada) and 4 emerging market economies (Hungary, Romania, South Korea and South Africa) is chosen, and a more complex approach, the 2-regime Markov-switching model, discussed in section 1.3.2 is used to study the behaviour of these currencies.

1.4 Discussion of Results

1.4.1 Descriptive statistics

The descriptive statistics presented are the mean, standard deviation, minimum, maximum, skewness and kurtosis. The discussion here will focus mainly on the mean and tail behaviour moments, that is, the skewness and kurtosis, to draw any kind of preliminary inference.

Table 1.1 presents the results for European currencies. From the mean results, the Armenian Dram and Hungarian Forint exhibit the highest figures per CHF, 397.578 and 207.866 respectively. Mean exchange rates are obviously very sensitive to the chosen reference currency. As expected, the British Pound and Euro show the lowest values per CHF in that order, reporting means of 0.571 and 0.742 per CHF respectively. The skewness and kurtosis of the Euro and many currencies, particularly in Europe, exhibit somewhat similar behaviour. The Danish Krone, Bulgarian Lev and Hungarian Forint mimic the behaviour of the Euro almost perfectly. This is evidence of pegging or a sign of convergence towards adopting the Euro; this is especially true for Denmark, an ERM II member, that is moving towards adopting the Euro.

Table 1.2 combines North America, Latin America and Caribbean currencies. The mean results indicate that the Pesos of Colombia and Chile reported the highest values per CHF, 2091.626 and 518.012 respectively. It is important to note that Latin America has over the recent past experienced crisis after crisis, both economic and political. These crises have inevitably had an effect on currency values and behaviour, with some countries facing pressures to devalue their currencies altogether, see for example Damill et al (2013). However, this is not the focus of this study. It can be said that the US Dollar, Bahamian Dollar and Canadian Dollar are relatively strong currencies in this region, reporting means of 0.899, 0.899 and 1.080 per CHF respectively, almost a 1:1 parity. The skewness and kurtosis of the Dollar currencies of USA, Bahamas, Barbados and the Florin of Aruba exhibit exactly the same behaviour, all with skewness and kurtosis values of -0.423 and 2.107 respectively. This is clear evidence of pegging, presumably to the US Dollar. Furthermore, it is important to observe that the US Dollar and Bahamian Dollar have exactly the same value per CHF, 0.899. From this result, it is obvious to conclude that the Bahamian Dollar maintains a strict 1:1 parity to the US Dollar.

Table 1.3 currencies are of Middle East, and South and East Asian countries, right from Saudi Arabia to Japan. Also included are the US Dollar descriptive statistics for comparison purposes. The mean figures show that the Korean Won and Japanese Yen reported the highest values per CHF, at 1005.998 and 94.442 respectively. For an advanced economy, Japan's exchange rate value may cause one to ask questions, it is rather out of range when compared with that of its peer countries. This may be attributed to its high level of indebtedness; Japan's debt is reported to be at about twice its annual GDP and its long-term sovereign debt rating has been cut by credit rating agencies due to this. It has the largest amount of debt on the globe. The Dinar of Bahrain and Rial of Oman are rather strong, reporting means of 0.338 and 0.346 per CHF respectively. Generally, Middle East currencies are stronger than the East Asian currencies, with mean values ranging from Bahrain's 0.338 to Israel's 3.541. Just like the Caribbean currencies in Table 1.2, the Bahraini Dinar, Omani Rial, Saudi Riyal, UAE Dirham and Qatari Rial exhibit exactly the same tail behaviour as the US Dollar, all with a skewness and kurtosis of -0.423 and 2.107 respectively. The Hong Kong Dollar too follows closely with only a slight and negligible difference in the kurtosis value at 2.110. Again, this is an indicator of perfect pegging, presumably to the US Dollar.

Table 1.4 presents the descriptive statistics of Oceania currencies. The mean statistics of these three currencies are rather low, ranging from the Australian Dollar's 1.153 to the Fijian Dollar at a value of 1.711 per CHF. The New Zealand Dollar reports the mid-point value at 1.339 per CHF. The skewness and kurtosis values seem rather neutral to all the 4 possible anchor currencies. Inference may not be drawn at this point.

Table 1.5 shows the descriptive statistics of African currencies. Also included are the Euro descriptive statistics for comparison purposes. The Shilling currencies of Uganda and Tanzania show the highest mean values at 2181.291 and 1318.461 per CHF respectively. The Tunisian Dinar and Ghanaian Cedi are perhaps the strongest currencies, reporting mean values of 1.458 and 1.602 per CHF respectively. Comparing the tail behaviour of the West African CFA to the possible anchor currencies, it is observable that the CFA's tail behaviour perfectly mimics that of the Euro, with a skewness and kurtosis of 0.462 and 1.691 respectively. For the rest of the currencies in the region, it is hard to draw any inference on possible pegging at this point.

Overall, the descriptive statistics do not reveal any evidence that currencies included in the sample tend to peg to the Japanese Yen and British Pound. The preferred currencies are the US Dollar and Euro.

1.4.2 Anchor currency regressions

In order to save on space, given the big number of countries in the sample, only a few of the regression results are presented. However, this is followed up with a geographical map that shows the preferred anchor currency for each country in the sample. Some of the results in the following discussion are taken in comparison to the descriptive statistics results, especially those from which some inference could be drawn.

Table 1.6 shows the regression results of 6 European countries. Based on the results presented, Armenia and Ukraine are the only European countries that attach a much higher weight to the US Dollar than the Euro. Bulgarian and Denmark attach extremely high weights to the Euro, 0.968 and 0.942 respectively. Poland and Sweden closely follow the Euro too, with statistically significant weights. Bulgaria and Ukraine prefer anchoring to the Euro and US Dollar respectively; the results of the other possible anchor currencies are not significant. As far as these results are concerned, there is evidence of pegging to the US Dollar and Euro in Europe, but not strictly perfect pegs. This, to a greater extent, is consistent with the skewness and kurtosis results discussed earlier.

Table 1.7 presents the regression results of the Americas. The results clearly indicate that the preferred anchor currency in this region is the US Dollar, with Mexico and Jamaica attaching weights of up to 0.850 and 0.973 respectively. Canada, on the other hand, attaches a moderate weight of 0.571 to the US Dollar, 0.363 to the Euro and 0.161 to the British Pound, with all weights significant to a certain extent. Argentina, Brazil, Chile and Colombia prefer the US Dollar only. Regarding possible perfect pegs, the regressions are able to clearly identify these currencies. The weights attached by Aruba, Bahamas and Barbados to the US Dollar are exactly equal to 1. This is strong evidence of perfect pegging, consistent with the skewness and kurtosis results reported in Table 1.2 that showed these statistics were exactly equal to those of the US Dollar. This is essentially a US Dollar dominated region.

Table 1.8 presents the regression results of Asia. Again, one can very fast see the influence of the US Dollar in this region, with Hong Kong and Philippines attaching weights of 0.990 and 0.844 to the US Dollar respectively. The US Dollar-weights of the other countries in the region are not far from the Hong Kong and Philippines benchmark. There are also basket currency anchor preferences too, for instance, Singapore attaches weights of 0.546, 0.179, 0.0699 and 0.109 to the US Dollar, Euro, British Pound and Japanese Yen respectively. South Korea and Thailand too prefer basket currency anchoring. Extending on from the descriptive statistics results presented in Table 1.3, there is strong evidence of perfect pegs to the US Dollar by Bahrain, Oman, Saudi Arabia, UAE and Qatar. These countries report regression coefficients exactly equal to 1 for the US Dollar anchor, which is very much consistent with the skewness and kurtosis tail behaviour results.

Table 1.9 is a presentation of the regression results of Oceania. The Euro, as an anchor, plays a significant role in this region, with Australia and New Zealand reporting weights of 0.638 and 0.424 respectively. The US Dollar and British Pound are not far behind though. There is no significance reported for the Japanese Yen but there is noticeable importance of the British Pound as an anchor in this region. The coefficients attached to the three preferred anchors are also moderate in value. Unlike some regions where countries prefer a single anchor currency, the countries in this region prefer anchoring to a currency basket.

Table 1.10 reports the regression results of Africa. The US Dollar is the preferred anchor for Ethiopia, Ghana, Nigeria and Uganda, reporting significant weights of 0.947, 1.537, 0.855 and 0.807 respectively, with Ethiopia and Ghana solely preferring the US Dollar to a currency basket. African periphery countries of Morocco and Tunisia that are close to Europe attach a higher weight to the Euro than other possible anchors, at 0.740 and 0.587 respectively. South Africa too is inclined towards the Euro as an anchor. The only country in the entire sample that has a preference for the British Pound as a number one anchor currency is found in this region, Seychelles, attaching a significant weight of 0.655. The Japanese Yen does not report any significant degree of importance in this region. As earlier reported in Table 1.5, the West African CFA exhibited the exact tail behaviour as the Euro, and this result is further supported in the regression results with a weight exactly equal to 1 in favour of the Euro. The strict pegging result is therefore confirmed.

In general, the Euro and US Dollar are the dominant anchor currencies, however, many countries prefer basket currency anchoring, spreading the risk in different proportions among the major anchor currencies. Figure 1.5 shows a summary of country preference for the two preferred anchor currencies across the globe. The British Pound and Japanese Yen are rather unpopular.

These regression results are robust and remain more or less the same when the numeraire is changed to the New Zealand Dollar.

1.4.3 Markov regime switching model

To the results of the 2-state/regime Markov-switching AR (2) model now. For all the eight currencies, each model is estimated separately, and the Akaike information criteria showed that 2 lags and 2 states were appropriate for each currency. Even after deciding to go against the Akaike information criteria on the appropriate number of lags and states, a global maximum is not reached, and so the specification remains appropriate. The maximum likelihood estimates are presented in Table 1.11 along with some diagnostic tests on the residuals of the different currency models.

The selected model allows the intercept, μ, and variance, σ^2, to vary across the two regimes, which is realistic for exchange rate behaviour. The point estimates indicate that the first regime for the British Pound, Euro and Swiss Franc are associated with a declining exchange rate (appreciation) and an increasing exchange rate (depreciation) for the other five currencies. The second regime is also characterized by a declining exchange rate for the British Pound and Euro. For cases where both states have the same sign, the point estimate magnitude will indicate which regime has a greater effect. For instance, in the case to the British Pound, the first state is characterized by a greater decline in the exchange rate than the second state, so the states/regimes are being decomposed into sub-regimes. Maximum likelihood estimates associated state 1 with a 0.473% monthly fall in the British Pound, 0.237% fall in the Euro, 0.115% fall in the Swiss Franc, 0.084% rise in the Canadian Dollar, 5.437% rise in the Hungarian Forint, 1.324% rise in the Romanian Leu, 6.999% rise in the Korean Won and 2.542% rise in the South African Rand. State 2 indicated a 0.445% fall in the British Pound, 0.223% fall in the Euro, 0.006% rise in the Swiss Franc, 0.180% rise in the Canadian Dollar, 5.455% rise in the Hungarian Forint, 1.345% rise in the Romanian Leu, 7.034% rise in the Korean Won and 2.685% rise in the South African Rand. The economic interpretation is much more straight forward and makes more sense if the regime dependent intercepts are of opposite signs, this important result is only captured by the Swiss Franc. Engel and Hamilton (1990), while investigating long swings[25] in the US Dollar stated that long swings will exist if; μ_1 and μ_2 are opposite in sign, with p_{11} and p_{22} large or close to 1. The transition probabilities are all close to 1, indicating that there is a high probability that the exchange rate stays in one regime, hence, fewer switches. This probability can be interpreted as a measure of regime is persistence. This persistence is not permanent since the probabilities, $p_{11}, p_{22} < 1$, a switch eventually occurs. Probability estimates of p_{11} range from 0.925 to 0.996 while p_{22} range from 0.871 to 0.996. The expected duration of each regime is also reported, the Swiss Franc and Canadian Dollar show the highest duration in specific regimes; the Swiss Franc will take an average of 255.289 months in an appreciating regime and 216.655 months in a depreciating regime while the Canadian Dollar will spend an average of 221.689 months in state 1 and 251.205 months in state 2. From this information, it is viable to conclude that the Swiss Franc and Canadian

[25] Engel and Hamilton (1990) define long swings as a situation in which the value of a currency increases in one direction over long periods of time.

Dollar may be more stable than the other currencies that spend minimal time in either regime, shifting more frequently. The Romanian Leu spends more or less an even amount of time in either of the two states, 60.718 and 59.424 months in state 1 and state 2 respectively, another sign of currency stability. The Korean Won, Hungarian Forint and South African Rand report the widest spread between the months spent in the two competing states.

The diagnostic tests show that the residuals are not normally distributed for all eight currencies, which is a common occurrence. Autocorrelation results are generally good, except for the Korean Won, which shows presence of autocorrelation. ARCH tests detect the presence of ARCH effects in the British Pound, Hungarian Forint and the Korean Won data; an indicator that GARCH models may also be used to model the behaviour of these specific currencies.

From observation of the filtered[26], smooth[27] and specifically one-step[28] probabilities presented alongside the exchange rate series, one can conclude that the MS-AR (2) model performs quite well, and is able to identify the important turning points in the evolution of most of the currencies, especially the 2007/2008 financial crisis. One can draw inference by observing the appreciation and depreciation regimes of the respective currencies along with the regime probabilities of choice.

Given that the one-step, filtered and smooth probabilities ideally identify the two competing regimes as appreciating and depreciating ones, it becomes difficult to easily interpret the findings, as the mean (μ) of all the currencies, with the exception of the Swiss Franc, are of the same sign in the different states as shown in Table 1.11. That, notwithstanding, the graphical results can still be interpreted. It is the usual assumption that there will be a regime switch if the probability is greater than 0.5. The model is therefore quite intuitive.

From Figure 1.6, one-step probability models are able to identify 4 depreciation periods of the British Pound and 11 depreciation periods for the Euro. Figure 1.7 shows that the Swiss Franc model clearly captures 2 depreciation periods, with one clearly lasting much longer than the other, almost 99 months. The Canadian Dollar results identify 5 depreciation regimes. From Figure 1.8, one can observe that the one-step probabilities capture at least 5 Hungarian Forint depreciation periods and 2 South African Rand depreciation periods. Romanian Leu results show 5 depreciation periods while the South Korean Won shows 2 depreciation periods, these

[26] Estimates probabilities of the states at each time period using previous and contemporaneous data by using the nonlinear filter.
[27] Estimates probabilities of the states at each time period using all sample data by using the smoothing algorithm.
[28] Estimates probabilities of the states at each time period using previous information on the dependent variable.

are shown in Figure 1.9. From these results, it is evident that the Euro currency switches the most while the Swiss Franc, South African Rand and the South Korean Won switch the least. Since these are probabilities, then the other side of the coin, appreciation, can simply be seen by flipping the one-step probability graphs over. Of course, the model is subject to weaknesses that can easily be observed from the graphical results as some depreciation regimes identified by the probabilities may include periods of appreciation. This is noticeable by comparing the one-step probability graphs to the exchange rate time series as demonstrated in Figure 1.6, Figure 1.7, Figure 1.8 and Figure 1.9. Consider, for example, the British Pound and Euro series, the shaded regions (regimes) may capture depreciations and appreciations. The filtered probabilities for both depreciation and appreciation regimes are shown in Figure 1.10 and Figure 1.11. Smooth probabilities are also presented in Figure 1.12 and Figure 1.13. The smooth probabilities of the Canadian Dollar differ a lot from the one-step and filtered probabilities. It is difficult to explain in detail why this is the case, but it could be due to the fact that different types of information are used to compute these 3 forms of probabilities.

The values of the two competing exchange rate regimes, for each currency, are decomposed and presented in the right panel of Figure 1.14, Figure 1.15, Figure 1.16 and Figure 1.17. The left panel simply shows the log exchange rate values with no competing regimes.

1.5 Conclusion

This study investigated exchange rate behaviour towards major global anchor currencies and made use of the Markov-switching autoregressive process to decompose exchange rate behaviour into possible states/regimes. There seems to be a major preference for particular anchor currencies within different global regions, re-enforcing the findings of Eichengreen (2011), with the Euro being predominantly preferred in Europe, some parts of Africa and Oceania. The US Dollar is preferred in the rest of the world, with strictly pegged regimes in the Gulf and the Middle East region, and the Caribbean, whose currencies exactly track the US Dollar, essentially eliminating volatility against this particular anchor currency. There is also evidence of some authorities preferring a 1:1[29] parity with their anchor currency of choice. From the results, it is evident that currencies like the British Pound and Japanese Yen have lost popularity over the years, especially with the emergence of the Euro and the unity that comes with it. Onto the Markov-switching results, the model was able to decompose the currency behaviour of 8 currencies into appreciating and depreciating regimes, and identified the key turning points in the exchange rate series, especially the 2008/2009 crisis period. However, the Markov model was not able to capture the Engel and Hamilton (1990) long swings phenomenon, with the exception of the Swiss Franc.

[29] This includes currencies like the Bahamian and Barbadian Dollars that clearly indicate a 1:1 parity against the US Dollar.

Table 1.1: Time series moment summary statistics - Europe

	Mean	Std. Dev	Min	Max	Skewness	Kurtosis
Albanian Lek	98.865	18.130	72.949	135.665	0.290	1.633
Armenian Dram	397.578	71.817	256.414	516.295	-0.141	1.780
British Pound	0.571	0.139	0.380	0.821	0.148	1.470
Bulgarian Lev	1.451	0.217	1.170	1.887	0.463	1.692
Czech Koruna	20.770	2.668	14.538	26.454	-0.084	2.393
Danish Krone	5.527	0.826	4.460	7.206	0.465	1.693
Euro	0.742	0.111	0.598	0.964	0.462	1.691
Hungarian Forint	207.866	49.635	143.297	298.616	0.466	1.615
Icelandic Krona	92.158	34.769	44.122	146.566	-0.046	1.247
Norwegian Krone	6.191	1.266	4.606	8.768	0.895	2.325
Polish Zloty	3.049	0.570	2.014	4.125	0.222	1.801
Romanian Leu	2.938	0.881	1.145	4.283	-0.075	1.807
Russian Ruble	33.894	16.805	15.647	77.668	1.052	2.694
Swedish Krona	6.911	1.136	5.225	9.255	0.573	2.077
Turkish Lira	1.815	1.133	0.344	6.550	1.458	5.286
Ukrainian Hryvnia	10.140	8.587	3.027	29.570	1.193	2.800

Table 1.2: Time series moment summary statistics - Americas

	Mean	Std. Dev	Min	Max	Skewness	Kurtosis
Argentine Peso	6.282	7.083	0.560	39.707	2.359	9.287
Brazilian Real	2.230	0.764	1.046	4.252	0.766	2.727
Canadian Dollar	1.080	0.156	0.830	1.411	0.505	2.079
Chilean Peso	518.012	104.090	303.621	716.918	0.111	2.295
Colombian Peso	2091.626	535.409	1175.520	3374.476	0.656	2.724
Jamaican Dollar	78.955	36.413	24.511	140.384	0.068	1.598
Mexican Peso	11.925	4.452	5.098	21.191	0.294	2.019
US Dollar	0.899	0.170	0.561	1.281	-0.423	2.107
Aruban Florin	1.610	0.305	1.003	2.292	-0.423	2.107
Bahamian Dollar	0.899	0.170	0.561	1.281	-0.423	2.107
Barbadian Dollar	1.798	0.341	1.121	2.561	-0.423	2.107

Table 1.3: Time series moment summary statistics - Asia

	Mean	Std. Dev	Min	Max	Skewness	Kurtosis
Chinese Renminbi	6.356	0.664	4.639	8.208	-1.000	3.733
Hong Kong Dollar	6.994	1.318	4.371	9.985	-0.423	2.110
Indian Rupee	47.486	15.142	25.592	74.610	0.263	1.520
Israeli new Shekel	3.541	0.468	2.299	4.538	-1.108	3.814
Japanese Yen	94.442	15.964	60.759	132.751	0.189	2.396
Korean Won	1005.998	190.607	635.803	1375.504	-0.308	1.565
Malaysian Ringgit	3.241	0.617	2.130	4.466	0.264	2.388
Philippine Peso	42.934	7.053	24.332	55.731	-0.802	3.214
Singapore Dollar	1.306	0.115	0.983	1.548	-1.195	3.816
Thai Bhat	31.587	3.319	22.635	38.266	-0.621	3.015
Bahraini Dinar	0.338	0.064	0.211	0.482	-0.423	2.107
Omani Rial	0.346	0.065	0.216	0.492	-0.423	2.107
Saudi Riyal	3.372	0.638	2.102	4.803	-0.423	2.107
UAE Dirham	3.302	0.625	2.058	4.703	-0.423	2.107
Qatari Rial	3.273	0.620	2.040	4.662	-0.423	2.107
US Dollar	0.899	0.170	0.561	1.281	-0.423	2.107

Table 1.4: Time series moment summary statistics - Oceania

	Mean	Std. Dev	Min	Max	Skewness	Kurtosis
Australian Dollar	1.153	0.131	0.947	1.457	0.602	2.109
Fijian Dollar	1.711	0.339	1.233	2.239	0.072	1.287
New Zealand Dollar	1.339	0.120	1.053	1.666	-0.027	2.613

Table 1.5: Time series moment summary statistics - Africa

	Mean	Std. Dev	Min	Max	Skewness	Kurtosis
Algerian Dinar	73.946	22.749	43.485	121.904	0.605	2.131
Egyptian Pound	6.779	4.422	1.983	18.867	1.720	5.074
Eritrean Nakfa	13.346	3.396	5.402	19.690	-0.860	2.825
Ethiopian Birr	13.443	7.475	4.661	29.147	0.365	1.606
Ghanaian Cedi	1.602	1.551	0.019	4.915	0.702	2.145
Kenyan Shilling	75.875	21.649	44.068	118.828	0.135	1.503
Moroccan Dirham	8.107	1.283	6.219	10.491	0.279	1.489
Nigerian Naira	151.443	74.377	57.420	327.476	1.035	3.196
Rwandan Franc	560.559	192.346	217.718	908.699	-0.001	1.935
Seychellois Rupee	9.312	4.663	3.169	15.654	-0.143	1.190
South African Rand	8.424	3.406	3.857	16.251	0.634	2.078
Tanzanian Shilling	1318.461	580.589	451.592	2400.617	0.257	1.810
Tunisian Dinar	1.458	0.561	0.784	2.997	0.795	2.560
Ugandan Shilling	2181.291	938.240	909.642	3926.727	0.405	1.716
West African CFA	486.682	72.638	392.529	632.646	0.462	1.691
Zambian Kwacha	5.263	2.781	1.656	12.399	0.918	2.763
Euro	0.742	0.111	0.598	0.964	0.462	1.691

Table 1.6: FX regression results - Europe

	Armenia	Bulgaria	Denmark	Poland	Sweden	Ukraine
USD	0.764***	-0.000951	0.00879	0.0271	-0.0183	0.876***
	(0.0738)	(0.00944)	(0.0120)	(0.0818)	(0.0531)	(0.164)
EUR	-0.118	0.968***	0.942***	0.892***	0.796***	0.0713
	(0.0989)	(0.0127)	(0.0161)	(0.110)	(0.0712)	(0.220)
GBP	0.215**	0.0184	0.0240*	0.156	0.182***	0.274
	(0.0741)	(0.00947)	(0.0120)	(0.0821)	(0.0533)	(0.164)
JPY	0.171**	0.000245	-0.00310	-0.158*	-0.0197	-0.0616
	(0.0598)	(0.00765)	(0.00972)	(0.0664)	(0.0431)	(0.133)
N	228	228	228	228	228	228

Standard errors in parentheses.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ significance level.

The table shows the weights that country monetary authorities attach to the major global anchor currencies. For instance, Bulgarian Lev authorities attach a high and significant weight of 0.968 to the Euro. This can be interpreted as, a 1% change in the value of the Euro leads to a 0.968% change in the value of the Bulgarian Lev.

Table 1.7: FX regression results - Americas

	Argentina	Brazil	Canada	Chile	Colombia	Jamaica	Mexico
USD	0.775^{***}	0.636^{***}	0.571^{***}	0.532^{***}	0.586^{***}	0.973^{***}	0.850^{***}
	(0.191)	(0.146)	(0.0683)	(0.0965)	(0.114)	(0.0501)	(0.0939)
EUR	-0.0224	0.306	0.363^{***}	0.203	0.278	-0.0357	0.208
	(0.256)	(0.196)	(0.0915)	(0.129)	(0.152)	(0.0671)	(0.126)
GBP	0.306	0.170	0.161^{*}	0.186	0.198	0.163^{**}	0.218^{*}
	(0.192)	(0.147)	(0.0685)	(0.0969)	(0.114)	(0.0503)	(0.0942)
JPY	0.101	-0.213	-0.0342	-0.00316	-0.0257	-0.0208	-0.245^{**}
	(0.155)	(0.118)	(0.0554)	(0.0782)	(0.0922)	(0.0406)	(0.0761)
N	228	228	228	228	228	228	228

Standard errors in parentheses.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ significance level.

The table shows the weights that country monetary authorities attach to the major global anchor currencies. For instance, Brazilian Real authorities attach a significant weight of 0.636 to the US Dollar. This can be interpreted as, a 1% change in the value of the US Dollar leads to a 0.636% change in the value of the Brazilian Real.

Table 1.8: FX regression results - Asia

	China	Hong Kong	Korea	Oman	Philippines	Singapore	Thailand
USD	0.913***	0.990***	0.461***	1.000	0.844***	0.546***	0.599***
	(0.0241)	(0.00424)	(0.0815)	(.)	(0.0576)	(0.0333)	(0.0469)
EUR	0.00170	-0.00147	0.218*	-2.24e-16	0.157*	0.179***	0.106
	(0.0323)	(0.00569)	(0.109)	(.)	(0.0772)	(0.0447)	(0.0629)
GBP	0.0331	-0.000548	0.249**	-2.68e-16	0.00486	0.0699*	0.0582
	(0.0242)	(0.00426)	(0.0818)	(.)	(0.0578)	(0.0335)	(0.0471)
JPY	0.0192	0.00620	0.0351	-3.00e-16	0.00156	0.109***	0.123**
	(0.0196)	(0.00344)	(0.0661)	(.)	(0.0467)	(0.0270)	(0.0381)
N	228	228	228	228	228	228	228

Standard errors in parentheses.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ significance level.

The table shows the weights that country monetary authorities attach to the major global anchor currencies. For instance, Korean Won authorities attach a significant weight of 0.249 to the British Pound. This can be interpreted as, a 1% change in the value of the British Pound leads to a 0.249% change in the value of the Korean Won.

Table 1.9: FX regression results - Oceania

	Australia	Fiji	New Zealand
USD	0.201*	0.498***	0.234*
	(0.0902)	(0.0567)	(0.0936)
EUR	0.638***	0.423***	0.424***
	(0.121)	(0.0761)	(0.126)
GBP	0.219*	0.0181	0.252**
	(0.0905)	(0.0571)	(0.0940)
JPY	-0.0470	0.0290	-0.100
	(0.0731)	(0.0460)	(0.0759)
N	228	227	228

Standard errors in parentheses.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ significance level.

The table shows the weights that country monetary authorities attach to the major global anchor currencies. For instance, Australian Dollar authorities attach a significant weight of 0.638 to the Euro. This can be interpreted as, a 1% change in the value of the Euro leads to a 0.638% change in the value of the Australian Dollar.

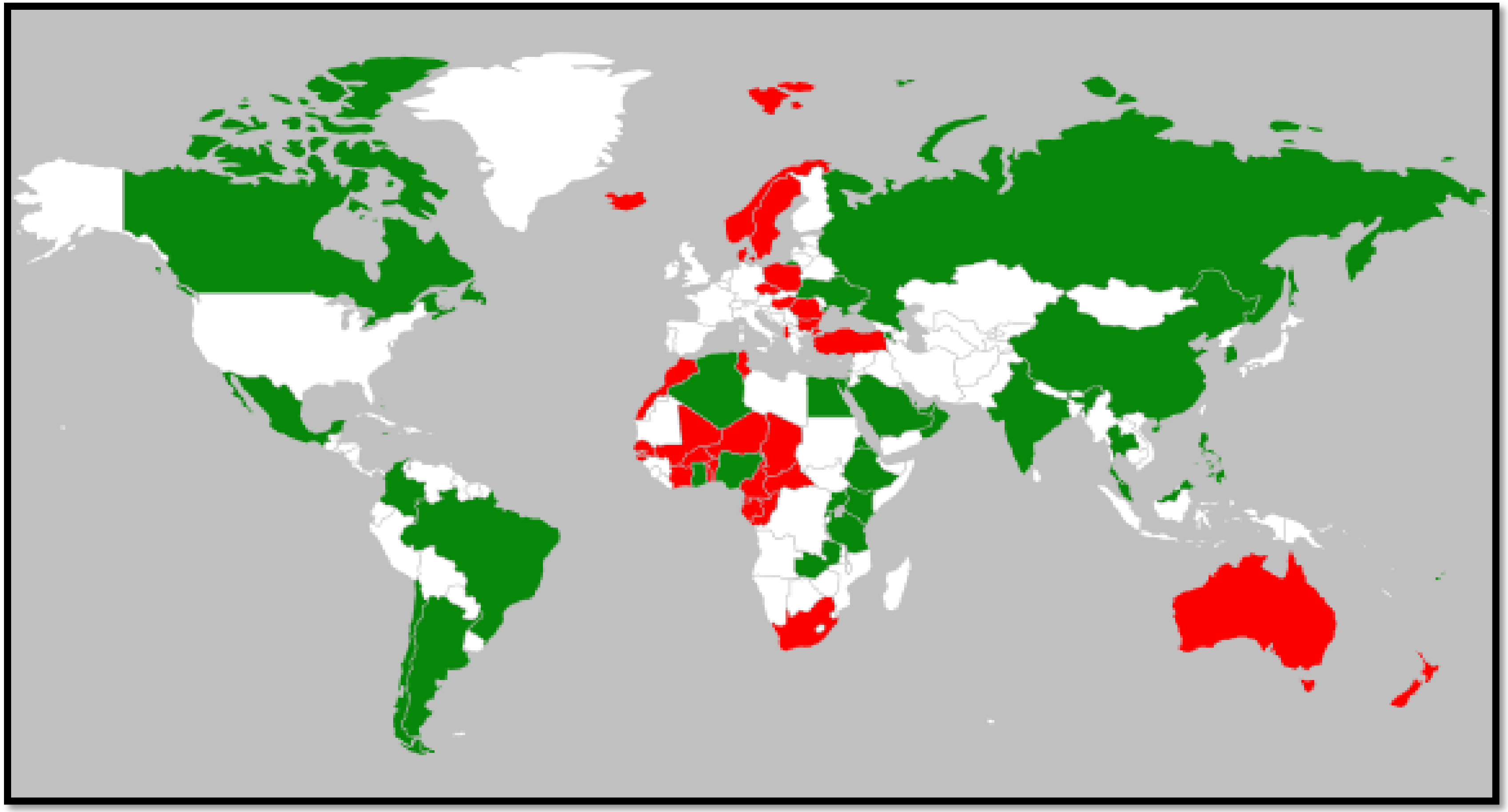
Table 1.10: FX regression results - Africa

	Ethiopia	Ghana	Morocco	Nigeria	South Africa	Seychelles	Tunisia	Uganda
USD	0.947***	1.537**	0.230***	0.855***	0.223	0.474**	0.267***	0.807***
	(0.0615)	(0.497)	(0.0229)	(0.0997)	(0.142)	(0.179)	(0.0339)	(0.0874)
EUR	0.0885	-0.0716	0.740***	-0.0917	0.391*	-0.174	0.587***	0.251*
	(0.0824)	(0.667)	(0.0307)	(0.134)	(0.191)	(0.240)	(0.0455)	(0.117)
GBP	0.106	-0.141	0.00634	0.360***	0.240	0.655***	0.0512	0.187*
	(0.0619)	(0.500)	(0.0230)	(0.100)	(0.143)	(0.180)	(0.0340)	(0.0877)
JPY	-0.00579	-0.377	0.00798	-0.0481	0.000960	-0.267	0.0201	-0.0593
	(0.0498)	(0.403)	(0.0185)	(0.0809)	(0.115)	(0.145)	(0.0275)	(0.0709)
N	225	225	228	228	228	228	228	228

Standard errors in parentheses.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ significance level.

The table shows the weights that country monetary authorities attach to the major global anchor currencies. For instance, Ugandan Shilling authorities attach a high and significant weight of 0.807 to the US Dollar. This can be interpreted as, a 1% change in the value of the US Dollar leads to a 0.807% change in the value of the Ugandan Shilling.

Figure 1.5: Anchor currencies



USD

EUR

Table 1.11: Markov-switching results

	British Pound	Euro	Swiss Franc	Canadian Dollar	Hungarian Forint	Romanian Leu	Korean Won	South African Rand
μ_1	-0.473	-0.237	-0.115	0.084	5.437	1.324	6.999	2.542
	(0.140)	(0.079)	(0.128)	(0.122)	(0.189)	(0.051)	(0.041)	(0.484)
μ_2	-0.445	-0.223	0.006	0.180	5.455	1.345	7.034	2.685
	(0.141)	(0.076)	(0.126)	(0.121)	(0.187)	(0.049)	(0.045)	(0.485)
Φ_1	1.165	1.300	1.131	1.290	1.208	1.379	1.261	1.232
	(0.067)	(0.069)	(0.065)	(0.062)	(0.064)	(0.061)	(0.062)	(0.066)
Φ_2	-0.174	-0.319	-0.142	-0.300	-0.218	-0.406	-0.289	-0.239
	(0.068)	(0.068)	(0.064)	(0.062)	(0.066)	(0.059)	(0.062)	(0.066)
σ_1^2	0.018	0.030	0.025	0.017	0.046	0.028	0.017	0.033
	(0.001)	(0.005)	(0.002)	(0.001)	(0.006)	(0.002)	(0.0009)	(0.002)
σ_2^2	0.035	0.017	0.016	0.018	0.024	0.011	0.055	0.029
	(0.006)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.013)	(0.005)
p_{11}	0.983	0.925	0.996	0.995	0.971	0.984	0.995	0.991
p_{22}	0.871	0.968	0.995	0.996	0.993	0.983	0.894	0.878
$ED(1)$	57.973	13.297	255.289	221.689	34.799	60.718	186.141	111.414
$ED(2)$	7.763	31.197	216.655	251.205	140.586	59.424	9.478	8.169
$Normality$[30]	[0.000]	[0.034]	[0.000]	[0.000]	[0.000]	[0.001]	[0.000]	[0.000]
$Autocorrelation$[31]	[0.427]	[0.328]	[0.757]	[0.403]	[0.623]	[0.318]	[0.001]	[0.479]
$ARCH(1)$[32]	[0.043]	[0.597]	[0.578]	[0.791]	[0.016]	[0.092]	[0.002]	[0.848]

Standard errors in parentheses and p-values in square brackets.

[30] Shapiro-Wilk, W test, H_o: normality.
[31] Breusch-Godfrey, LM test, H_o: no serial correlation.
[32] ARCH, LM test, H_o: no ARCH effects.

Figure 1.6: Exchange rates and one-step probabilities

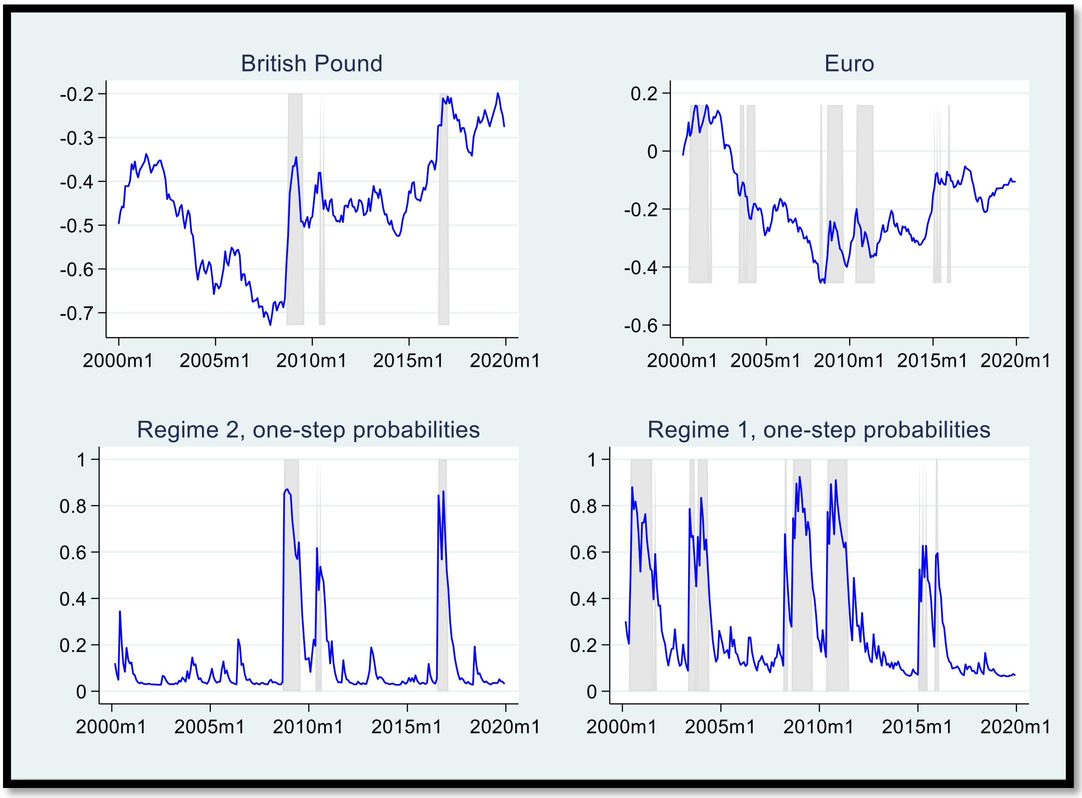


Figure 1.7: Exchange rates and one-step probabilities

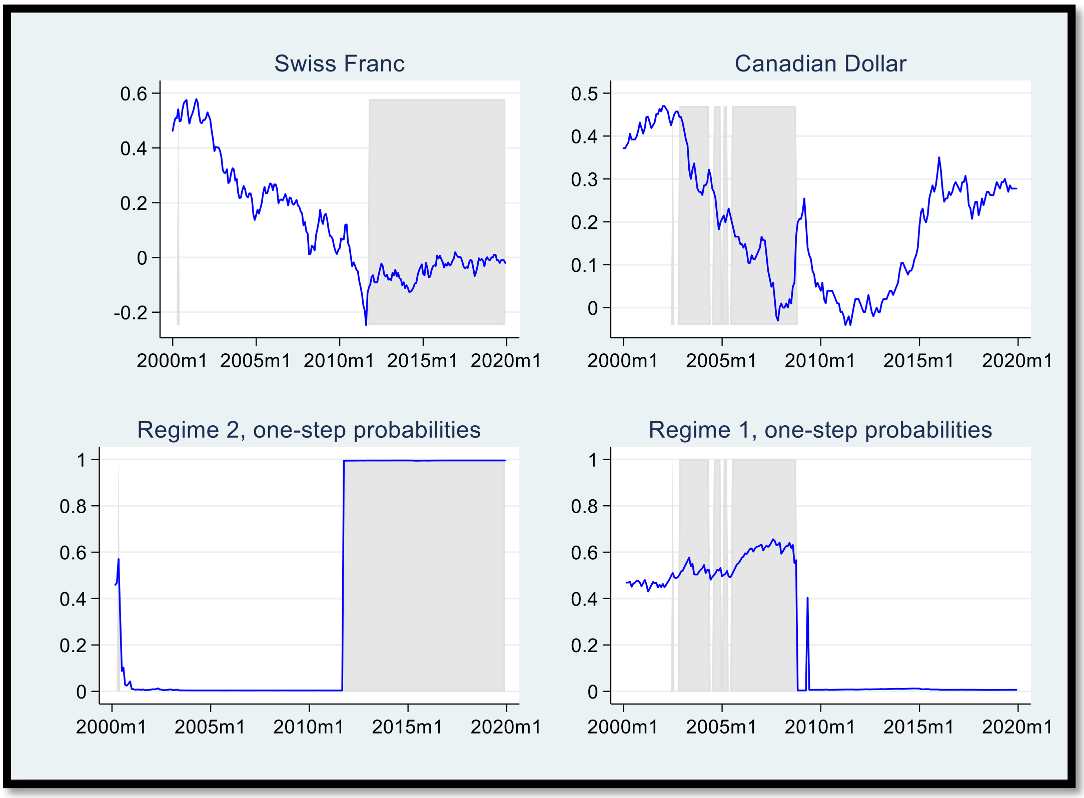


Figure 1.8: Exchange rates and one-step probabilities

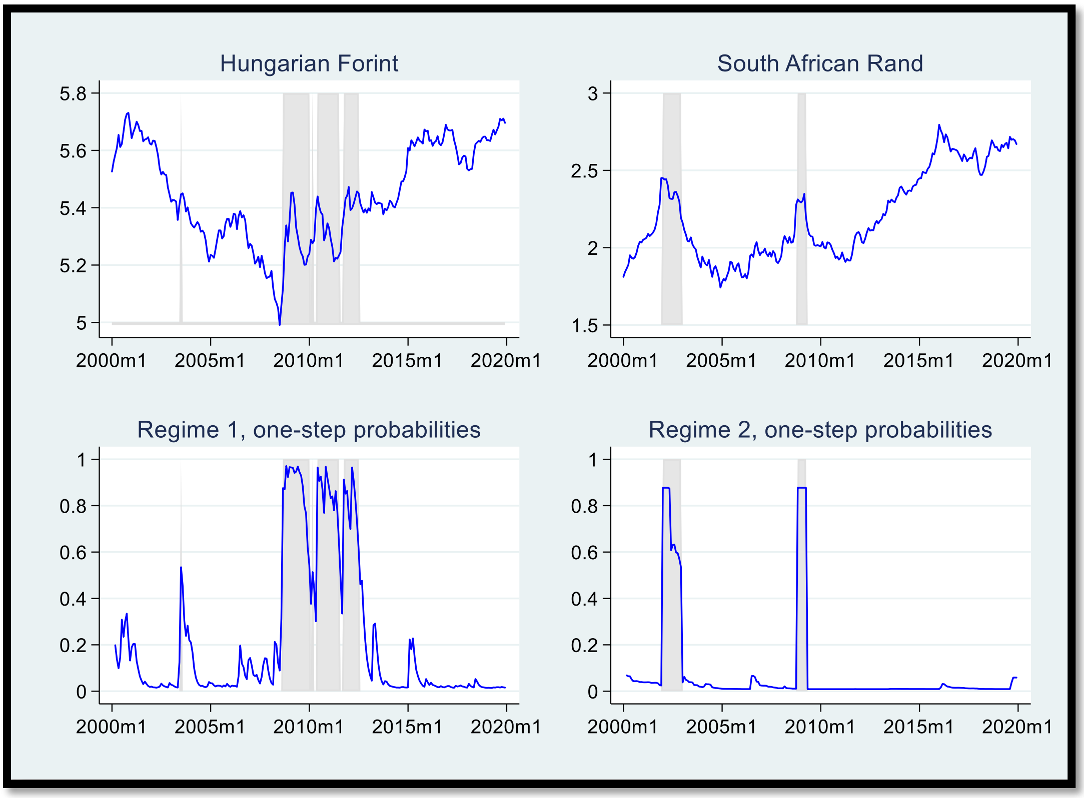


Figure 1.9: Exchange rates and one-step probabilities

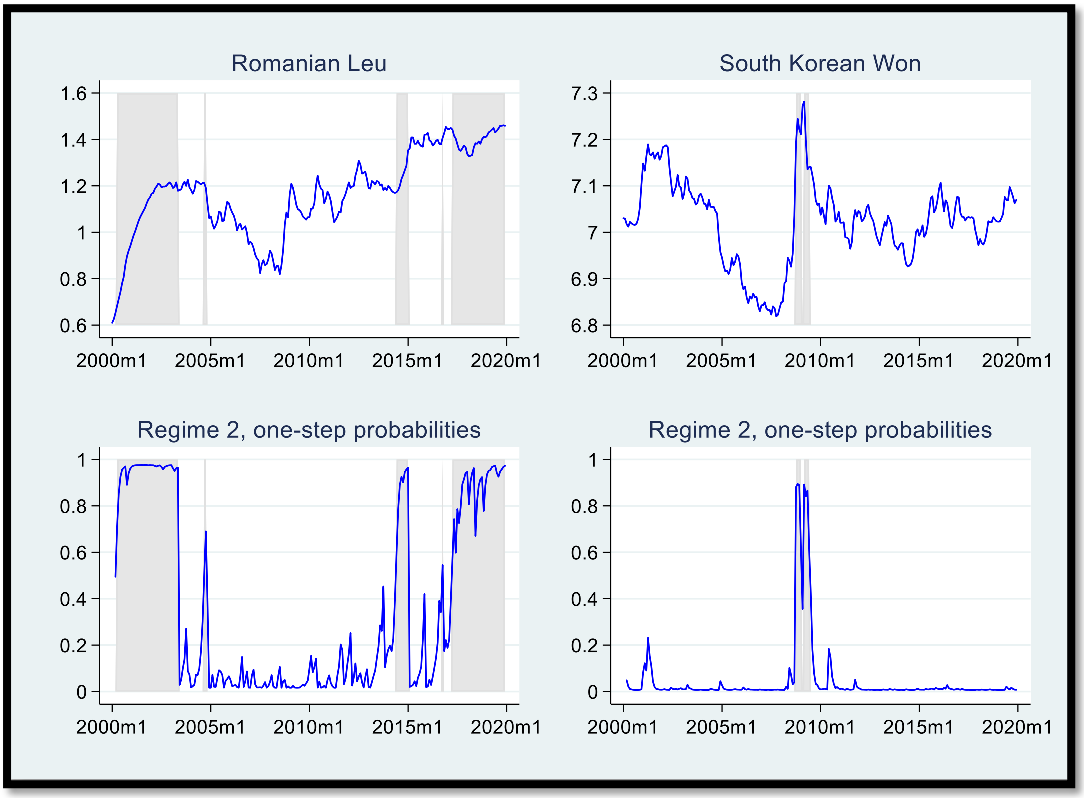


Figure 1.10: Filtered probabilities

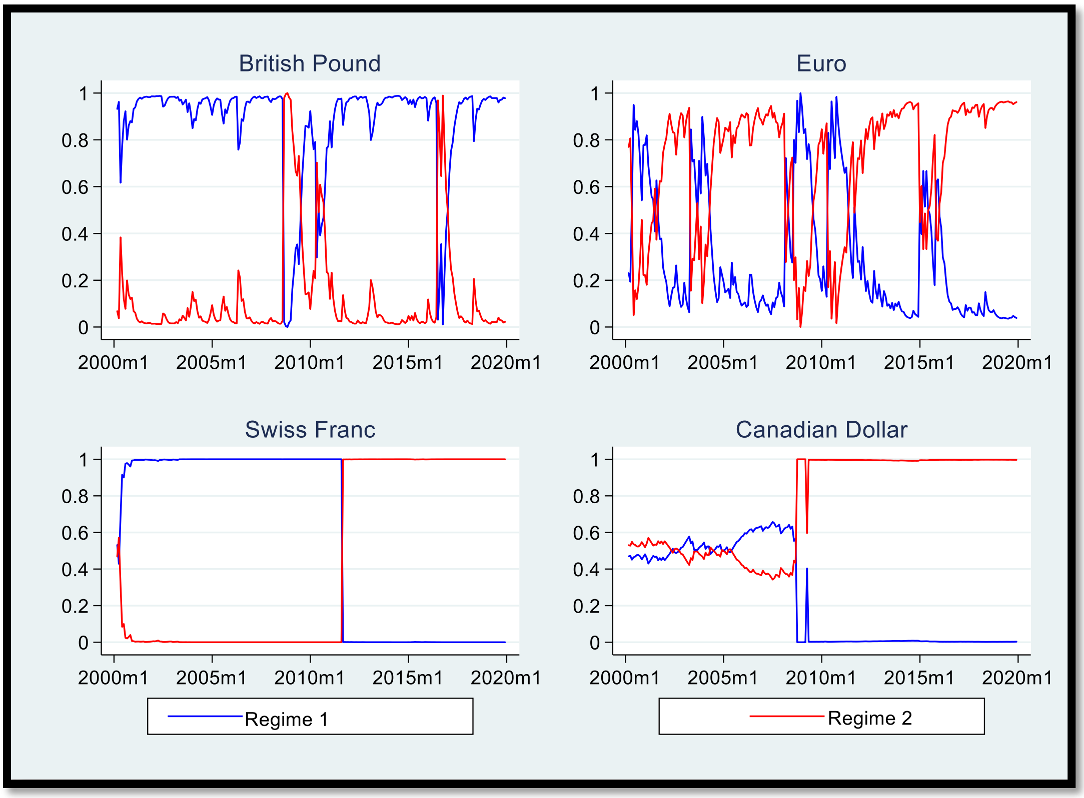


Figure 1.11: Filtered probabilities

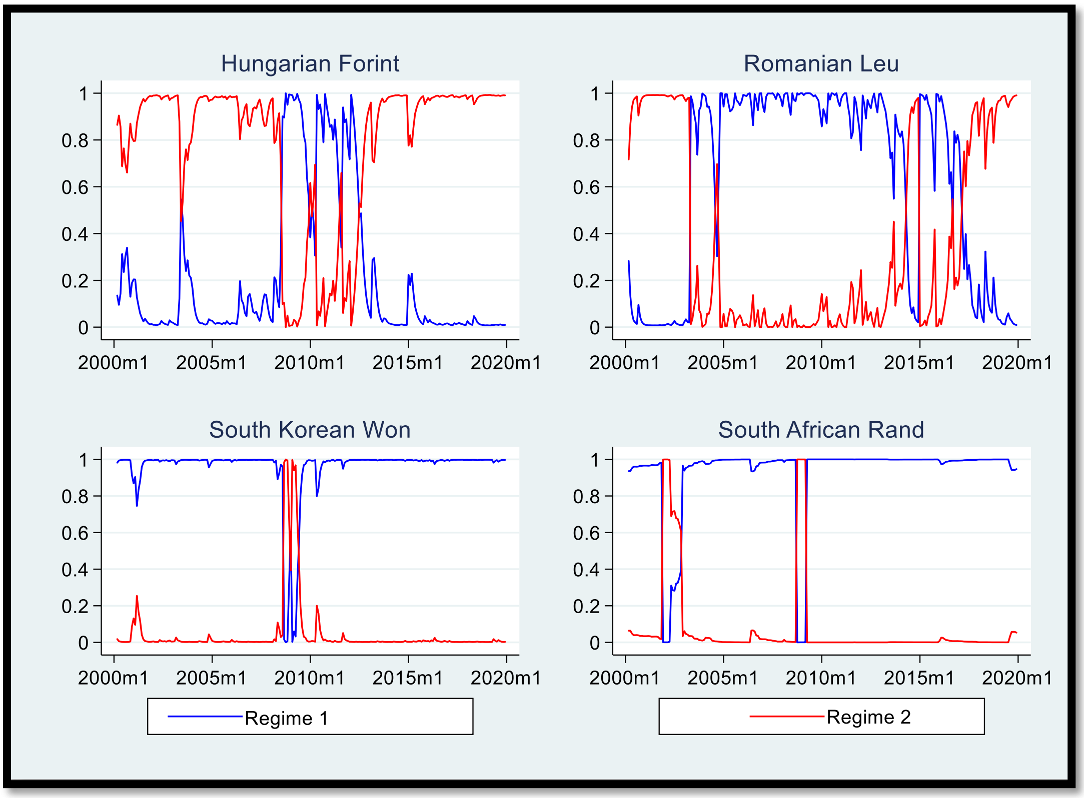


Figure 1.12: Smooth probabilities

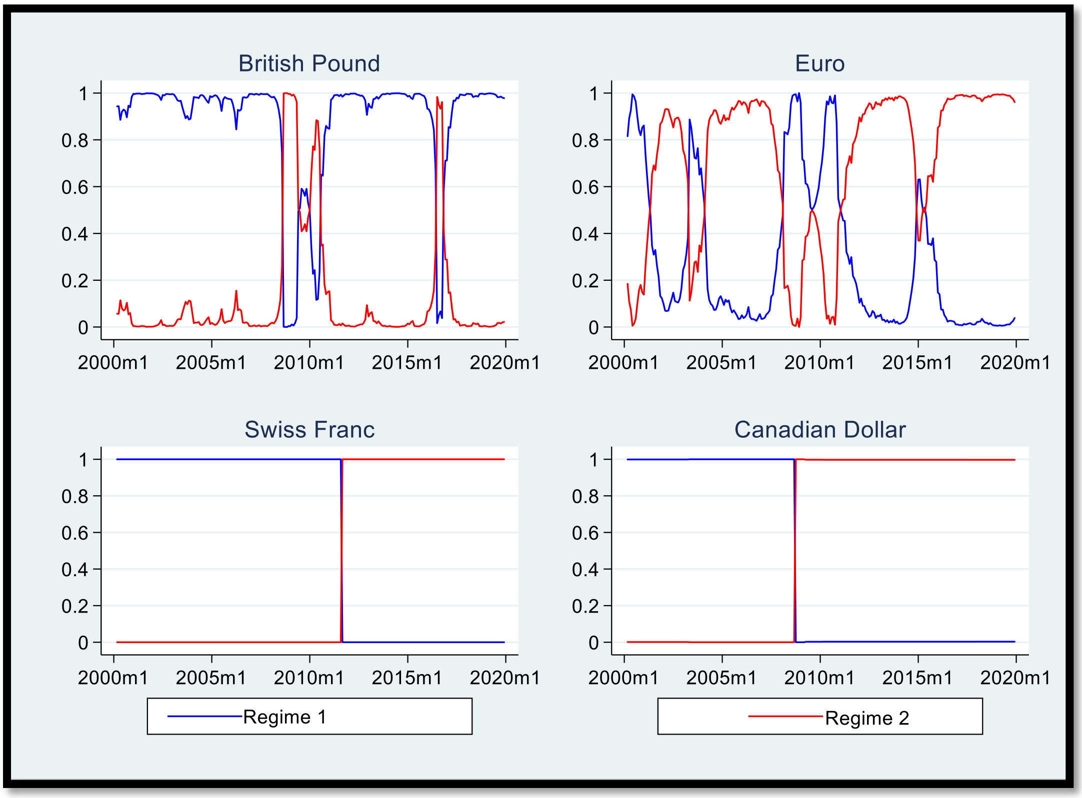


Figure 1.13: Smooth probabilities

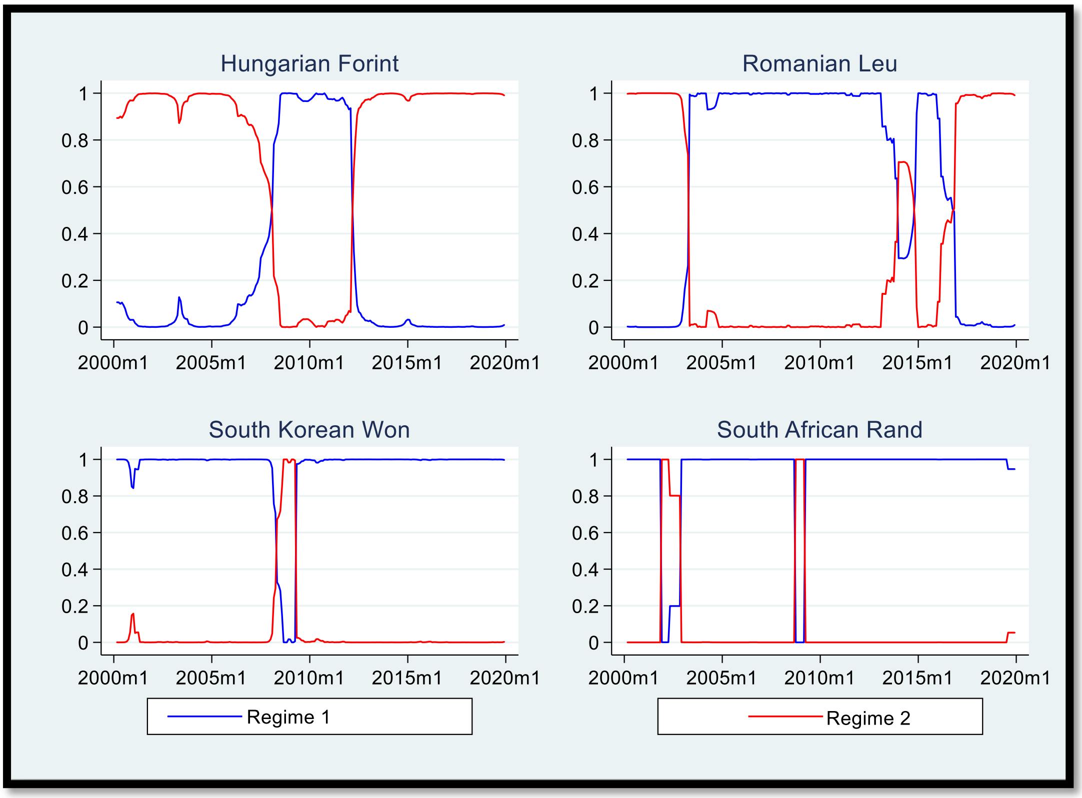


Figure 1.14: Regime decomposition

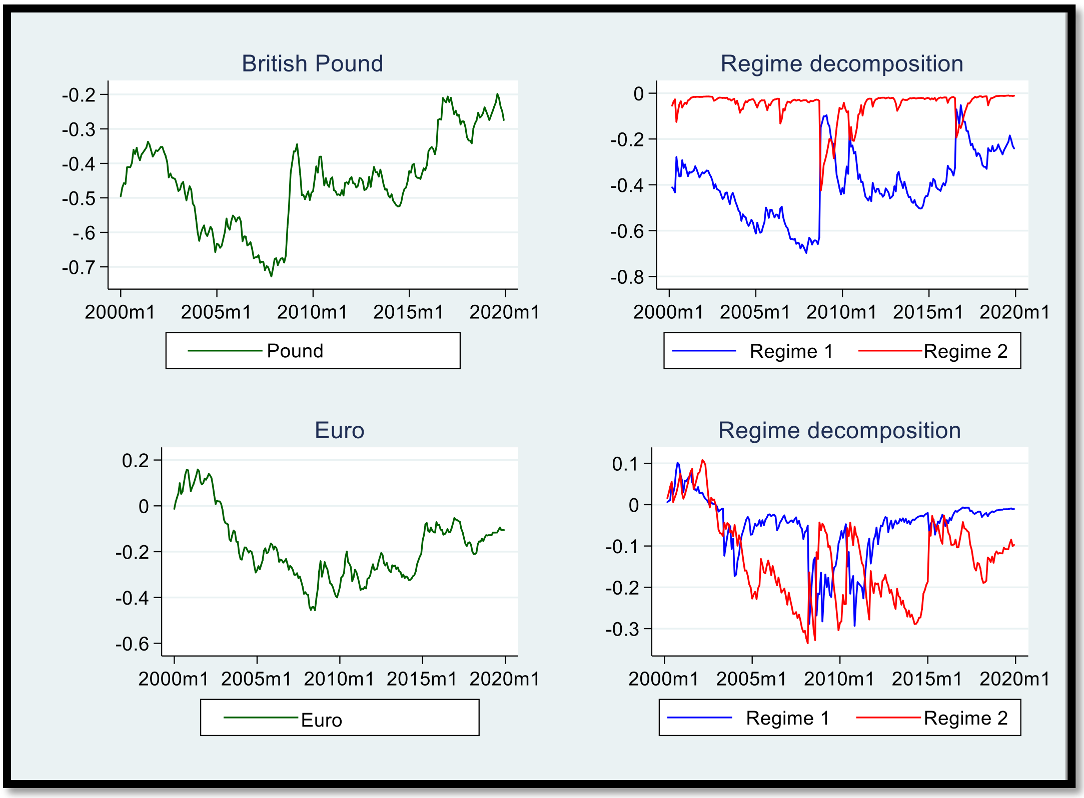


Figure 1.15: Regime decomposition

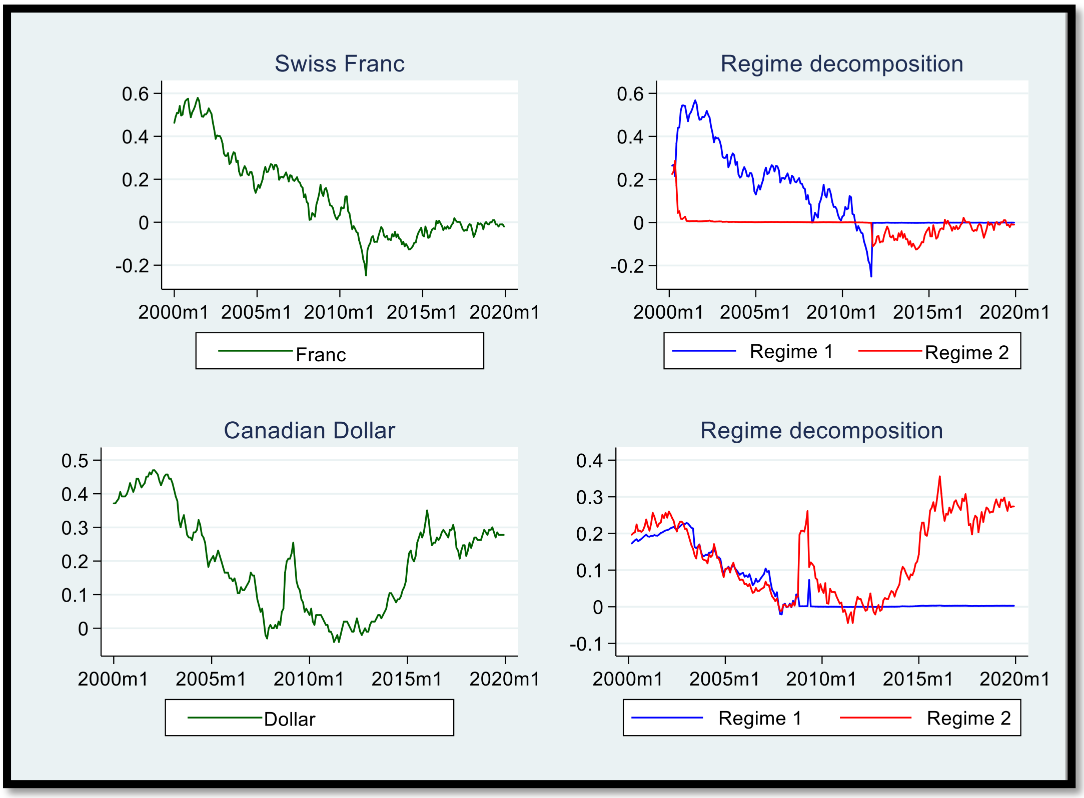


Figure 1.16: Regime decomposition

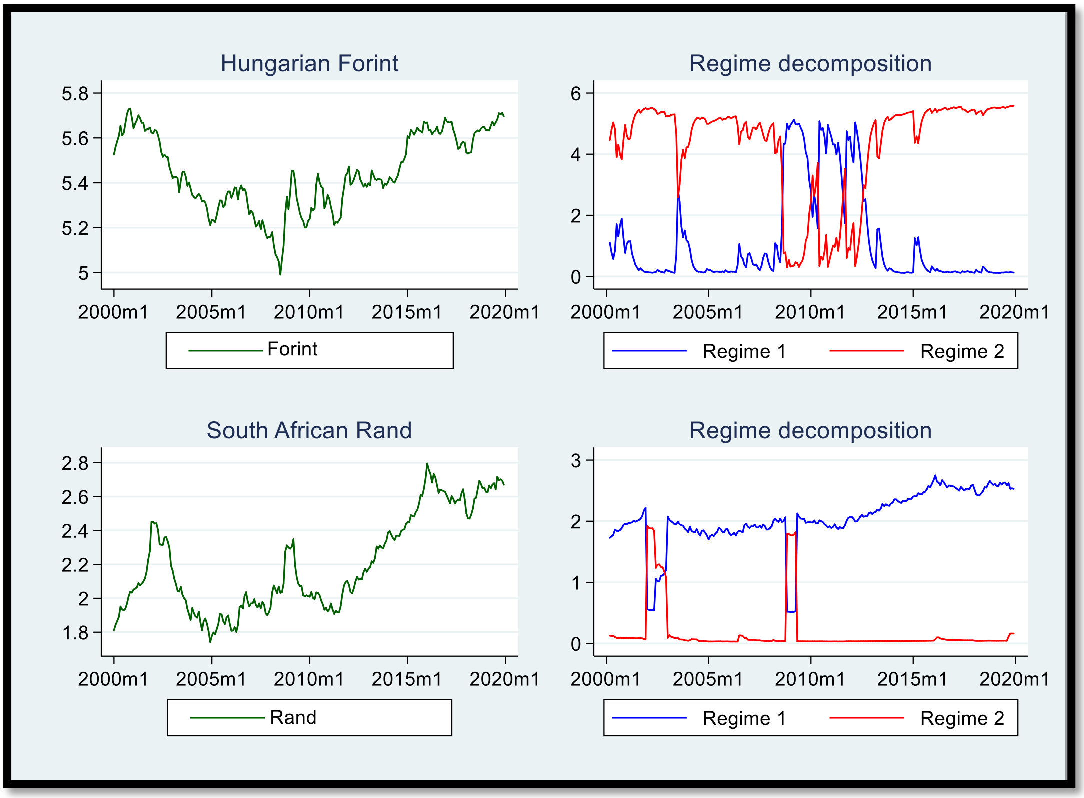
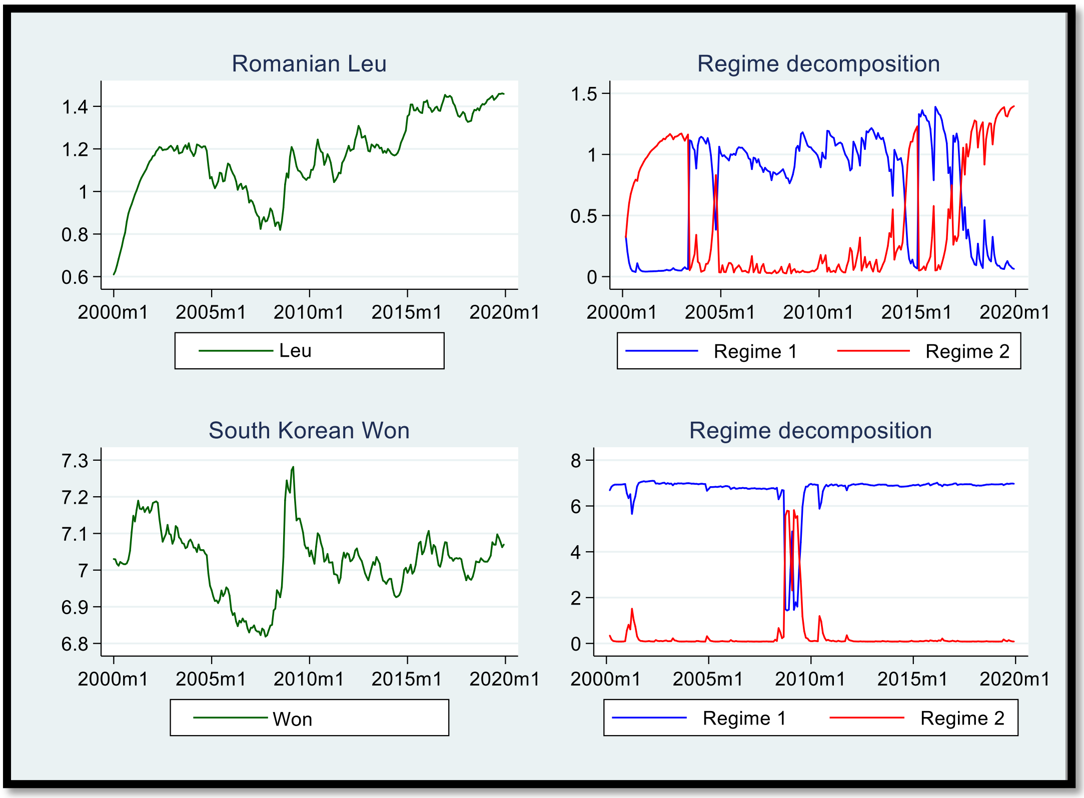


Figure 1.17: Regime decomposition



Chapter 2: Investigating Currency Value Parity in the pre-Euro Era

Abstract

Some countries adopted the Euro on 1st of January 1999, and the question is whether there was indeed a convergence in real value of the respective currencies right before the adoption of the Euro. This study investigates the extent to which there was currency value parity by testing for the existence of purchasing power parity using the French Franc and Deutsche Mark as reference currencies. Using time series data on the real exchange rate, nominal exchange rate, and price differential, the data reveals that, to a greater extent, there was indeed currency value convergence for some countries. The weak-form test (a co-integration test) for purchasing power parity reveals that the long-run speed of adjustment for all currencies in the sample is less than 1% per month and that deviations from purchasing power parity may be permanent too.

Key Words: *Exchange rate, purchasing power parity, convergence*

2.1 Introduction

This study applied a univariate time series and a panel data approach to monthly data on real exchange rates, nominal exchange rates and price differential data of early adopters, late adopters and non-Euro countries to test the extent to which there was convergence to purchasing power parity relative to the French Franc and Deutsche Mark right before the Euro came into circulation. The results revealed that, to some extent, exchange rate convergence held for some currencies while it did not for others.

Section 2.2 presents a literature review on purchasing power parity. Section 2.3 discusses the stationarity and co-integration models used in the study, it also gives a detailed description of the data, and some exchange rate controls in Europe. Section 2.4 gives a detailed discussion of the results and section 2.5, a conclusion of the study.

Although it dates back earlier, probably by several centuries, the terminology of purchasing power parity, hereafter PPP, was introduced in the years after World War I (1914-1918) during the international policy debate concerning the appropriate level of nominal exchange rates among major industrialised countries after the large scales inflation during and after the war (Cassel, 1918). See Rogoff (1996) for a good review on PPP puzzle and its history.

Taylor and Taylor (2004)[33] state that the idea behind PPP is that a unit of currency should be able to buy the same basket of goods in one country as the equivalent amount of foreign currency, at the going exchange rate, can buy in a foreign country, so that there is parity in the purchasing power of the unit of currency across the two economies. One very simple way of gauging whether there may be discrepancies from PPP is to compare the prices of similar or identical goods from the basket in the two countries. The Economist newspaper publishes the prices of McDonald's Big Mac burgers for countries around the world and compares them in a common currency, the US Dollar, at the market exchange rate as a simple measure of whether a currency is overvalued or undervalued relative to the Dollar at the current exchange rate (on the supposition that the currency would be valued just right if the Dollar price of the burger were the same as in the United States). As of July 2020, the cheapest burger was in South Africa, at $1.86, compared with an average American price of $5.71. This implied that the South African Rand was 67.44% undervalued. The average price of a Big Mac in Switzerland was $6.91, suggesting that the Swiss Franc was 20.94% overvalued against the Dollar. The

[33] This paper provides an adequate explanation of PPP, bringing forth detailed discussions and perspectives, some of which have been adopted in this paragraph.

average price in the Euro-area was $4.79, suggesting that the Euro was undervalued by 16.18%. PPP is related to the Law of One Price, which holds that the price of an internationally traded good should be the same anywhere in the world once that price is expressed in a common currency, however, there are many objections to this.

Over the short or medium term, a set of countries can maintain rigidly fixed exchange rates without PPP holding. However, if the countries have large trading sectors with each other, then, stable, fixed exchange rates necessitate PPP to avoid de-stabilising trade imbalances. The goal of the Euro-project is both open trading borders and a common currency. To reflect this goal, the study tests for real exchange rate convergence and long-run PPP.

Lin et al. (2011) and Bahmani-Oskooee et al. (2017) state that PPP holds when exchange rates between currencies are in equilibrium, that is, their purchasing power is the same in each of the two countries. This means that the exchange rate between any two countries should equal the ratio of the prices of a fixed basket of goods and services in the two currencies. In other words, due to arbitrage activities (which are eventually traded away) in the international commodities market, the real exchange rates (that combine the movements of relative prices with nominal exchange rates) are expected to return to a constant equilibrium value in the long-run. That is, a non-stationary real exchange rate indicates that there is no long-run relationship between the nominal exchange rate and the domestic and foreign prices, thereby invalidating the PPP hypothesis.

Taylor and Taylor (2004) argue that the question of how exchange rates adjust is central to exchange rate policy since countries with fixed exchange rate regimes need to know what the equilibrium exchange rate is likely to be and countries with floating regimes want to know what level and variation in real and nominal exchange rates to expect. In broader terms, the question of whether exchange rates adjust toward a level established by PPP helps to determine the extent to which the international macroeconomic system is self-equilibrating.

It is of great importance to study the validity of PPP, and thus, stationarity in the real exchange rate; a well-studied phenomenon is that a depreciation in the real exchange rate could cause disparities in international competitiveness that could result in a movement of employment toward the country whose currency depreciates. Bahmani-Oskooee et al. (2017) state that non-stationarity in the real exchange rate can result to unbounded gains from arbitrage in traded goods, and add that Parikh and Williams (1998) observed and pointed out that a non-stationary real exchange rate can cause severe macroeconomic disequilibrium that can lead to real exchange rate devaluation in order to correct for external imbalance. Bahmani-Oskooee et al. (2017) also argue that an invalid PPP cannot be used to determine the equilibrium exchange rate and further disqualifies the monetary approach to exchange rate determination of a given monetary authority. These arguments are also put forth in Lin et al. (2011).

2.2 Literature Review

Many PPP scholars have argued that the pre-float periods supported the long-run existence of PPP while the after-float periods, adopted in the early 1970s, have seen less evidence of real exchange rate reversion. Frankel and Rose (1996) argue that, say, a typical 100 or 200-year sample of the Pound/Dollar rate includes several shifts between fixed, floating and intermediate regimes, and in their words, "it has been well known since at least Mussa (1986) that real exchange rates behave differently under different exchange rate regimes", thus, it is reasonable to suppose that the speed of PPP adjustment may also vary with the nature of the exchange rate regimes. McCloskey and Zecher (1984) argued that the PPP phenomenon worked well under the Anglo-American Gold Standard before 1914. Many have also opted to explain PPP based on the frequency of the data used in their studies, arguing that findings may depend on the power[34] of the techniques used in testing for PPP, stating that longer runs of data are needed to improve the power of the test-statistic, while others have attributed it to exchange rate regimes adopted by the different monetary authorities. Froot and Rogoff (1995), and Caporale and Hanck (2009) argue that stage-one tests failed to take into account the possible non-stationarity in the series, stage-two tests were not able to discern between a purely random walk and slow mean reversion, and stage-three tests used a co-integration approach but have exhibited the same weaknesses of being low power. Caporale et al. (2003), focussing on stage-two tests, argue that the type of stationarity exhibited by the real exchange rate cannot be accommodated by the autoregressive models employed in most of the studies, even when considering WPI and CPI based measures of real exchange rate.

Lothian and Taylor (1996) studied the mean reverting behaviour of the real exchange rate between the Dollar-Sterling and Franc-Sterling spanning a period of two centuries (1791-1990)[35], accounting for a floating regime period, and conclude that there was strong evidence of mean reversion with half-life shocks of 6 years for Dollar-Sterling and under 3 years for Franc-Sterling rates. Taylor (2002) investigated evidence of PPP over a 100-year period since the late nineteenth century and concluded that there is evidence of PPP when using more recent multivariate and univariate tests of higher power. In addition, his findings revealed that, as may be expected, floating exchange rate regimes were associated with larger deviations from PPP

[34] This is the ability of a test to reject the null when it is false and size of a test is the probability of rejecting the null when it is actually true.

[35] A long time series such as this gives a better chance of finding any evidence of PPP.

but did not blame the longer half-lives on the regime deployed but rather on the size of shocks to the real exchange rate.

Frankel and Rose (1996) use a panel data set of 45 years of post WWII annual data for 150 countries and conclude that their panel shows strong evidence of mean reversion that is similar to that from long time series data and any PPP deviations are eroded at a rate of about 15% annually, therefore, a half-life of around four years. They argue that such significant findings can be masked in time-series data but are easy to find in cross-sectional data.

Drine and Rault (2008), applying a more recent panel co-integration technique developed by Pedroni (1999, 2004) regionalise their study of 80 countries and find that the strong-form PPP is evident for OECD countries and the weak-form for MENA nations. Their study revealed that PPP does not characterize the long-run behaviour of the real exchange rate in African, Asian, Latin American and CEE countries. Further results indicated that the nature of the exchange rate regime deployed by a monetary authority does not condition the validity of PPP and PPP is more easily accepted for countries with high inflation than for those with low inflation.

Alba and Papell (2007) sought to look for evidence of PPP in a sample comprising of 84 countries. Their panel analysis results showed stronger evidence of PPP in countries more open to trade, closer to the United States, with lower inflation and moderate nominal exchange rate volatility, and with similar economic growth rates as the United States. Thus, country characteristics may be a key factor in explaining any form of adherence to and deviations from PPP. Furthermore, they show that PPP holds for panels of European and Latin American countries, however, there is no evidence for African and Asian countries.

Lin et al. (2011) employing a stationarity test with a Fourier function introduced by Becker et al. (2006), arguing that this test has the ability to test for unit roots in the presence of smooth structural breaks, find that PPP does not hold true for transition countries[36] included in the sample except Lithuania. They also argue that this test does not suffer from low power and has good size properties.

Bahmani-Oskooee et al. (2017) revisit PPP in 7 Eastern European transition economies using quantile unit root tests developed by Koenker and Xiao (2004) and Galvao (2009) and find a positive result. Their results show that the conventional unit root tests (ADF, PP and KPSS) fail to reject the unit root null hypothesis but the quantile unit root tests did reject the null

[36] Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania and Russia.

hypothesis, with an estimated half-life of about 12-25 months. Hosseinkouchack and Wolters (2013) while checking whether shocks to US real GDP have permanent or temporary effects argue that this approach takes into account the fact that the transmission of a shock might depend on the sign and size of the shock, that is, large recessionary shocks might have a different effect than smaller recessionary or expansionary shocks. In addition, they argue that the test has more power than conventional unit root tests, as already stated.

Cheung and Lai (2000) use impulse response functions to analyse the adjustment dynamics of the real exchange rate and state that half-life estimates have substantial imprecision and that the convergence toward PPP is found to be non-monotonic and argue that the non-monotonic dynamics can substantially prolong the adjustment process and augment the persistence of the real exchange rate. Chang et al. (2012) apply the AESTAR[37] unit root test proposed by Sollis (2009) to the real exchange rate data of G-7 countries spanning over the period 1980-2008 and conclude that PPP does hold true for all the G-7 countries except Canada. Furthermore, they state that the adjustment toward PPP is non-linear but in a symmetric way. This concurs with the conclusion by Sarno and Taylor (2002)[38] who contend that PPP might be viewed as a valid long-run international parity condition when applied to bilateral exchange rates of industrialised countries and the real exchange rate mean reversion process is characterized by significant non-linearities.

Bahmani-Oskooee et al. (2014, 2015) apply a panel data stationarity test that accounts for sharp breaks and smooth shifts in the data to African countries and European transition economies and conclude that PPP was valid for 10[39] out of the 20 African countries while it held true for only 2[40] out of the 8 countries included in the European sample.

Wu et al. (2018) found evidence of PPP in 2[41] of the G-6 countries after applying a smooth time-varying co-integration technique developed by Park and Hahn (1999) to monthly data on nominal exchange rate and CPI over the period 1971-2013. The authors added that the Euro exchange rate does not adjust to relative prices in Italy probably due to rigidities in the Italian economy compared to the French and German economies. They go further and conclude that

[37] Asymmetric Exponential Smooth Transition Auto-Regressive.
[38] Their paper provides a detailed assessment on the progress made on PPP studies using a number of empirical techniques.
[39] Burkina Faso, Cameroon, Ghana, Kenya, Niger, Senegal, Seychelles, South Africa, Tanzania and Togo.
[40] Lithuania and Poland.
[41] France and Germany.

for the non-Euro[42] area countries for which PPP did not hold, this could be due to productivity differentials between each of these countries and the reserve country, the US in this case.

Bell et al. (2017), using a unique hand-collected dataset of exchange rates for five currencies (Lira of Barcelona, Pound Sterling of England, Pond Groot of Flanders, Florin of Florence and Livre Tournois of France) in medieval Europe during the 14^{th} and early 15^{th} centuries, and employing panel unit root tests and co-integration analysis, find that the Law of One Price and PPP held for the Pound Sterling and some of the Florentine Florin series individually. Around half of the real exchange rate series are best characterized as stationary, mean reverting processes.

Lothian and Devereux (2011), studying a long time series dataset on exchange rates and prices for Netherlands and Britain over a period of four centuries (1590-2009) argue that real factors have had substantial effects on real exchange rates, and hence PPP, but such effects eventually dissipate, and so, PPP held for these countries.

Jacobo and Sosvilla-Rivero (2020) applied co-integration and error correction models allowing for structural breaks to Argentine and American exchange rate and price differential annual data over the period 1810-2016 and found a long-run relationship, evidence supporting PPP. Their model gave a correction rate of 41% disequilibrium correction annually to the steady state for the full sample, with sub-sample adjustment speeds of 46% for 1982-2016 and 33% for 1810-1981.

Parikh and Williams (1998) studied the bilateral real exchange rate (CPI and PPI based) behaviour between Germany and fourteen major economies incorporating the concept of exchange rate volatility and risk premia using GARCH-type models tested these hypotheses; whether the real exchange rate is mean reverting, whether deviations follow a stable time series process, whether the underlying process can be modelled adequately and whether there is any evidence of risk premia. Their data indicated that evidence of a positive result for these hypotheses can be established for some economies, and that despite economic policy directed toward exchange rate stability, significant risk premia are present in the bilateral real exchange rates included in the sample.

These arguments put forth by several scholars have given rise to a phenomenon referred to as the PPP puzzle.

[42] Canada, Japan and UK.

2.3 Models and Data

2.3.1 Anchor currency regression model

This study makes use of the regression equation below. This form of regression goes a long way in determining the extent to which there was pegging to these important anchor currencies, right before the introduction of the Euro.

$$\Delta Ln(\frac{LCY}{CHF})_t = \beta_1 + \beta_2 \Delta Ln(\frac{FF}{CHF})_t + \beta_3 \Delta Ln(\frac{DM}{CHF})_t + \beta_4 \Delta Ln(\frac{GBP}{CHF})_t + \beta_5 \Delta Ln(\frac{USD}{CHF})_t + \varepsilon_t$$

Where LCY is the domestic currency of the country under study, FF is the French Franc, DM is the Deutsche Mark, GBP is the British Pound, USD is the US Dollar, and finally CHF is the Swiss Franc, the numeraire.

The PPP phenomenon will be used to determine the extent to which there was a convergence in European currency dynamics to the French Franc and Deutsche Mark right before the Euro era begun. This convergence will be tested by modelling the mean reverting behaviour and long-run currency dynamics in relation to the French Franc and Deutsche Mark.

The strong-form test for PPP can be determined by testing for stationarity in the real exchange rate where the real exchange rate is constructed as;

$$RER_t = E_t \times \frac{P_t^*}{P_t}$$

Where E_t is the nominal exchange rate (domestic price of foreign currency), P_t^* and P_t, the foreign and domestic price indices respectively.

For PPP to hold, the nominal exchange rate between two currencies should be equal to the ratio of aggregate price levels between the two countries, thus, a unit of currency of one country will have the same purchasing power in a foreign country. There has to be proportionality between the nominal exchange rate and the price ratio between the two countries. This condition is described by Equation 1 below.

$$E_t = \frac{P_t}{P_t^*} \quad (1)$$

Taking logs;

$$E_t = P_t - P_t^* = R_t \quad (2)$$

Then;

$$E_t = R_t \quad (3)$$

2.3.2 Unit root test

The Dickey and Fuller (1979) procedure for testing for unit root involves fitting Model 1 specified below.

$$y_t = \alpha + \rho y_{t-1} + \delta t + u_t \quad (1)$$

Where y_t may be the nominal exchange rate, price differential or the real exchange rate.

However, to control for serial correlation, the augmented Dickey-Fuller (ADF) test fits Model 2 described below, adding more lagged values of the variable of interest.

$$\Delta y_t = \alpha + \beta y_{t-1} + \delta t + \zeta_1 \Delta y_{t-1} + \zeta_2 \Delta y_{t-2} + \cdots + \zeta_k \Delta y_{t-k} + \epsilon_t \quad (2)$$

Where α is the drift term and δt the trend term which may be included or not. Hamilton (1994) gives a detailed discussion of the four cases in which this unit root type of test can be applied. Equation 2 can simply be modified to Equation 3 below.

$$\Delta y_t = \alpha + \beta y_{t-1} + \delta t + \sum_{j=1}^{k} \zeta_j \Delta y_{t-j} + \epsilon_t \quad (3)$$

$H_0: \beta = 0$, the series is non-stationary, and the test statistic is computed as $Z_t = \hat{\beta}/\hat{\sigma}_\beta$ and $\hat{\sigma}_\beta$ is the standard error of $\hat{\beta}$.

2.3.3 Co-integration test

Engle and Granger (1987) introduced a test for co-integration for $I(1)$ variables that involves estimating a model by OLS. In this case, estimating the equation describing the relationship between the nominal exchange rate and the price differential (the PPP condition), then testing whether the residuals in the regression are stationary or not. Stationarity in the residuals is an indication of co-integration. This is referred to as the two-step technique and is appropriate for a bivariate model because there will be one unique co-integrating vector.

Johansen (1988, 1991, 1995), and Johansen and Juselius (1990, 1992) developed a likelihood ratio-based test that can be applied to multivariate case models. In this case, an unrestricted VAR is estimated for the system then the rank, r, which is the number of co-integrating vectors is determined.

The Vector Error Correction Model (VECM)

Consider a simple VAR specification below with p lags.

$$\boldsymbol{y}_t = \boldsymbol{v} + \boldsymbol{A}_1\boldsymbol{y}_{t-1} + \boldsymbol{A}_2\boldsymbol{y}_{t-2} + \cdots + \boldsymbol{A}_p\boldsymbol{y}_{t-p} + \boldsymbol{\epsilon}_t \qquad (1)$$

Where $\boldsymbol{y}_t$ is a $K \times 1$ vector of variables, $I(1)$ in nature, $\boldsymbol{v}$ is a $K \times 1$ vector of parameters, $\boldsymbol{A}_1 - \boldsymbol{A}_p$ are $K \times K$ matrices of parameters and $\boldsymbol{\epsilon}_t$ is a $K \times 1$ vector of disturbances. The VAR(p) model above can be modified in VECM form as;

$$\boldsymbol{\Delta y}_t = \boldsymbol{v} + \boldsymbol{\Pi y}_{t-1} + \sum_{\boldsymbol{i=1}}^{\boldsymbol{p-1}} \boldsymbol{\Gamma}_i\boldsymbol{\Delta y}_{t-i} + \boldsymbol{\epsilon}_t \qquad (2)$$

Where $\boldsymbol{\Pi} = \sum_{j=1}^{j=p} \boldsymbol{A}_j - \boldsymbol{I}_k$ and $\boldsymbol{\Gamma}_i = -\sum_{j=i+1}^{j=p} \boldsymbol{A}_j$. In Equation 2 above, on the right-hand side, the second term describes the long-run dynamics while the third term describes the short-run dynamics. If $\boldsymbol{\Pi}$ is of reduced rank, $0 < r < K$, then $\boldsymbol{\Pi} = \boldsymbol{\alpha\beta}'$, where $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ are $r \times K$ matrices of rank r. $\boldsymbol{\alpha}$ describes the adjustment coefficients and $\boldsymbol{\beta}$, the co-integrating vector, contains the parameters in the co-integrating equation. Consider a vector of length K, there may be at most $K - 1$ distinct co-integrating vectors.

The VECM described above postulates that if the variables in the vector $\boldsymbol{y}_t$ are $I(1)$ but not co-integrated then $\boldsymbol{\Pi}$ is a matrix of zeros, so it has a rank of 0. However, if all the variables in $\boldsymbol{y}_t$ are $I(0)$ then $\boldsymbol{\Pi}$ has full rank, K.

The trace statistic and the maximum eigenvalue statistic are used to draw conclusions about the number of co-integrating vectors. The trace statistic tests the null hypothesis that there are r co-integrating vectors against the alternative that there are K co-integrating vectors and is computed as;

$$\lambda_{trace} = -T \sum_{i=r+1}^{p} In(1-\hat{\lambda}_i) \quad (3)$$

With $r = 0,1,2,3, \dots, K-1$, T is the number of observations and $\hat{\lambda}_i$ is the i-th largest eigenvalue.

The maximum eigenvalue test statistic tests the null hypothesis that there are r co-integrating vectors against the alternative that there are $r+1$ co-integrating vectors and is computed as;

$$\lambda_{max} = -TIn(1-\hat{\lambda}_{r+1}) \quad (4)$$

With $r = 0,1,2,3, \dots, K-1$, T is the number of observations.

2.3.4 Panel unit root tests

As argued earlier, single time series tests like the ADF may suffer from low power, and so, a panel analysis may reveal more information.

The Levin-Lin-Chu (2002), hereafter LLC, test runs the regression of the form below with the restriction that all panels share a common autoregressive parameter, ϕ. To minimise the problem of serial correlation, just like the ADF test, LLC augment the model with additional lags of the dependent variable.

$$\Delta y_{it} = \phi y_{i,t-1} + \boldsymbol{z}'_{it}\boldsymbol{\gamma}_i + \sum_{j=1}^{p} \theta_{ij}\Delta y_{i,t-j} + u_{it}$$

Where $i = 1, \dots, N$ respresents the number of panels; $t = 1, \dots, T_i$ stands for time; $\boldsymbol{z}_{it}$ represents panel-specific means (fixed-effects) and a time trend.

Under the null hypothesis of a unit root or non-stationary series, $H_O: \phi = 0$ and $H_A: \phi < 0$.

The Im-Pesaran-Shin (2003), hereafter IPS, departs from the LLC type test in a sense that it relaxes the assumption that the panels share a common autoregressive parameter and recognises the fact that countries, or groups or subjects under study may differ in terms of cultural, institutional, and other factors. Thus, in the IPS test, the autoregressive parameter, ϕ, is indexed by i.

$$\Delta y_{it} = \phi_i y_{i,t-1} + \boldsymbol{z}'_{it}\boldsymbol{\gamma}_i + \sum_{j=1}^{p} \Delta y_{i,t-j} + \epsilon_{it}$$

Under the null hypothesis, all panels contain a unit root, and the alternative is that the fraction of panels that follow stationary processes is non-zero, that is, $H_O: \phi_i = 0$ for all i.

2.3.5 Panel co-integration tests

The Kao (1999), Pedroni (1999, 2004) and Westerlund (2005) are based on the panel data model for $I(1)$ dependent variables.

$$y_{it} = \boldsymbol{X}'_{it}\boldsymbol{\beta}_i + \boldsymbol{z}'_{it}\boldsymbol{\gamma}_i + \varepsilon_{it}$$

Each of the covariates in $\boldsymbol{X}_{it}$ is an $I(1)$ series; $\boldsymbol{\beta}_i$ is the co-integrating vector; $\boldsymbol{\gamma}_i$ is a vector of coefficients on $\boldsymbol{z}_{it}$, the terms that control for panel-specific effects. The tests apply different approaches and test-statistics to check whether the residuals are stationary or not, details of which are not discussed here.

2.3.6 Data

The study used monthly data on nominal and real exchange rates (deflated by the consumer price indices) relative to France and Germany. The countries included in the sample can be characterized as early and late adopters of the Euro currency, and some non-Euro countries. The early adopters included in the study are Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal and Spain. The late adopters; Latvia, Lithuania, Slovakia and Slovenia. The non-Euro countries are Hungary, Poland, Sweden, Switzerland and United Kingdom. To investigate the evidence of nominal exchange rate pegging for the early adopters, the data was divided into sub-samples covering the pre-Maastricht (1971-1991) and strict convergence (1992-1998) periods while that on late adopters covered the pre- and post-Euro periods, where pre-Euro data mostly runs from 1991-1998 and post-Euro data covers the period after December 1998 until when the country adopted the Euro. Data on late adopters was limited due to some reasons including the political fact that Latvian and Lithuanian independence from the Soviet Union was only restored in 1991 when the Soviet Union was dissolved. Furthermore, Slovenia only gained independence from Yugoslavia in 1991 and Slovakia evolved out of the Czechoslovak federation between 1990 and 1993. The sub-sample periods for non-Euro countries are defined as in the early adopters' case, pre-Maastricht and strict convergence periods.

To study the real exchange rate behaviour and evidence of co-integration between the nominal exchange rates and price differentials for early adopters and non-Euro countries, the data is simply consolidated, combining the pre-Maastricht and strict convergence periods (1960-1998) in order to gain a longer time series to study any evidence of any kind of convergence in the currencies. However, data on Hungary and Poland CPI is limited, thereby shortening the study period for these two countries. For late adopters, due to limited data as well, evidence of long-run convergence is studied only for the strict convergence period, that is, anywhere from between 1992 to 1998, depending on data availability.

For the panel analysis, given that some tests like the LLC unit root test may require balanced panels, the nominal exchange rate, real exchange rate and price differential data on early adopters runs from 1960-1998, late adopters from 1993-1998 and non-Euro countries from 1989-1998.

The data is collected from the IMF-IFS database and the FRED database.

Brief description of exchange rate controls in Europe

The exchange rate mechanism of the EMS influenced the evolution of the exchange rates for a considerable proportion of time in Europe. Its formal objective has been the stabilization of member countries' nominal exchange rates within generally narrow pre-agreed bounds. The limit was set at ±2.25% from central parity for Belgium, France, Germany and the Netherlands in 1979. For the Italian Lira, the limit was ±6% which was changed to ±2.25% from January 1990. As well as the provision of a margin of fluctuation, realignments are permitted and in all, eleven such realignments have taken place so far. The system has been organised around the ECU, a composite currency unit, with central rates for participating currencies expressed in terms of this measure. A divergence indicator and threshold position have also been introduced such that corrective action would be indicated if a currency went above or below the ECU value of 75% of its bilateral exchange rate against all other currencies in the system. The introduction of the ERM did not require countries to abolish exchange controls or restrictions on capital movements. France and Italy, for example, retained controls but they were gradually eased. Controls could be used to help these countries achieve stability both in negotiating realignments and avoiding monetary policy convergence. Belgium, by comparison, operated a system of dual exchange markets. In December 1991, at Maastricht, the EC members agreed on a plan to move towards monetary union and a common currency. In September 1992, speculative pressures against some member currencies forced Italy and the United Kingdom to withdraw from the ERM. The Portuguese Escudo and the Spanish Peseta were devalued several times throughout 1992 and 1993 and in February 1993, the Irish Punt was also devalued. The exchange rate crises ended in August 1993 with the expansion of the bands from ±2.25% to ±15% for all bilateral rates with the exception of the Guilder/DM rate. The perception is that the wider bands have reduced the prospects for exchange rate crises in the ERM. In March 1995, however, those countries within the ERM again experienced snap fluctuations and the Escudo and Peseta were again devalued.

Adopted from Parikh and Williams (1998)

2.4 Discussion of Results

2.4.1 Anchor currency regressions

From Table 2.1, it is evident that the Austrian Schilling was significantly pegged to the DM, especially in the strict convergence period, reporting a weight of 0.981. The data also shows that there was a shift from strong DM preference during the pre-Maastricht period to FF preference during the strict convergence period for the Belgian Franc. The Finnish Markka registered significant weights for all four possible anchor currencies during the pre-Maastricht period but only registered a significant weight of 0.465 to the GBP during the strict convergence period. The Greek Drachma showed significant preference for the USD during the pre-Maastricht but there is a clear movement away from USD preference to FF preference during the strict convergence period with a weight of 0.524. The Irish Pound, on the other, hand had significant preference to the GBP during pre-Maastricht and strict convergence periods with weights of 0.436 and 0.404 respectively. The Italian Lira showed strong inclination to the FF in both periods with the weight even getting higher from 0.556 to 0.858. From Table 2.2, it is observable that the Dutch Guilder was strongly pegged to the DM during both the pre-Maastricht and strict convergence periods, attaching weights of 0.827 and 0.930 respectively. The Portuguese authorities attached a significant weight of 0.307 and 0.756, and the Spanish authorities attached a weight of 0.524 and 0.766 to the FF during the pre-Maastricht and strict convergence periods. It is also observable that for most countries, a higher weight is attached to the preferred anchor currency during the strict convergence period compared to the pre-Maastricht period. This totally makes sense.

The pre- and post-Euro regression results for late adopters presented in Table 2.3 show that the Latvian Lats and Lithuanian Litas monetary authorities attached a much higher weight to the USD than any of the anchor currency candidates during the pre-Euro period, 0.476 and 1.498 respectively. The Lithuanian Lats also showed some evidence of pegging to the FF, attaching a weight of 1.261 during the pre-Euro period. The Slovak Koruna showed significant weights to the FF and USD, 0.772 and 0.380 respectively during the pre-Euro period. The Slovenian Tolar only recorded a significant weight of 1.415 to the DM. The post-Euro results for Latvia and Lithuania showed significant results for all the three anchor currencies with more preference to the USD (0.262) and GBP (0.306) respectively. Both Slovakia and Slovenia showed significant weights for the GBP only in the post-Euro period, reporting point estimates of 0.371 and 0.191 respectively.

Table 2.4 shows the regression results from the non-Euro countries over the pre-Maastricht and strict convergence periods. The Hungarian Forint showed strong evidence of pegging to the USD (0.705) over the pre-Maastricht period, with lower weights attached to the FF (0.402) and DM (0.177). However, the strict convergence period witnessed a strong shift towards the DM and FF, significantly dropping the USD. The Polish Zloty does not bring forth interesting results, only showing a significant weight of 0.524 attached to the DM over the strict convergence period. The Swedish Krona only registered significant weights for all four possible anchors over the pre-Maastricht period showing more inclination towards the FF with a weight of 0.279.

From the results obtained after estimating the anchor currency regressions for each of the countries, it is evident that there was a strong preference for the FF and DM right before these currencies ceased and the EUR was adopted, thus, it makes sense to assume the existence of *French Franc and Deutsche Mark currency areas*. This result makes France and Germany the foreign countries of reference in the test for currency value convergence. It is important to note that several countries prefer pegging to a currency basket than to a single currency.

2.4.2 Unit root tests

As already discussed, the strong-form test involves testing for stationarity in the real exchange rate. If the real exchange rate is stationary, then there is a price convergence and PPP holds while non-stationarity indicates otherwise.

Table 2.5, Table 2.6 and Table 2.7 show the unit root test p-value results for the real exchange rates for the early adopters, late adopters and non-Euro countries. The results in Table 2.5 indicate that the real exchange rates for the early adopters are all non-stationary except for the real exchange rate between the Greek Drachma and the French Franc that is significant at the 5% level. This is an indication that there was some strong price convergence between Greece and France before the adoption of the Euro. The late adopters, whose results are presented in Table 2.6, however, show strong evidence of stationarity in the real exchange rate except for the Slovak Koruna. Again, it can be concluded that the strong-form test for PPP confirms price convergence for the Latvian Lats, Lithuanian Litas and Slovenian Tolar. The non-Euro countries, whose results are shown in Table 2.7 all show non-stationarity in the real exchange rate, indicating the absence of price convergence when the strong-form test is applied. The real exchange rates relative to France and Germany are shown in Figure 2.1, Figure 2.2, Figure 2.3, Figure 2.4, Figure 2.5 and Figure 2.6.

2.4.3 Co-integration tests

The weak-form test for PPP involves a co-integration test between the nominal exchange rate and price ratio or price differential. The Johansen and Juselius (1990 and 1992) test is appropriate for this. It requires that the nominal exchange rate, E_t, and price differential, R_t, be $I(1)$. For the early adopters, whose ADF test p-value results are presented in Table 2.8 and Table 2.9, both variables are integrated of order 1, and thus, meeting the requirement for a balanced equation. Late adopter p-value results presented in Table 2.10 and Table 2.11 indicate that the nominal exchange rate variable is $I(1)$ except for the Slovenian Tolar that is $I(0)$. The price differential variable is $I(0)$, that is, it is already stationary at level for all the countries. This result indicates that the equation will not be balanced as the variables are not $I(1)$ on either side so it may not be possible to proceed with the Johansen and Juselius co-integration test for the late adopters. Recall that the real exchange rate variable, used in the strong-form test for PPP was already stationary for all the late adopters except Slovakia whose real exchange rate was non-stationary. Non-Euro country p-value results presented in Table 2.12 and Table 2.13 indicate that the nominal exchange rate and price differential are both $I(1)$ except for Poland whose results are $I(0)$.

The Johansen and Juselius co-integration test results are presented in Table 2.14 and Table 2.15. The results reveal evidence of a long-run relationship (evidence of PPP) between the French Franc and five currencies among the early adopters, that is, the Belgian Franc, Greek Drachma, Italian Lira, Dutch Guilder and Spanish Peseta. Also, among the early adopters, there is evidence of PPP holding between the Deutsche Mark and four currencies, that is, the Greek Drachma, Irish Pound, Italian Lira and Dutch Guilder. From this result, it is also important to note that the Greek Drachma, Italian Lira and Dutch Guilder showed evidence of convergence with both the French Franc and Deutsche Mark.

For the late adopters, because the E_t variable is $I(1)$, except for Slovenia, and the R_t variable is $I(0)$, as discussed earlier, then one can say the variables are unbalanced in relation to the order of integration and one may not proceed with the Johansen and Jusleius co-integration test.

Moving on to the non-Euro countries, there is evidence of PPP holding between the French Franc and three currencies, that is, the Hungarian Forint, Swiss Franc and British Pound. The Deutsche Mark attained parity with the Hungarian Forint and British Pound. Poland, on the other hand had stationary variables, and thus, a co-integration test was not applied. For observational purposes, graphical representations of the nominal exchange rates and price ratios are shown in Figure 2.7, Figure 2.8, Figure 2.9, Figure 2.10, Figure 2.11 and Figure 2.12.

2.4.4 The long-run speeds of adjustment

Table 2.16 and Table 2.17 show the long-run speeds of adjustment parameters for the nominal exchange rates and prices towards equilibrium (parity). For most of the countries, only one of the variables has a significant speed of adjustment, the exception being Spain and United Kingdom where both the nominal exchange rate and price differential are significant. It is important to note the sign differences too. Opposite signs of the coefficients make more sense as it implies that each of the variables is adjusting back to an equilibrium. For instance, the parameters for the UK are of opposite signs and are significant implying that when the nominal exchange rate is too high, it drops toward an equilibrium or toward the price differential level at a rate of 0.0219624% per month. On the other hand, if the nominal exchange rate is too high, the price differential variable adjusts toward an equilibrium or the nominal exchange level at a rate of 0.0095189% per month. These adjustments take place simultaneously until parity is reached. However, it is important to further recognise the fact that the adjustments toward equilibrium or parity are very slow and may take several years.

2.4.5 Impulse response functions (IRFs)

After estimating the VECMs and reporting the long-run speeds of adjustment, the IRFs for each of the countries showing the effect of a shock to each of the variables over a period of 36 months are estimated as shown in Figure 2.13 to Figure 2.26. It is evident that the effect of a shock to the nominal exchange rate on the price differential and the effect of a shock to the price differential on the nominal exchange rate have permanent effects, that is, the shock effects are seen to persist and do not die out within the selected 36-month period. This is simply because these IRFs have been produced from co-integrating VECMs whose variables are $I(1)$. IRFs from a stationary VAR, that is, a VAR model whose variables are $I(0)$, die out over time, the effects of the shocks are simply transitory.

These IRFs show that PPP deviations for all the countries included in the sample are permanent which may not necessarily be the case.

2.4.6 Price differential forecasts

Since the French Franc and Deutsche Mark were dropped in 1998 and replaced by the Euro, it is only possible to forecast what the exchange rates of the currencies of the countries included in the sample could have been relative to these two major currencies but have no actuals to compare the forecast with. Because of this limitation, only the forecasts of the price differentials are presented alongside the actual price differentials over a period of 36 months as shown in Figure 2.27, Figure 2.28, Figure 2.29 and Figure 2.30. This helps to check how well some of these models are performing. The forecasts all fall within the 95% confidence interval, however, the graphs representing the bands are not presented to save on space. For most of the countries, there is a well observable difference between the actuals and forecasts, however, the Spanish and Irish models seem to predict the price differentials much better compared to that of the other countries.

2.4.7 Panel unit root tests

The panel analysis results from the LLC tests presented in Table 2.18 indicate that the panels are stationarity at the 5% level of significance for early adopters and 10% level of significance for the late adopters. From this, one can conclude that there is stronger evidence of PPP for the early adopters compared to the late adopters, and non for the non-Euro countries included in the sample. As shown in Table 2.19, the results remain robust for the early adopters and non-Euro countries when the IPS stationarity test is applied to the data, however, there is loss of PPP evidence for late adopters.

2.4.8 Panel co-integration tests

As indicated in Table 2.20, the nominal exchange rate, E_t and the price differential, R_t are $I(1)$ for the early adopters and $I(0)$ for the late adopters and non-Euro countries when the LLC unit root test is applied to the data. This result is robust to the IPS unit root test as presented in Table 2.21. These results imply that the co-integration test can only be applied to the data on early adopters since it meets the requirement of $I(1)$ variables. The Kao co-integration test results presented in Table 2.22 indicate strong evidence of co-integration in the early adopters' data as shown by the significance of the computed statistics at the 1% level of significance. The unadjusted Dickey-Fuller t-statistic is however only significant at the 5% level. For the Pedroni test whose results are presented in Table 2.23, there is still evidence of co-integration in the data at the 10% significance level with the exception of the augmented Dickey-Fuller t-statistic that is not significant. The Westerlund result shown in Table 2.24 gives another strong indicator of co-integration in the early adopters' data. From these three co-integration tests, in combination with the unit root test results, there is clear evidence supporting the presence of PPP between the early adopters' currencies and the French Franc.

2.5 Conclusion

The study investigated whether convergence toward PPP held for the early adopters, late adopters and non-Euro countries right before the Euro was adopted, that is up until 1998, and post-Euro behaviour for the late adopters. Using a series of regressions, it was determined that the French Franc and Deutsche Mark were strong anchor currencies for several countries in the sample, and so, it made sense to use them as reference or numeraire currencies when testing for currency value and price convergence in exchange rates. The single series results revealed that the strong-form test for real exchange rate mean reversion held only for the Greek Drachma among the early adopters. Among the late adopters, evidence of mean reversion was found for Latvia, Lithuania and Slovenia. The real exchange rates for non-Euro countries all showed random walk behaviour. The weak-form test for long-run PPP, a co-integration test, confirmed a long-run relationship between the nominal exchange rate and the price differential for some early adopters and non-Euro countries, however, for the late adopters, the weak-form test could not be carried out because some series were stationary at level and for most pairs, the nominal exchange rate and price differential were integrated of different order. The long-run speeds of adjustment were low for all currencies, less than 1% per month. The panel analysis too confirmed evidence of mean reversion in the real exchange rates and co-integration between the nominal exchange rates and price differentials. It can therefore be concluded that the long-run PPP hypothesis and price convergence did hold for some early adopters, late adopters and non-Euro countries.

Table 2.1: Anchor currency regressions for early adopters

	FF	DM	GBP	USD
Austria				
Pre-Maastricht	0.108***	0.747***	-0.00931	0.0228
	(0.0246)	(0.0268)	(0.0155)	(0.0119)
Strict convergence	0.0199	0.981***	-0.00984*	0.00269
	(0.0154)	(0.0170)	(0.00461)	(0.00440)
Belgium				
Pre-Maastricht	0.221***	0.739***	0.0713**	0.00366
	(0.0386)	(0.0419)	(0.0242)	(0.0186)
Strict convergence	0.611***	0.338***	0.00436	-0.0169
	(0.0862)	(0.0950)	(0.0257)	(0.0246)
Finland				
Pre-Maastricht	0.159**	0.274***	0.222***	0.262***
	(0.0595)	(0.0646)	(0.0374)	(0.0288)
Strict convergence	0.437	0.113	0.465***	-0.138
	(0.328)	(0.361)	(0.0978)	(0.0936)
Greece				
Pre-Maastricht	0.243**	0.196	0.262***	0.332***
	(0.0923)	(0.100)	(0.0580)	(0.0446)
Strict convergence	0.524*	0.161	0.124	0.128*
	(0.214)	(0.236)	(0.0638)	(0.0610)
Ireland				
Pre-Maastricht	0.383***	0.110	0.436***	0.0536
	(0.0594)	(0.0646)	(0.0374)	(0.0287)
Strict convergence	0.458	0.189	0.404***	0.0179
	(0.284)	(0.313)	(0.0849)	(0.0812)
Italy				
Pre-Maastricht	0.556***	0.0735	0.146***	0.170***
	(0.0659)	(0.0716)	(0.0414)	(0.0319)
Strict convergence	0.858*	-0.326	0.495***	0.0711
	(0.355)	(0.392)	(0.106)	(0.101)

Standard errors in parentheses.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ significance level.

Table 2.2: Anchor currency regressions for early adopters

	FF	DM	GBP	USD
Netherlands				
Pre-Maastricht	0.118***	0.827***	0.0626**	0.0128
	(0.0306)	(0.0332)	(0.0192)	(0.0148)
Strict convergence	0.0516**	0.930***	0.00152	0.00243
	(0.0188)	(0.0207)	(0.00561)	(0.00537)
Portugal				
Pre-Maastricht	0.307***	0.394***	0.165**	0.131**
	(0.0856)	(0.0930)	(0.0538)	(0.0414)
Strict convergence	0.756***	0.343	0.149*	0.0168
	(0.215)	(0.237)	(0.0643)	(0.0615)
Spain				
Pre-Maastricht	0.524***	0.00101	0.236***	0.253***
	(0.0900)	(0.0977)	(0.0565)	(0.0435)
Strict convergence	0.766***	0.446	0.272***	-0.134*
	(0.221)	(0.243)	(0.0659)	(0.0630)

Standard errors in parentheses.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ significance level.

Table 2.3: Anchor currency regressions for late adopters

	FF	DM/EUR	GBP	USD
Latvia				
Pre-Euro	-0.106	0.177	0.175	0.476***
	(0.370)	(0.399)	(0.148)	(0.130)
Post-Euro		0.0572**	0.239***	0.262***
		(0.0193)	(0.0567)	(0.0464)
Lithuania				
Pre-Euro	-1.261*	0.407	-0.0951	1.498***
	(0.540)	(0.583)	(0.217)	(0.190)
Post-Euro		0.0522**	0.306***	0.223***
		(0.0185)	(0.0539)	(0.0440)
Slovakia				
Pre-Euro	0.772**	0.203	-0.0537	0.380***
	(0.235)	(0.254)	(0.0944)	(0.0828)
Post-Euro		0.0149	0.371***	-0.118
		(0.0226)	(0.0860)	(0.0653)
Slovenia				
Pre-Euro	-0.162	1.415***	-0.0525	0.00575
	(0.179)	(0.193)	(0.0716)	(0.0628)
Post-Euro		0.0194	0.191**	-0.0475
		(0.0110)	(0.0659)	(0.0395)

Standard errors in parentheses.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ significance level.

Table 2.4: Anchor currency regressions for non-Euro countries

	FF	DM	GBP	USD
Hungary				
Pre-Maastricht	0.402***	-0.177*	0.0235	0.705***
	(0.0843)	(0.0706)	(0.0597)	(0.0521)
Strict convergence	0.267*	0.545***	0.0648	0
	(0.114)	(0.0667)	(0.0730)	(.)
Poland				
Pre-Maastricht	-0.793	0.230	-0.113	0.961
	(0.797)	(0.667)	(0.564)	(0.492)
Strict convergence	0.380	0.524***	0.0923	0
	(0.207)	(0.122)	(0.133)	(.)
Sweden				
Pre-Maastricht	0.279***	0.160**	0.225***	0.207***
	(0.0666)	(0.0557)	(0.0471)	(0.0411)
Strict convergence	0.339	0.155	0.212	0
	(0.187)	(0.110)	(0.120)	(.)

Standard errors in parentheses.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ significance level.

Table 2.5: Early adopters - ADF tests on real exchange rates

	France	Germany
Austria	0.6910	0.7086
Belgium	0.3383	0.2169
Finland	0.1640	0.4999
France		0.3720
Germany	0.3991	
Greece	0.0438*	0.1415
Ireland	0.1667	0.2537
Italy	0.2773	0.4810
Netherlands	0.4380	0.2677
Portugal	0.6964	0.3667
Spain	0.3991	0.2756

*Indicates statistical significance.

Table 2.6: Late adopters - ADF tests on real exchange rates

	France	Germany
Latvia	0.0000*	0.0000*
Lithuania	0.0000*	0.0001*
Slovakia	0.4159	0.6373
Slovenia	0.0034*	0.0258*

*Indicates statistical significance.

Table 2.7: Non-Euro countries - ADF tests on real exchange rates

	France	Germany
Hungary	0.4376	0.2684
Poland	0.4802	0.4097
Sweden	0.4291	0.8140
Switzerland	0.7472	0.7612
UK	0.1965	0.3323

Table 2.8: Early adopters - ADF tests on E_t and R_t relative to France

	E_t		R_t	
	Level	First difference	Level	First difference
Austria	0.8550	0.0000*	0.8750	0.0000*
Belgium	0.7628	0.0000*	0.5362	0.0000*
Finland	0.4407	0.0000*	0.3538	0.0000*
France				
Germany	0.7015	0.0000*	0.4047	0.0000*
Greece	0.9989	0.0000*	1.0000	0.0000*
Ireland	0.6797	0.0000*	0.7950	0.0000*
Italy	0.9702	0.0000*	0.9990	0.0000*
Netherlands	0.7752	0.0000*	0.9513	0.0000*
Portugal	0.9931	0.0000*	0.9975	0.0000*
Spain	0.9439	0.0000*	0.9450	0.0000*

*Indicates statistical significance.

Table 2.9: Early adopters - ADF tests on E_t and R_t relative to Germany

	E_t		R_t	
	Level	First difference	Level	First difference
Austria	0.0805	0.0000*	0.4891	0.0000*
Belgium	0.7173	0.0000*	0.8235	0.0000*
Finland	0.7298	0.0000*	0.1383	0.0000*
France	0.7015	0.0000*	0.4047	0.0000*
Germany				
Greece	0.9980	0.0000*	1.0000	0.0000*
Ireland	0.6679	0.0000*	0.7115	0.0000*
Italy	0.9283	0.0000*	0.9832	0.0000*
Netherlands	0.6275	0.0000*	0.4013	0.0000*
Portugal	0.9811	0.0000*	0.9930	0.0000*
Spain	0.9175	0.0000*	0.7025	0.0000*

*Indicates statistical significance.

Table 2.10: Late adopters - ADF tests on E_t and R_t relative to France

	E_t		R_t	
	Level	First difference	Level	First difference
Latvia	0.5421	0.0000*	0.0000*	0.0000*
Lithuania	0.0501	0.0000*	0.0000*	0.0603
Slovakia	0.6520	0.0000*	0.0025*	0.0000*
Slovenia	0.0000*	0.0000*	0.0000*	0.0000*

*Indicates statistical significance.

Table 2.11: Late adopters - ADF tests on E_t and R_t relative to Germany

	E_t		R_t	
	Level	First difference	Level	First difference
Latvia	0.5507	0.0000*	0.0000*	0.0000*
Lithuania	0.0937	0.0000*	0.0000*	0.0714
Slovakia	0.4569	0.0000*	0.0269*	0.0000*
Slovenia	0.0000*	0.0000*	0.0000*	0.0000*

*Indicates statistical significance.

Table 2.12: Non-Euro countries - ADF tests on E_t and R_t relative to France

	E_t		R_t	
	Level	First difference	Level	First difference
Hungary	0.9991	0.0000*	1.0000	0.0000*
Poland	0.0000*	0.0000*	0.0000*	0.0000*
Sweden	0.9266	0.0000*	0.9620	0.0000*
Switzerland	0.8673	0.0000*	0.8951	0.0000*
UK	0.5658	0.0000*	0.9710	0.0000*

*Indicates statistical significance.

Table 2.13: Non-Euro countries - ADF tests on E_t and R_t relative to Germany

	E_t		R_t	
	Level	First difference	Level	First difference
Hungary	0.9989	0.0000*	1.0000	0.0000*
Poland	0.0000*	0.0000*	0.0000*	0.0000*
Sweden	0.9738	0.0000*	0.9274	0.0000*
Switzerland	0.8371	0.0000*	0.1803	0.0000*
UK	0.6933	0.0000*	0.7979	0.0000*

*Indicates statistical significance.

Table 2.14: Early adopters - co-integration tests

	France		Germany	
	Trace statistic	5% critical	Trace statistic	5% critical
Austria	10.2147*	15.41	10.6836*	15.41
Belgium	1.0289**	3.76	10.6472*	15.41
Finland	12.7443*	15.41	7.2789*	15.41
France			11.4851*	15.41
Germany	11.4851*	15.41		
Greece	1.2159**	3.76	0.0516**	3.76
Ireland	12.7560*	15.41	1.3307**	3.76
Italy	0.4796**	3.76	0.2655**	3.76
Netherlands	1.4019**	3.76	3.0945**	3.76
Portugal	10.1743*	15.41	8.8681*	15.41
Spain	0.3907**	3.76	9.9706*	15.41

*Indicates no presence of co-integration since the trace statistic for zero rank is less than the critical value, and so, failure to reject the null hypothesis of no co-integration.
** Indicates the presence of co-integration since the trace statistic for a rank of one is less than the critical value, and so, failure to reject the null hypothesis of the presence of one co-integrating vector.

Table 2.15: Non-Euro countries - co-integration tests

	France		Germany	
	Trace statistic	5% critical	Trace statistic	5% critical
Hungary	3.3519**	3.76	2.6791**	3.76
Poland				
Sweden	10.0657*	15.41	7.7682*	15.41
Switzerland	0.4329**	3.76	8.0591*	15.41
UK	0.4731**	3.76	1.0710**	3.76

*Indicates no presence of co-integration since the trace statistic for zero rank is less than the critical value, and so, failure to reject the null hypothesis of no co-integration.
** Indicates the presence of co-integration since the trace statistic for a rank of one is less than the critical value, and so, failure to reject the null hypothesis of the presence of one co-integrating vector.

Table 2.16: Early adopters - long-run speeds of adjustment, α

	France		Germany	
	E_t	R_t	E_t	R_t
Belgium	-0.005959	0.0109408*		
	(0.447)	(0.000)		
Greece	0.007056	0.0511037*	0.0099047	0.0374732*
	(0.423)	(0.000)	(0.143)	(0.000)
Ireland			0.004503	0.0289283*
			(0.530)	(0.000)
Italy	-0.0108935	0.0068321*	-0.0006362	0.0109142*
	(0.167)	(0.001)	(0.927)	(0.000)
Netherlands	0.0024043	0.011628*	-0.037945*	-0.0121222
	(0.626)	(0.000)	(0.000)	(0.216)
Spain	-0.0401575*	-0.0082633*		
	(0.000)	(0.050)		

P-values in parentheses. *Indicates statistical significance.

Table 2.17: Non-Euro countries - long-run speeds of adjustment, α

	France		Germany	
	E_t	R_t	E_t	R_t
Hungary	0.0128837	0.0282806*	0.0148331	0.0317397*
	(0.339)	(0.000)	(0.302)	(0.000)
Switzerland	-0.0009475	0.0103365*		
	(0.907)	(0.000)		
UK	-0.0219624*	0.0095189*	-0.0043523	0.0110908*
	(0.028)	(0.000)	(0.573)	(0.000)

P-values in parentheses. *Indicates statistical significance.

Table 2.18: Levin-Lin-Chu tests on real exchange rates

	P-value
Early adopters	0.0181*
Late adopters	0.0734*
Non-Euro	0.2203

H_O: Panels contain unit roots. H_A: Panels are stationary.
*Indicates statistical significance.

Table 2.19: Im-Pesaran-Shin tests on real exchange rates

	P-value
Early adopters	0.0383*
Late adopters	0.5426
Non-Euro	0.6536

H_O: All panels contain unit roots. H_A: Some panels are stationary.
*Indicates statistical significance.

Table 2.20: Levin-Lin-Chu tests on E_t and R_t relative to France

	E_t		R_t	
	Level	First difference	Level	First difference
Early adopters	0.9837	0.0000*	0.9999	0.0000*
Late Adopters	0.0000*	0.0000*	0.0000*	0.0000*
Non-Euro	0.0000*	0.0000*	0.0000*	0.0000*

H_O: Panels contain unit roots. H_A: Panels are stationary.
*Indicates statistical significance.

Table 2.21: Im-Pesaran-Shin tests on E_t and R_t relative to France

	E_t		R_t	
	Level	First difference	Level	First difference
Early adopters	1.0000	0.0000*	1.0000	0.0000*
Late Adopters	0.0000*	0.0000*	0.0000*	0.0000*
Non-Euro	0.0000*	0.0000*	0.0000*	0.0000*

H_0: All panels contain unit roots. H_A: Some panels are stationary.
*Indicates statistical significance.

Table 2.22: Kao test

	P-value
Modified Dickey-Fuller t	0.0001*
Dickey-Fuller t	0.0095*
Augmented Dickey-Fuller t	0.0013*
Unadjusted modified Dickey-Fuller t	0.0056*
Unadjusted Dickey-Fuller t	0.0274*

H_0: No co-integration. H_A: All panels are co-integrated.
*Indicates statistical significance.

Table 2.23: Pedroni test

	P-value
Modified Phillips-Perron t	0.0791*
Phillips-Perron t	0.0661*
Augmented Dickey-Fuller t	0.1943

H_0: No co-integration. H_A: All panels are co-integrated.
*Indicates statistical significance.

Table 2.24: Westerlund test

	P-value
Variance ratio	0.0039*

H_0: No co-integration. H_A: Some panels are co-integrated.
*Indicates statistical significance.

Figure 2.1: Early adopters - real exchange rates relative to France

Figure 2.2: Early adopters - real exchange rates relative to Germany

Figure 2.3: Late adopters - real exchange rates relative to France

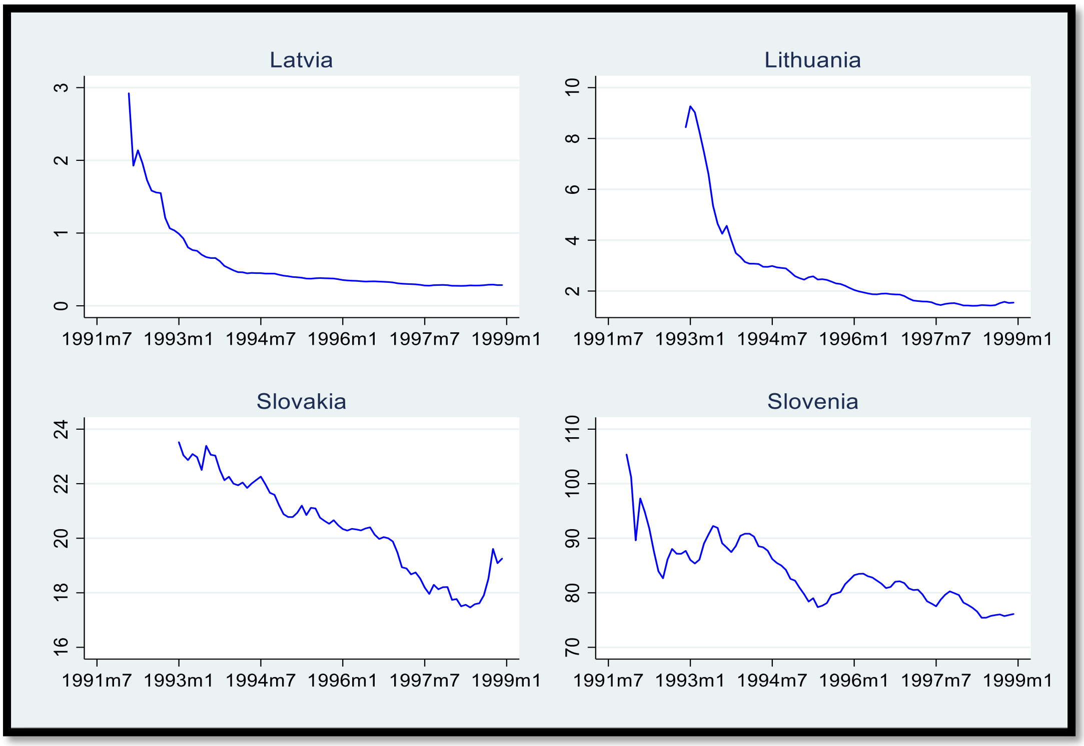


Figure 2.4: Late adopters - real exchange rates relative to Germany

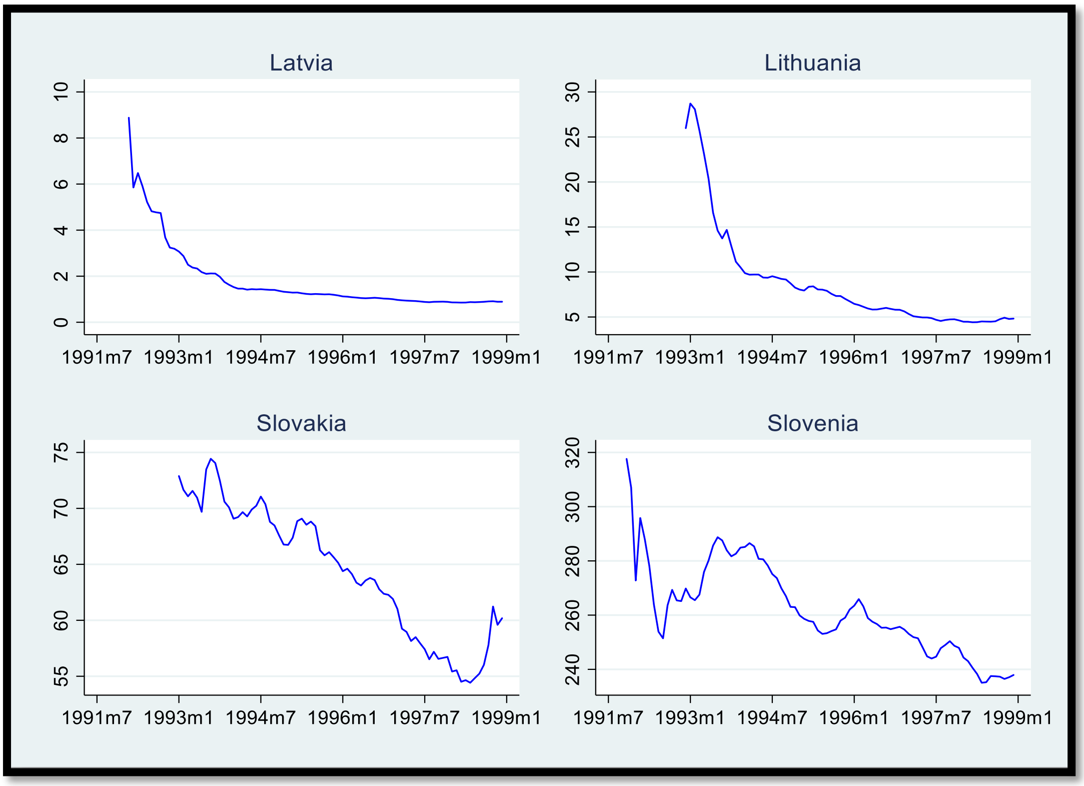


Figure 2.5: Non-Euro countries - real exchange rates relative to France

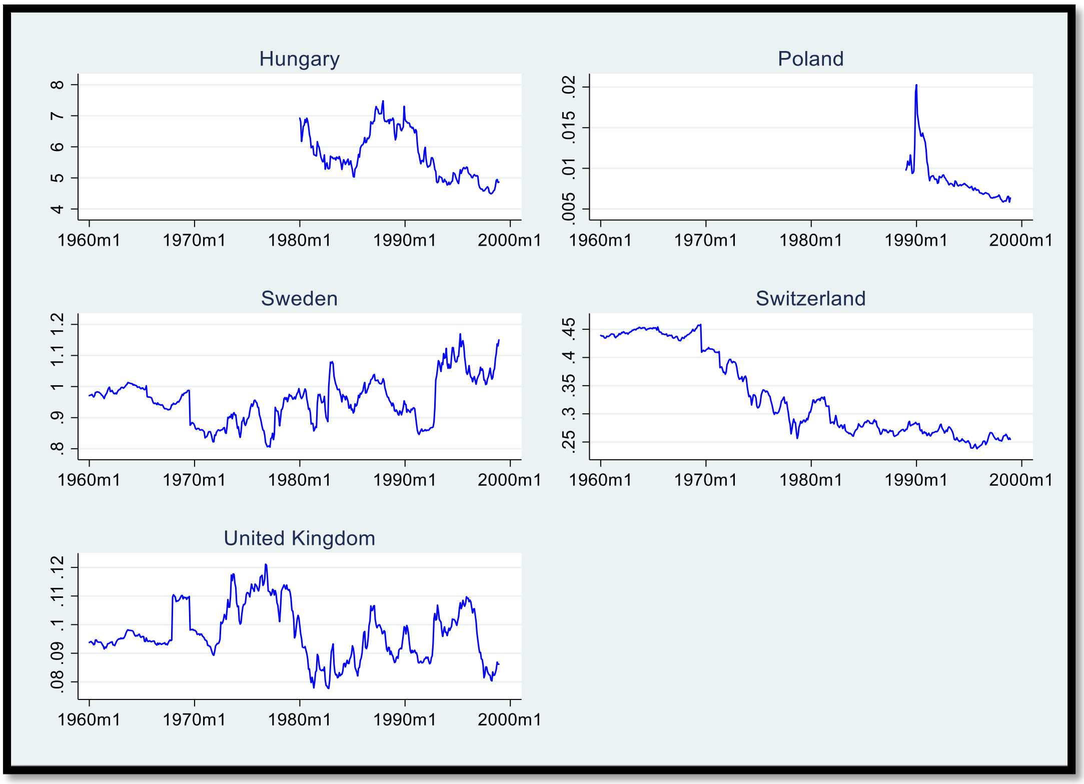


Figure 2.6: Non-Euro countries - real exchange rates relative to Germany

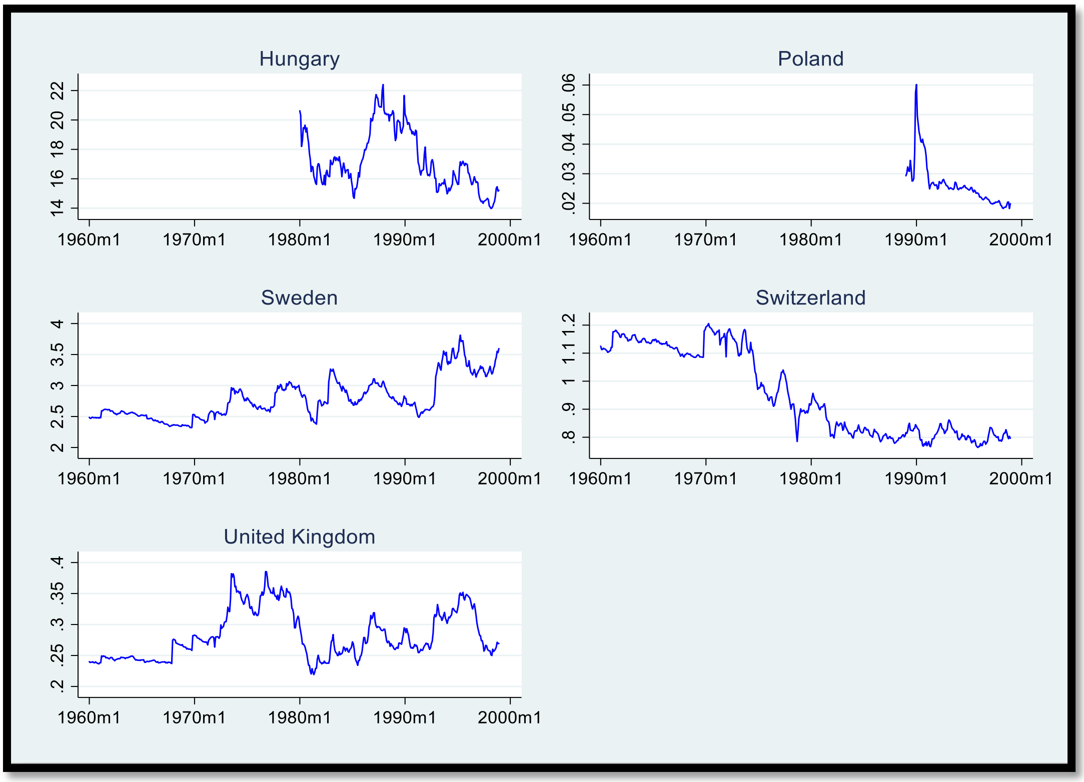


Figure 2.7: Early adopters - nominal exchange rates and price ratios relative to France

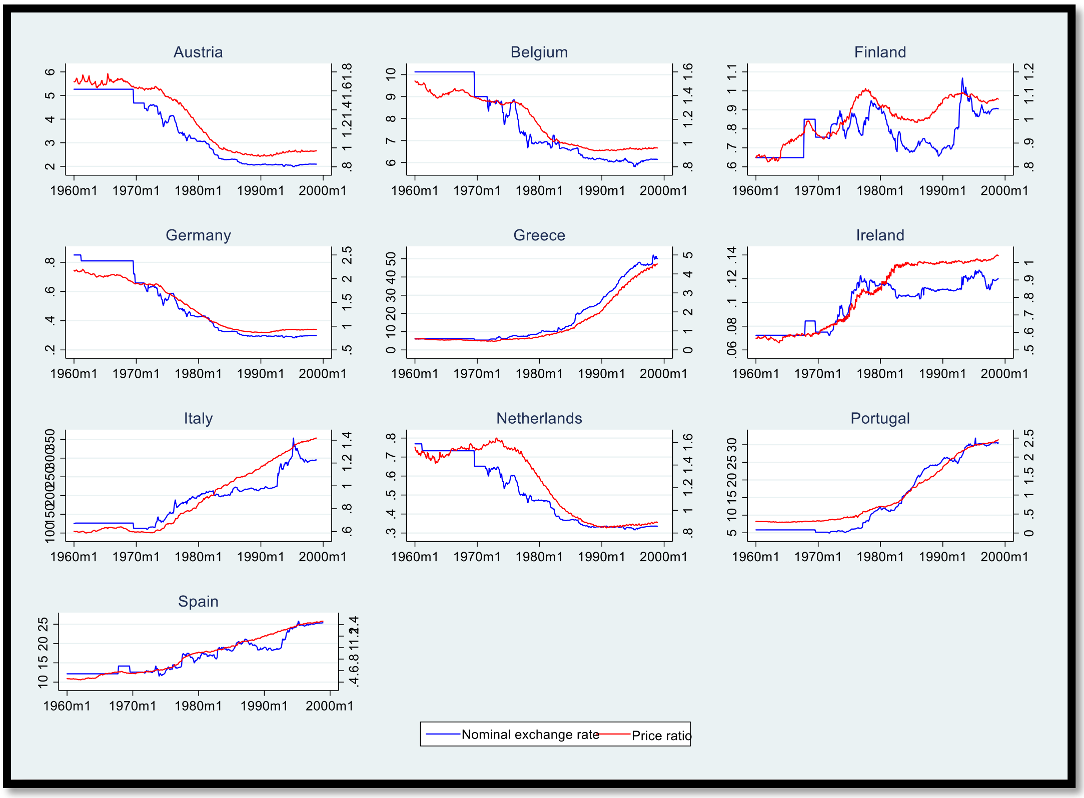


Figure 2.8: Early adopters - nominal exchange rates and price ratios relative to Germany

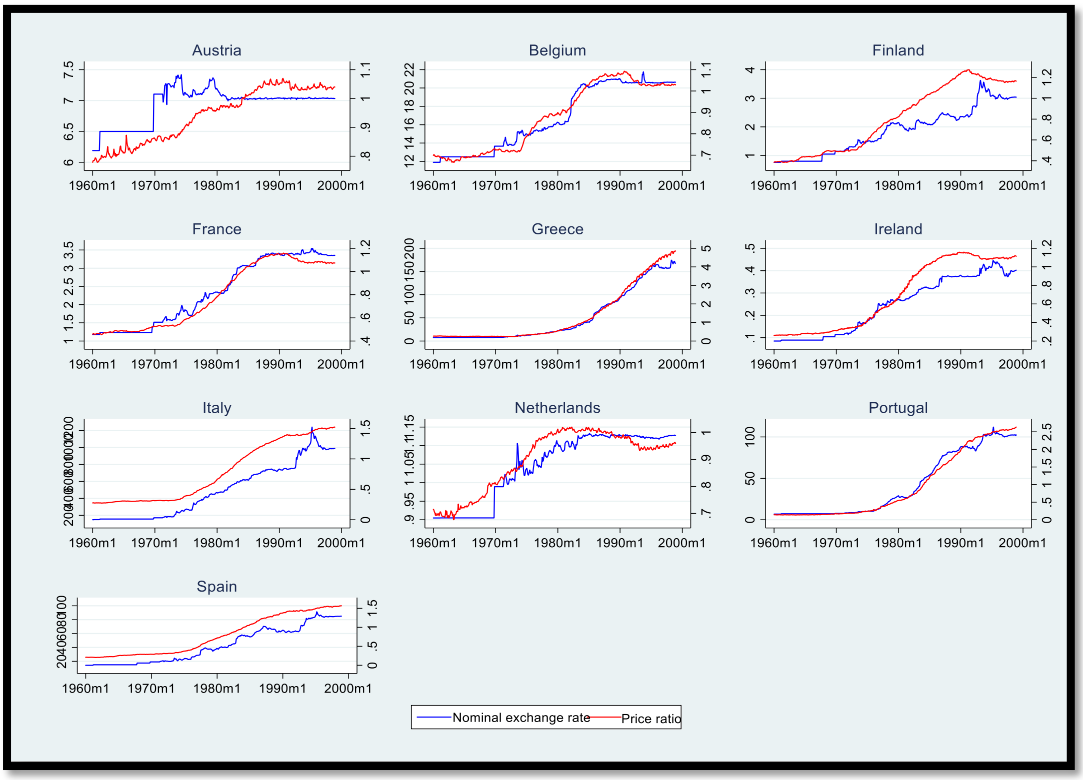


Figure 2.9: Late adopters - nominal exchange rates and price ratios relative to France

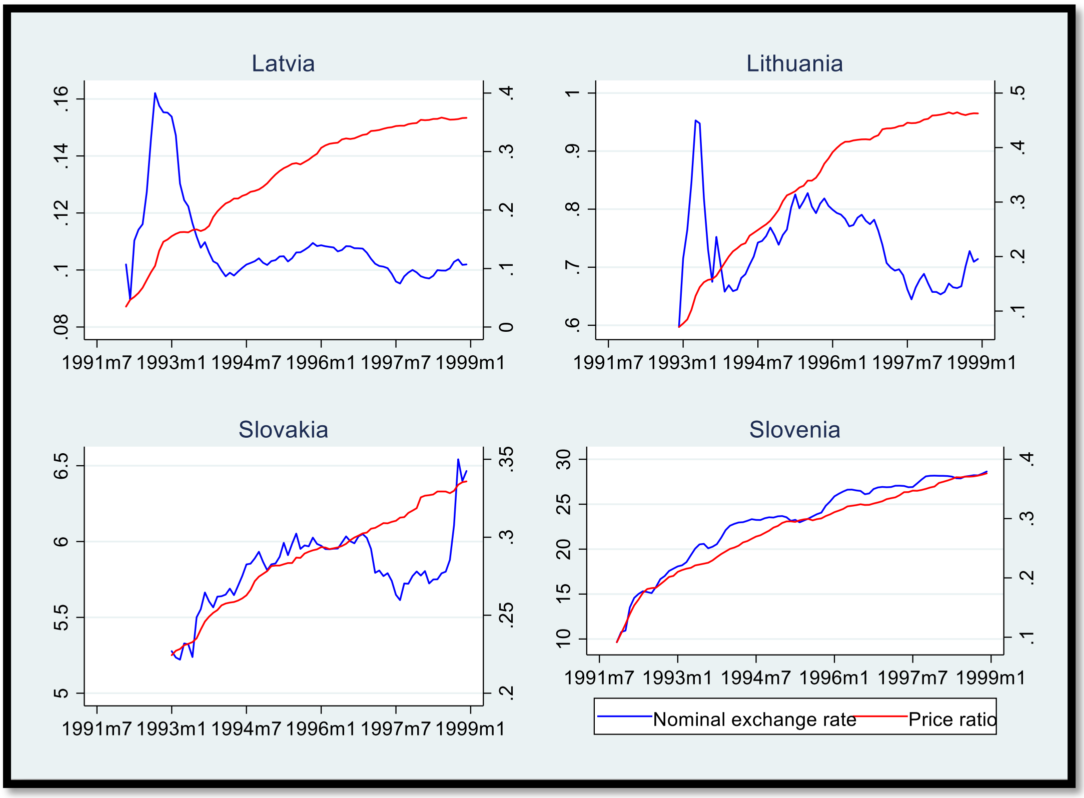


Figure 2.10: Late adopters - nominal exchange rates and price ratios relative to Germany

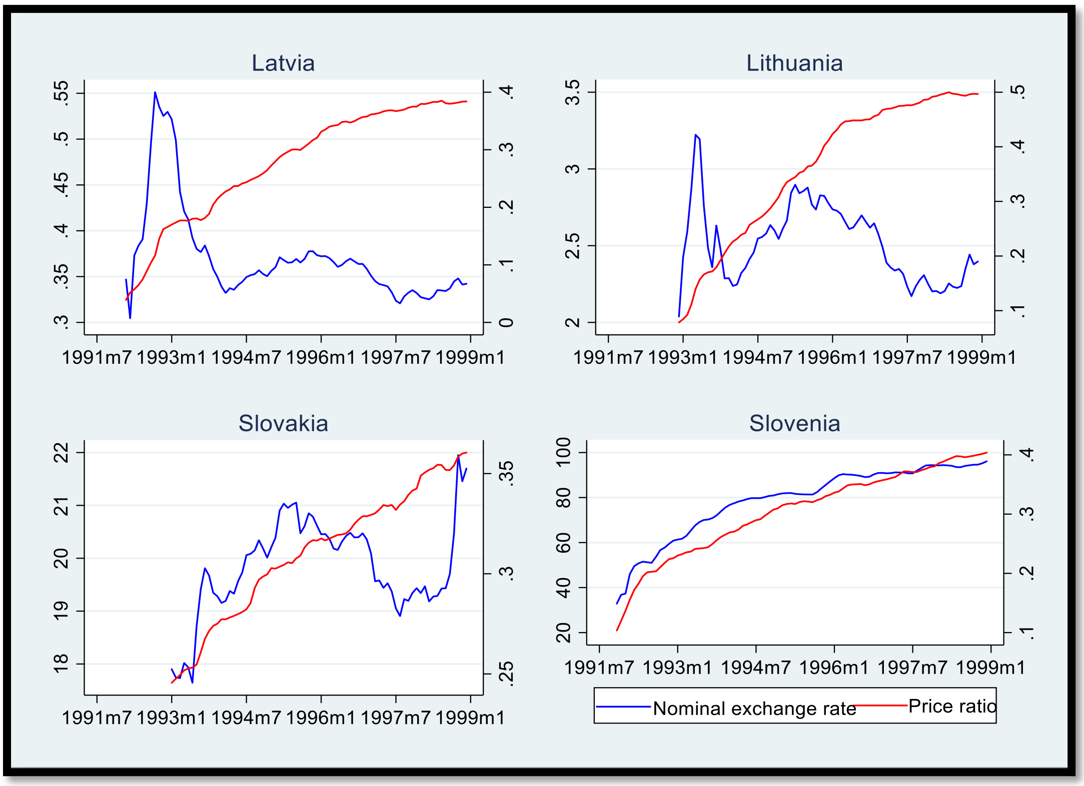


Figure 2.11: Non-Euro countries - nominal exchange rates and price ratios relative to France

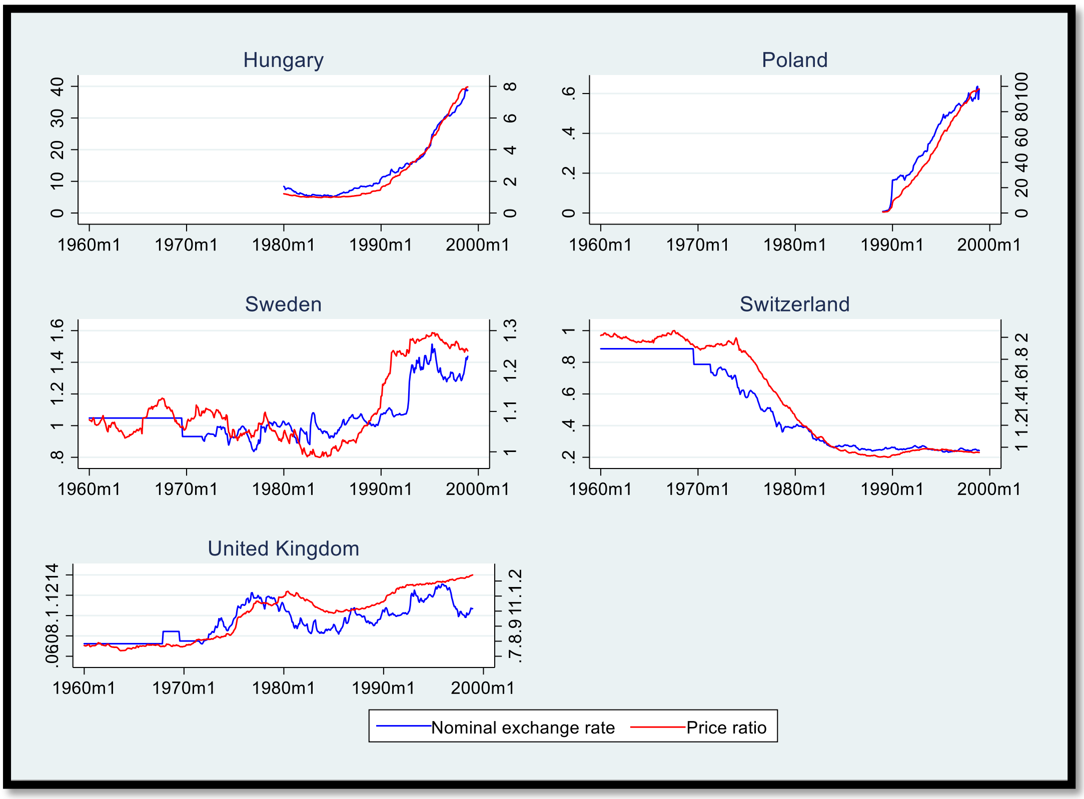


Figure 2.12: Non-Euro countries - nominal exchange rates and price ratios relative to Germany

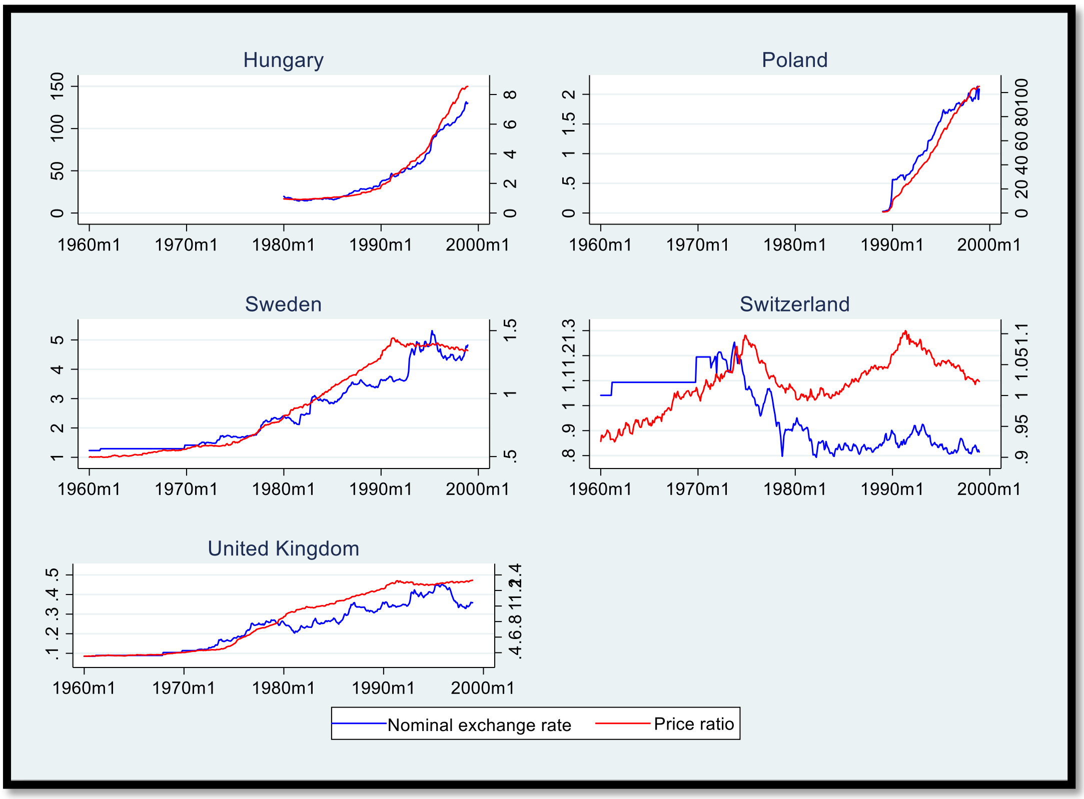


Figure 2.13: Belgium impulse response functions relative to France

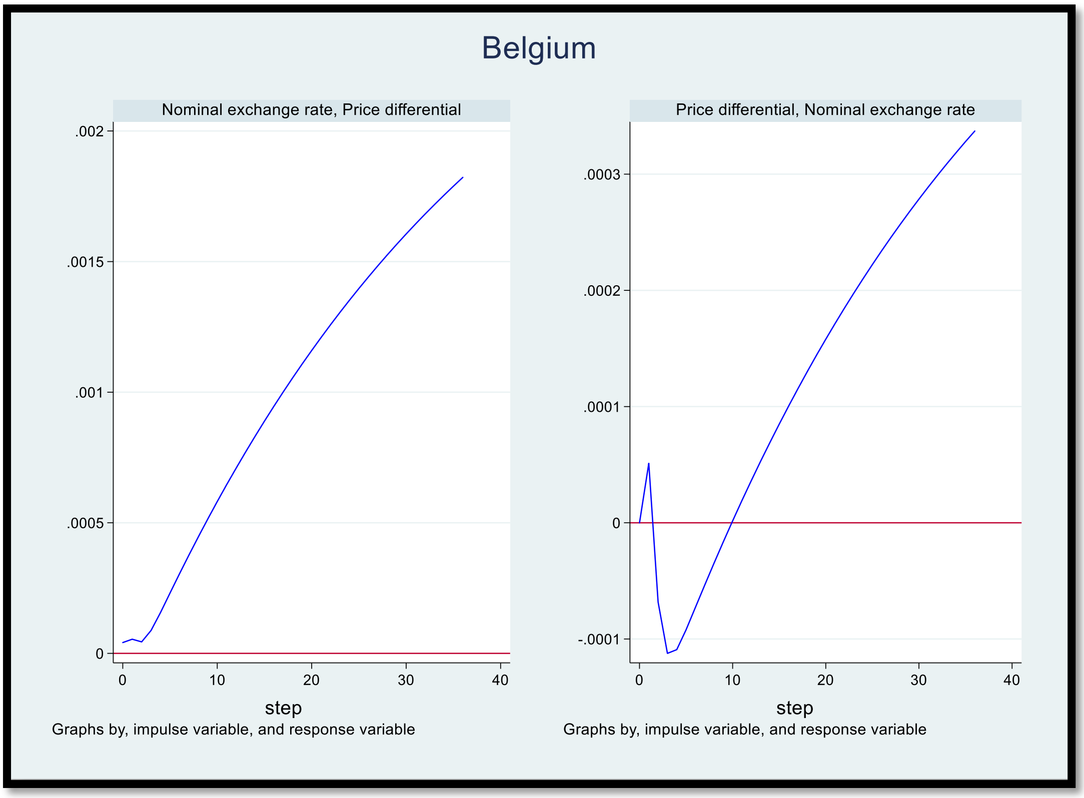


Figure 2.14: Greece impulse response functions relative to France

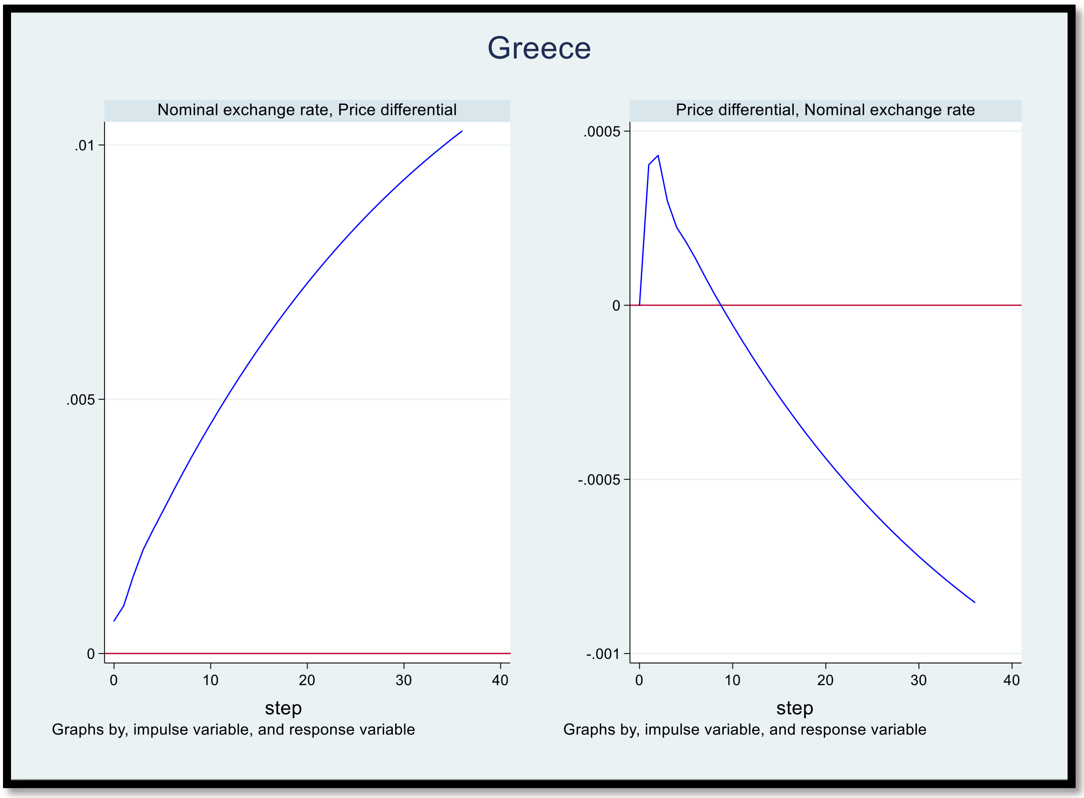


Figure 2.15: Greece impulse response functions relative to Germany

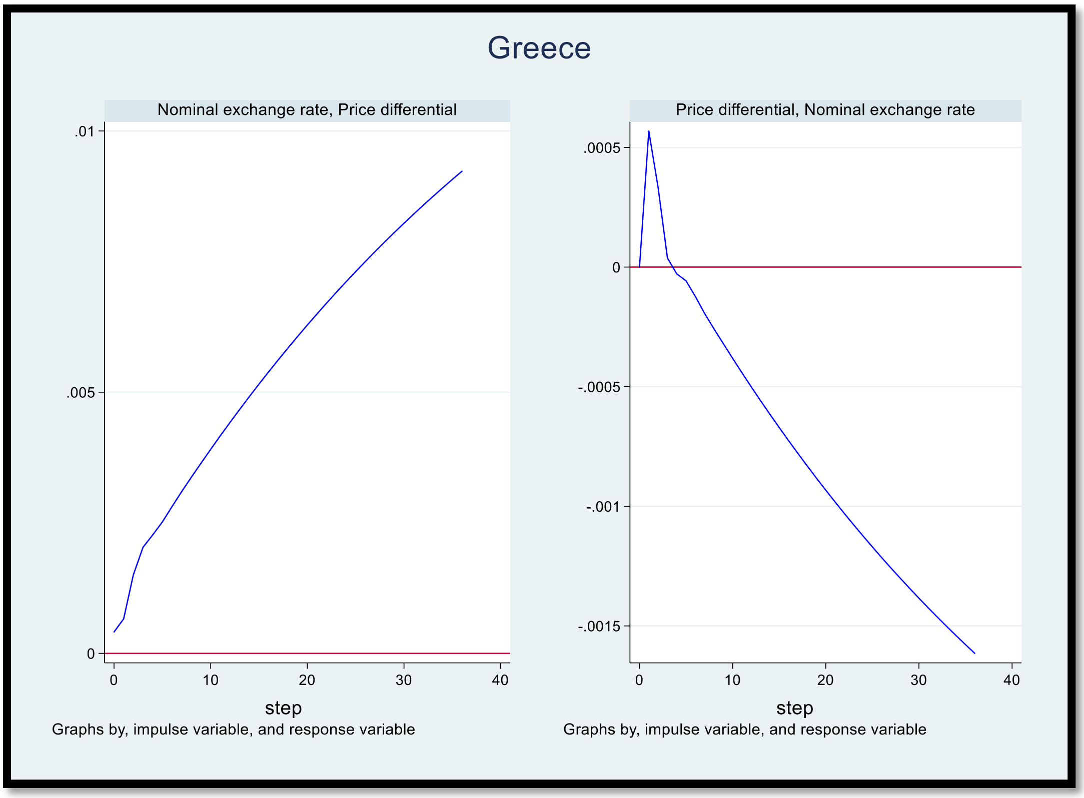


Figure 2.16: Ireland impulse response functions relative to Germany

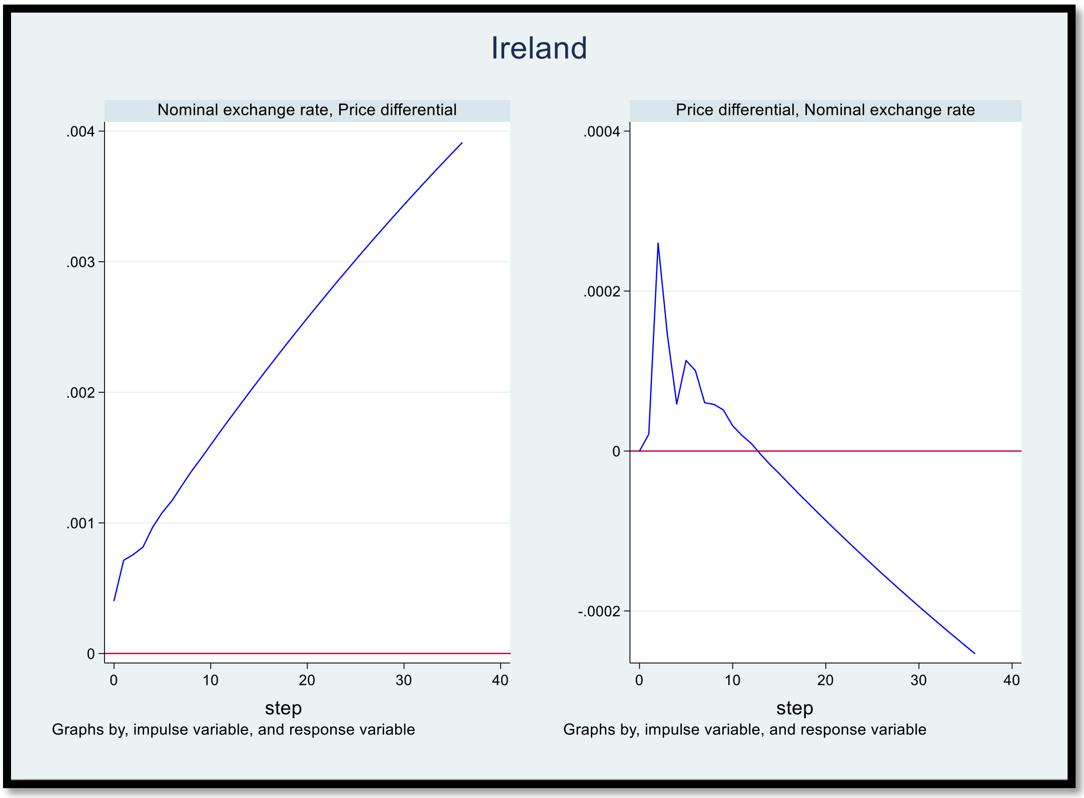


Figure 2.17: Italy impulse response functions relative to France

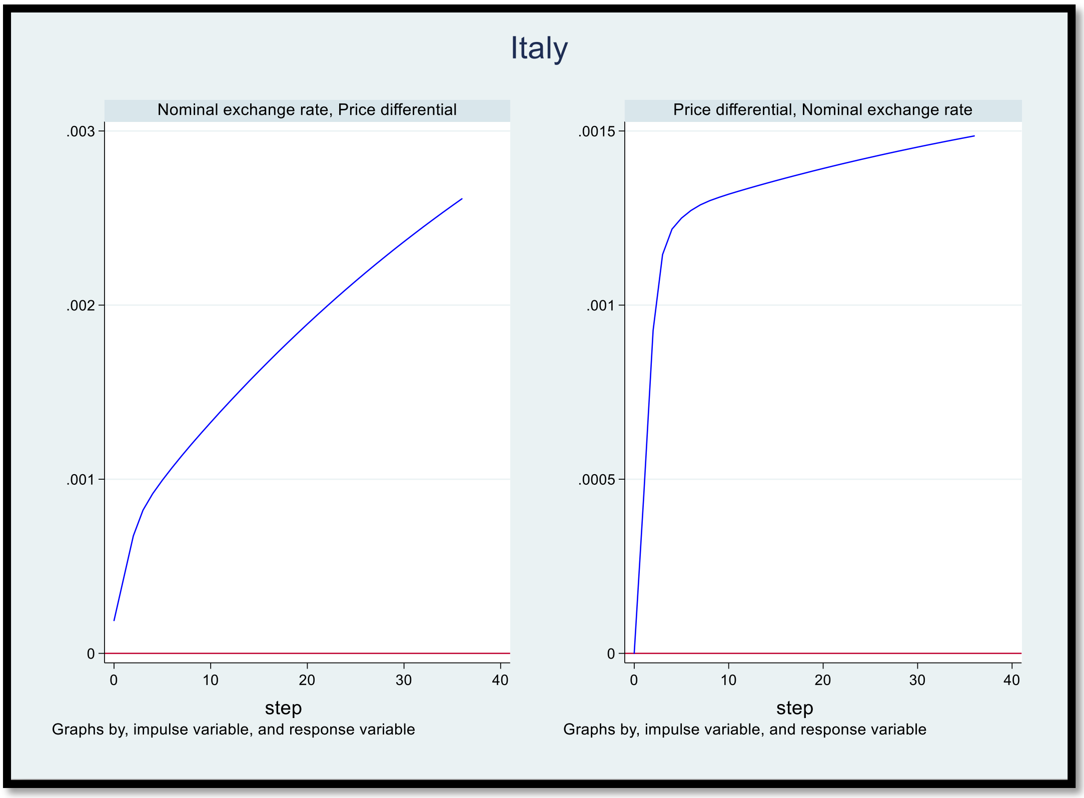


Figure 2.18: Italy impulse response functions relative to Germany

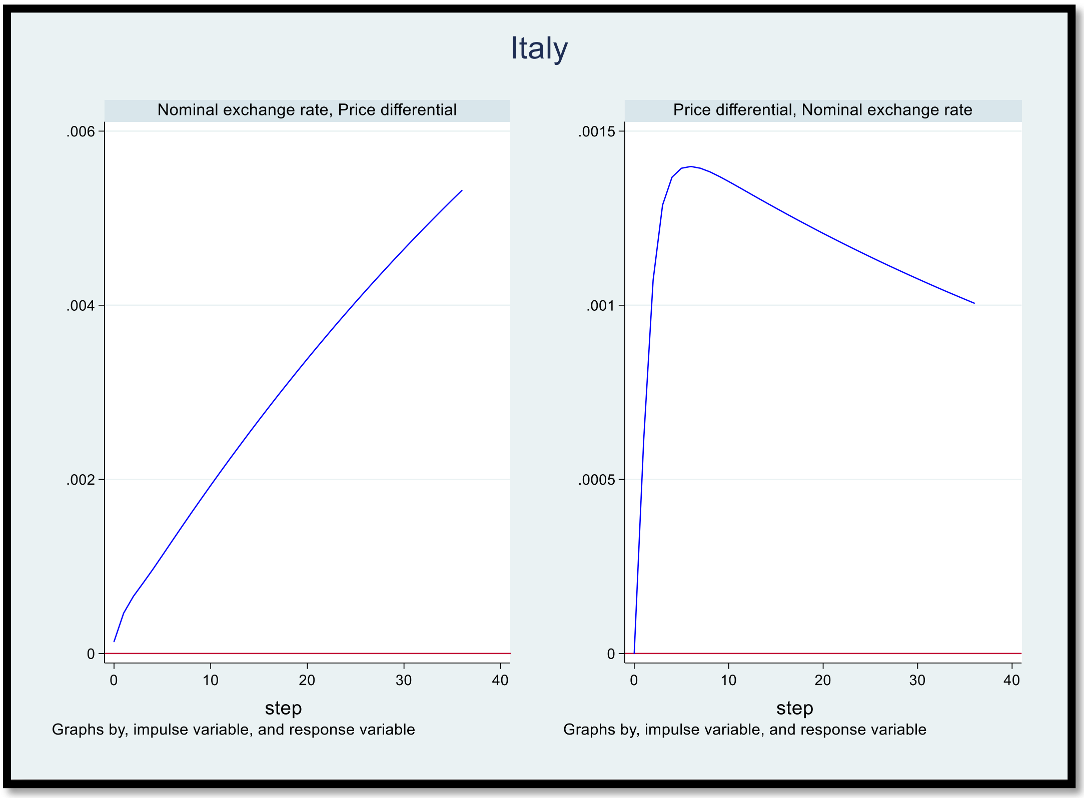


Figure 2.19: Netherlands impulse response functions relative to France

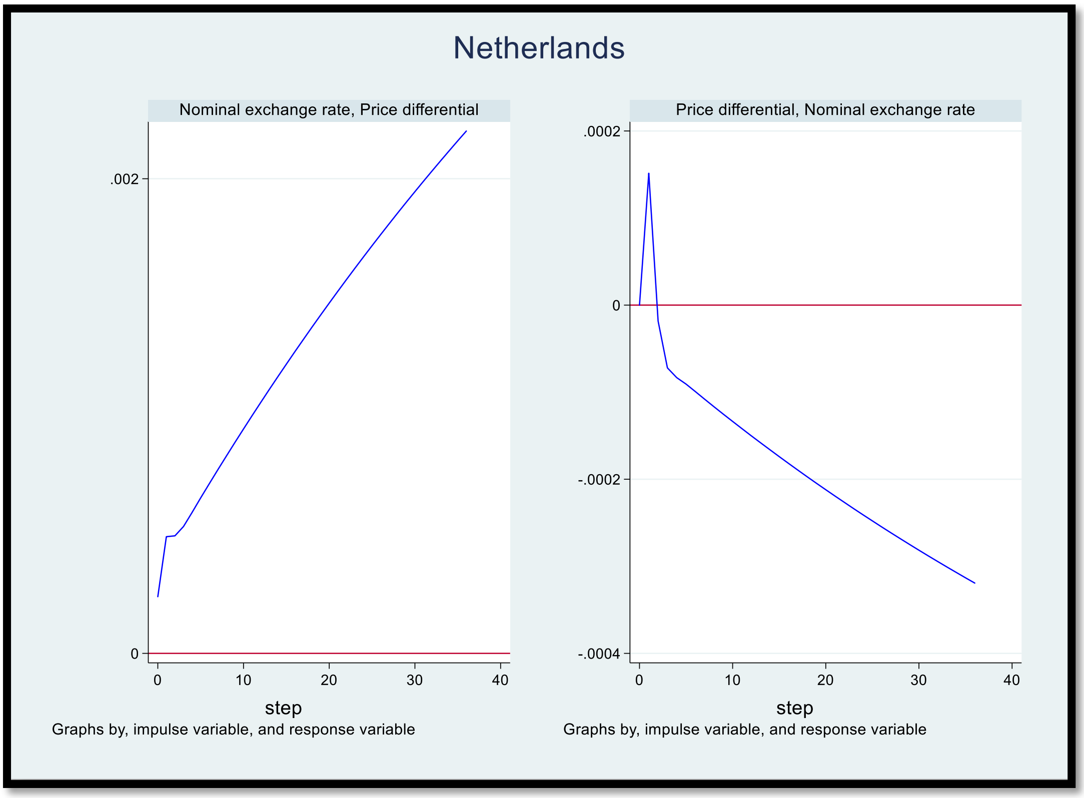


Figure 2.20: Netherlands impulse response functions relative to Germany

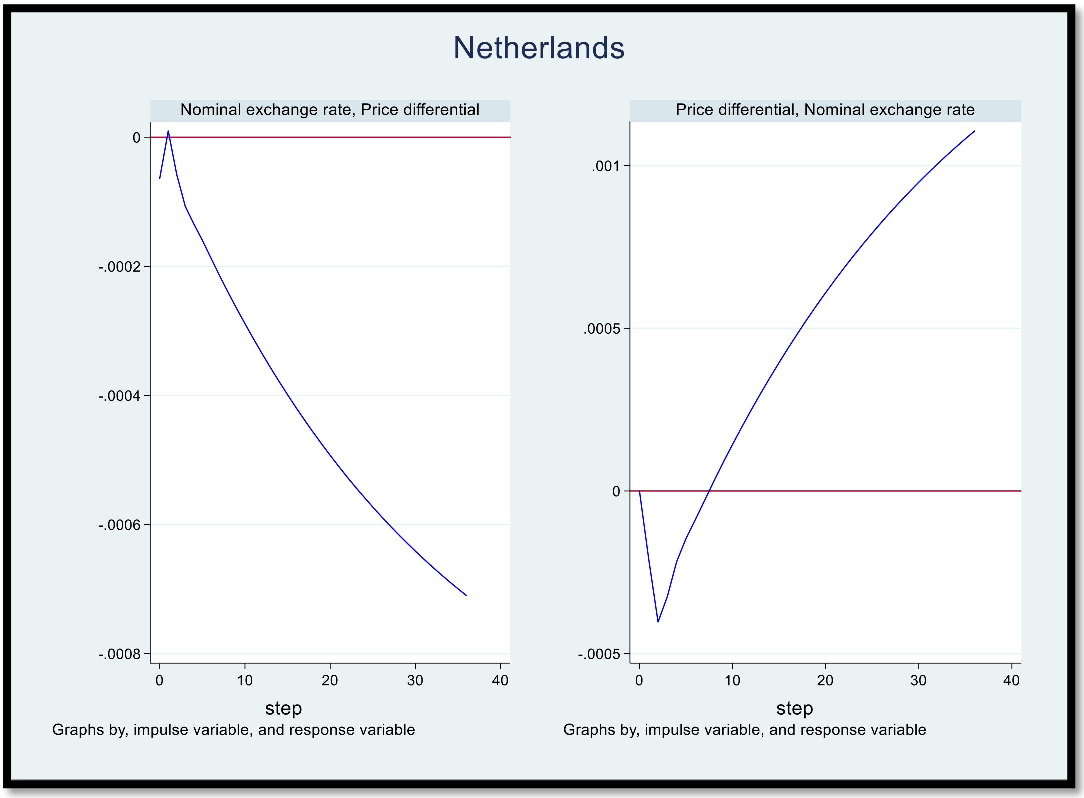


Figure 2.21: Spain impulse response functions relative to France

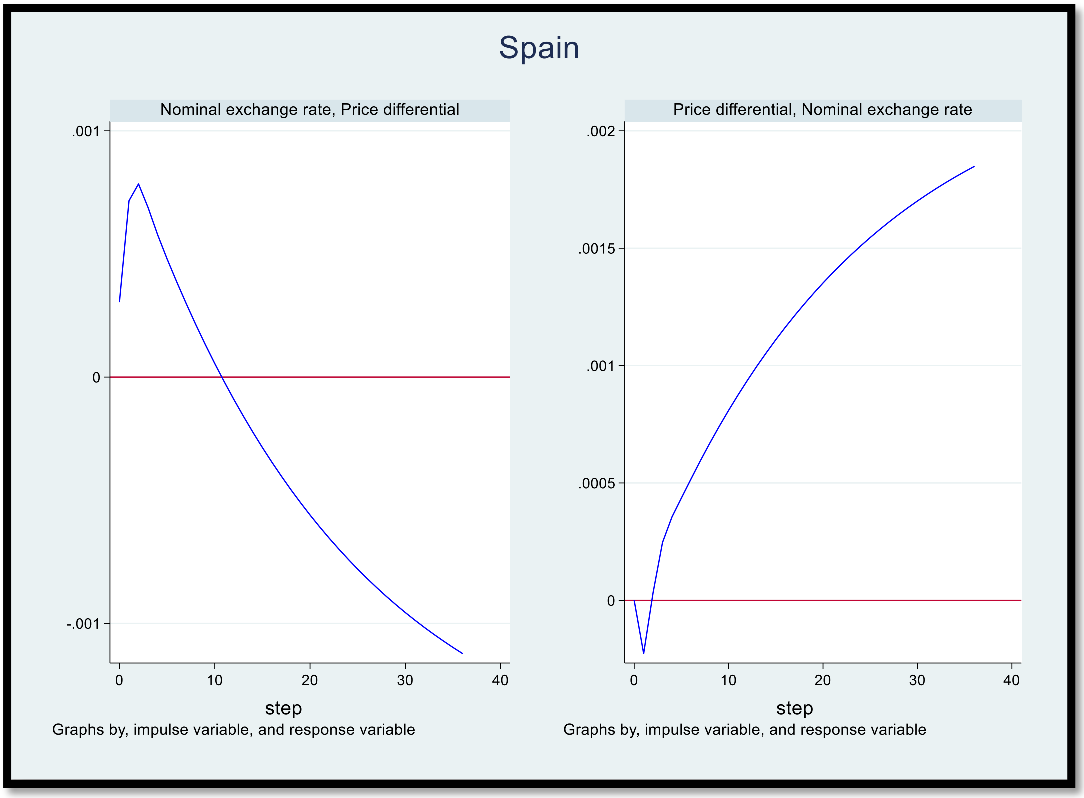


Figure 2.22: Hungary impulse response functions relative to France

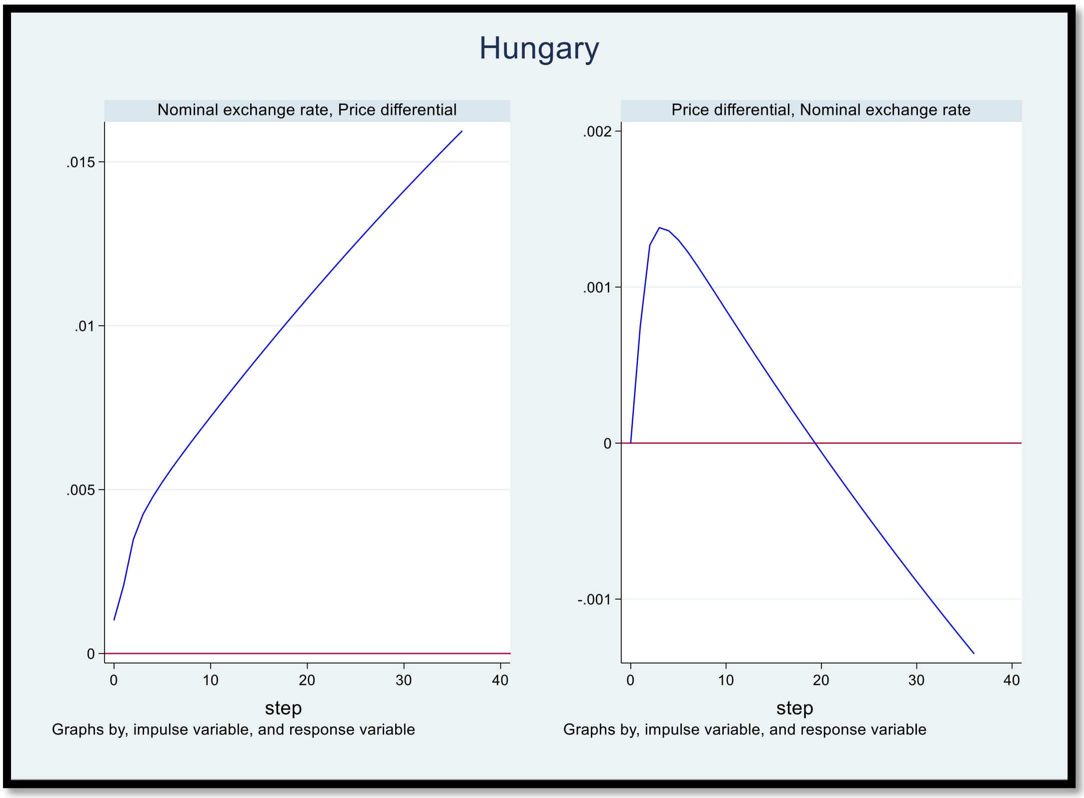


Figure 2.23: Hungary impulse response functions relative to Germany

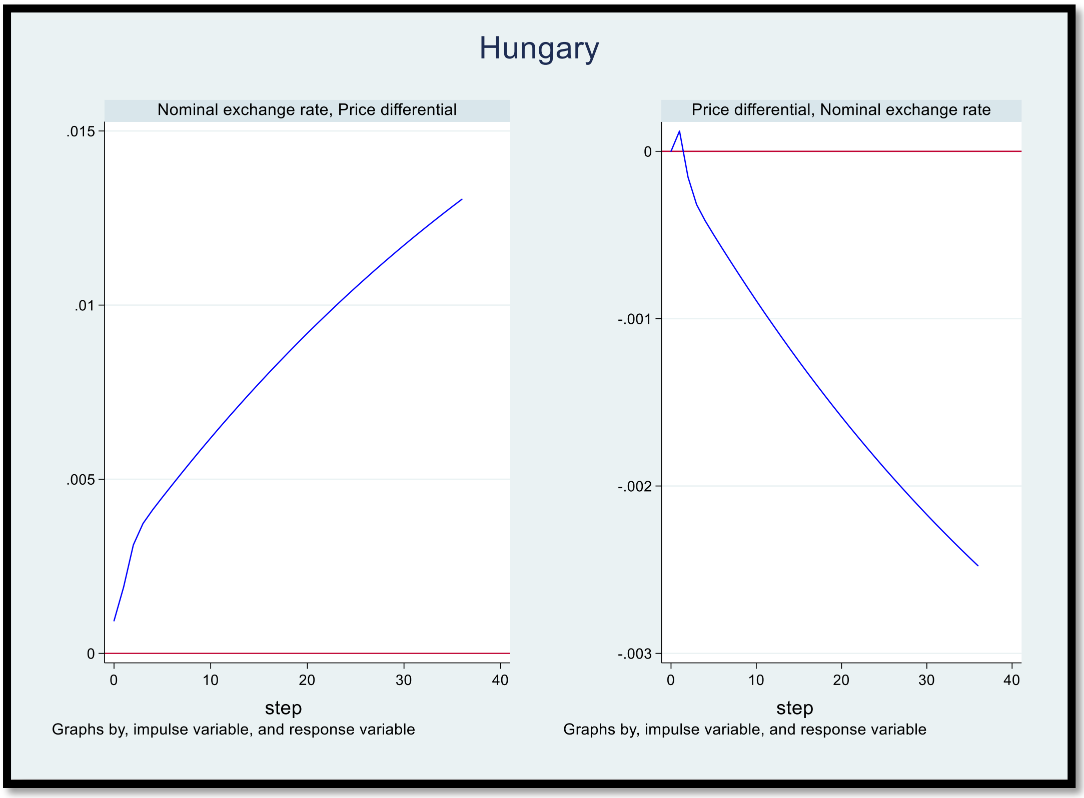


Figure 2.24: Switzerland impulse response functions relative to France

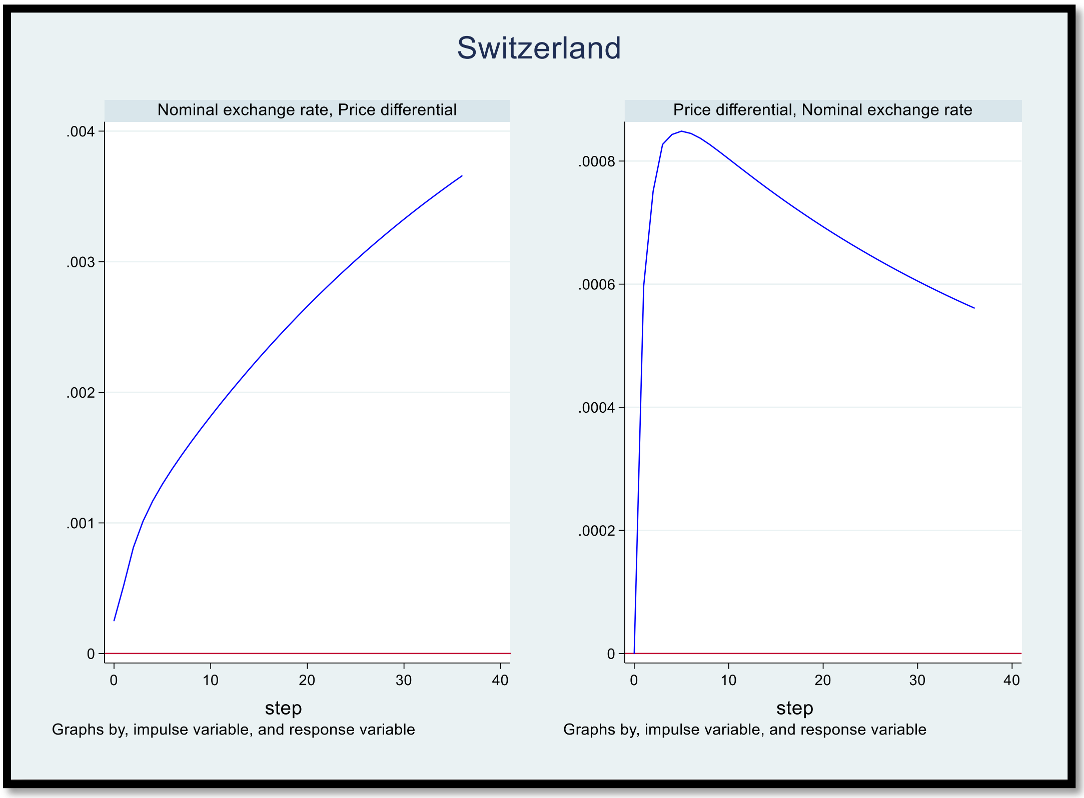


Figure 2.25: United Kingdom impulse response functions relative to France

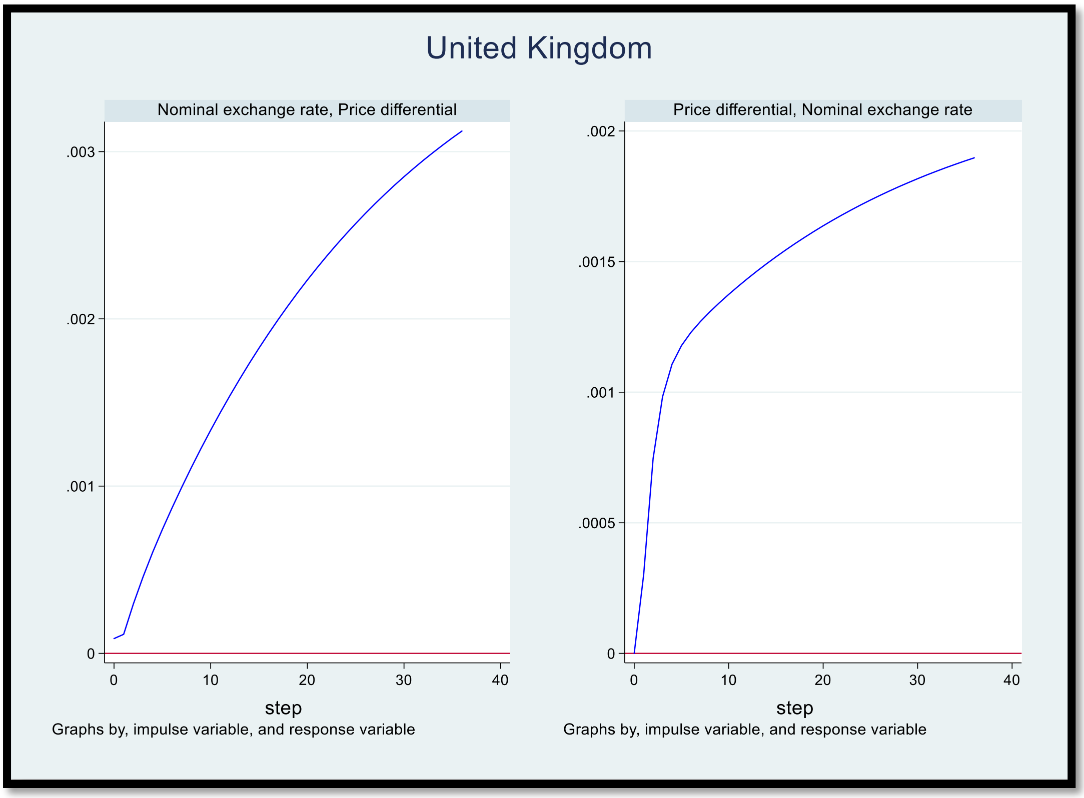


Figure 2.26: United Kingdom impulse response functions relative to Germany

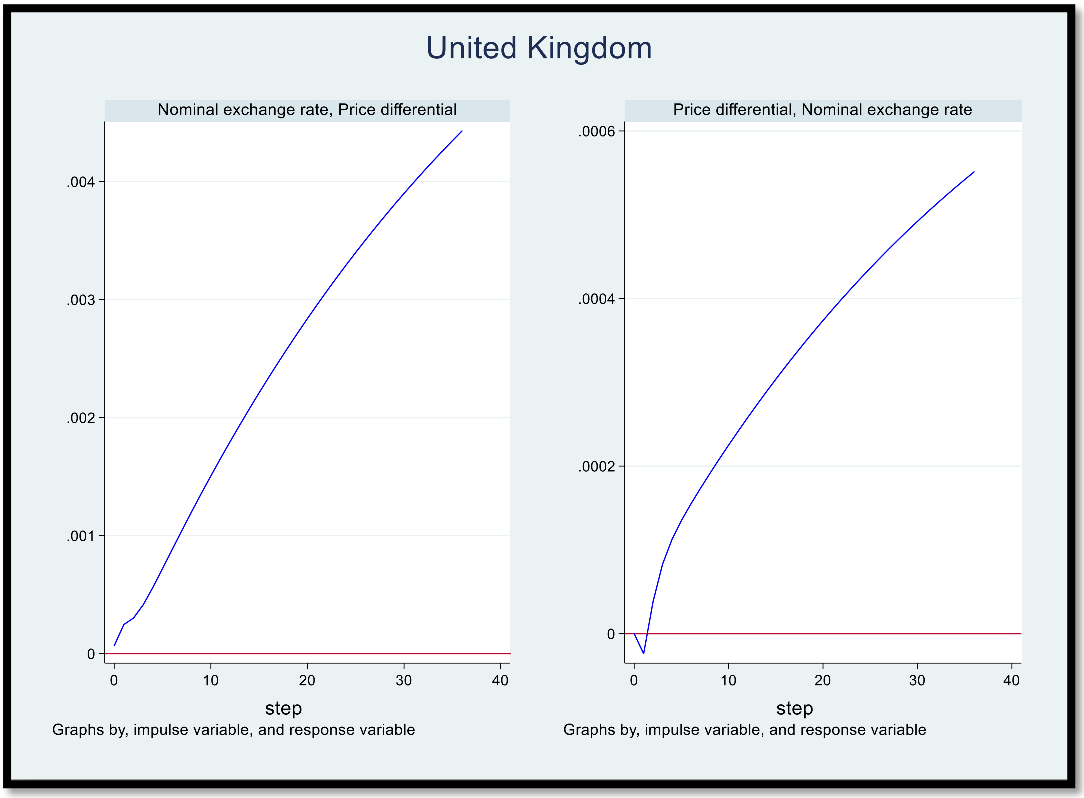


Figure 2.27: Early adopters - price differential forecasts relative to France

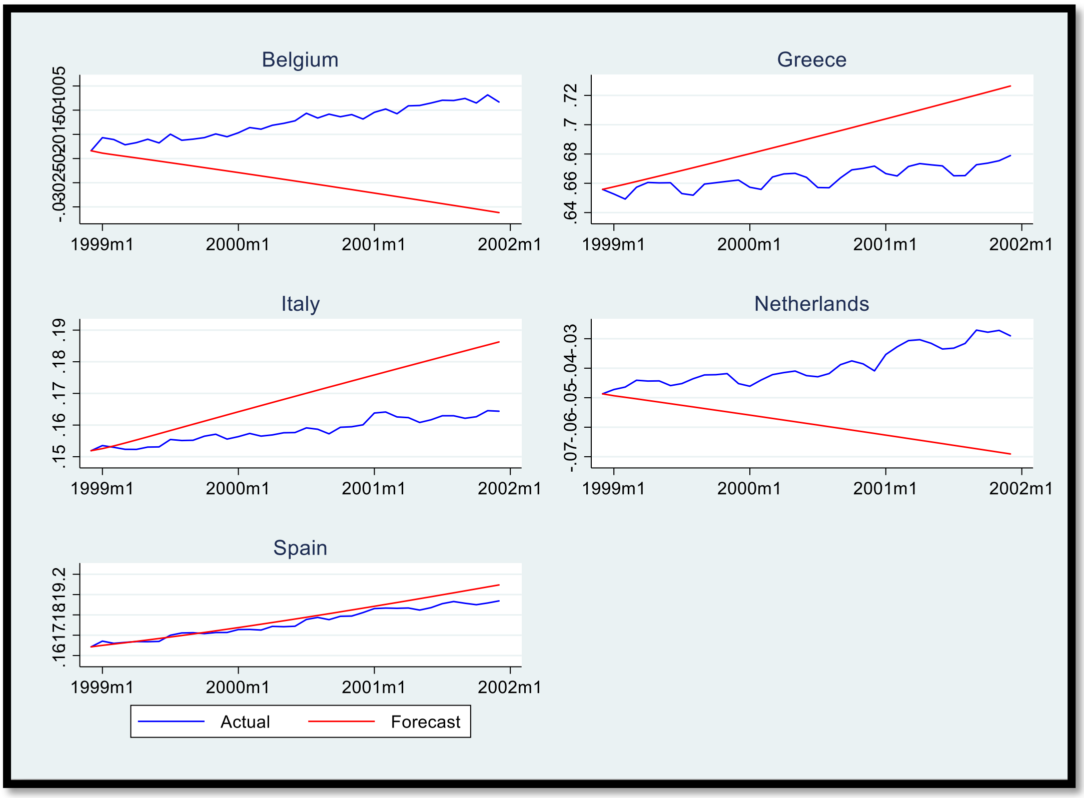


Figure 2.28: Early adopters - price differential forecasts relative to Germany

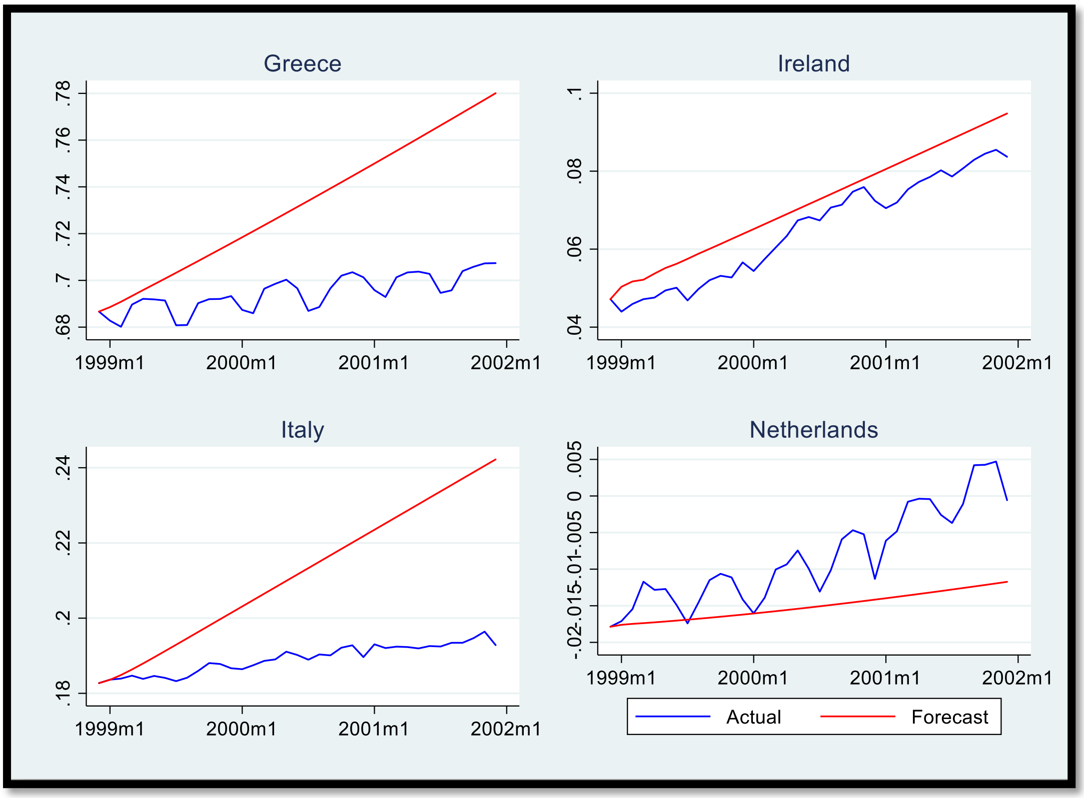


Figure 2.29: Non-Euro countries - price differential forecasts relative to France

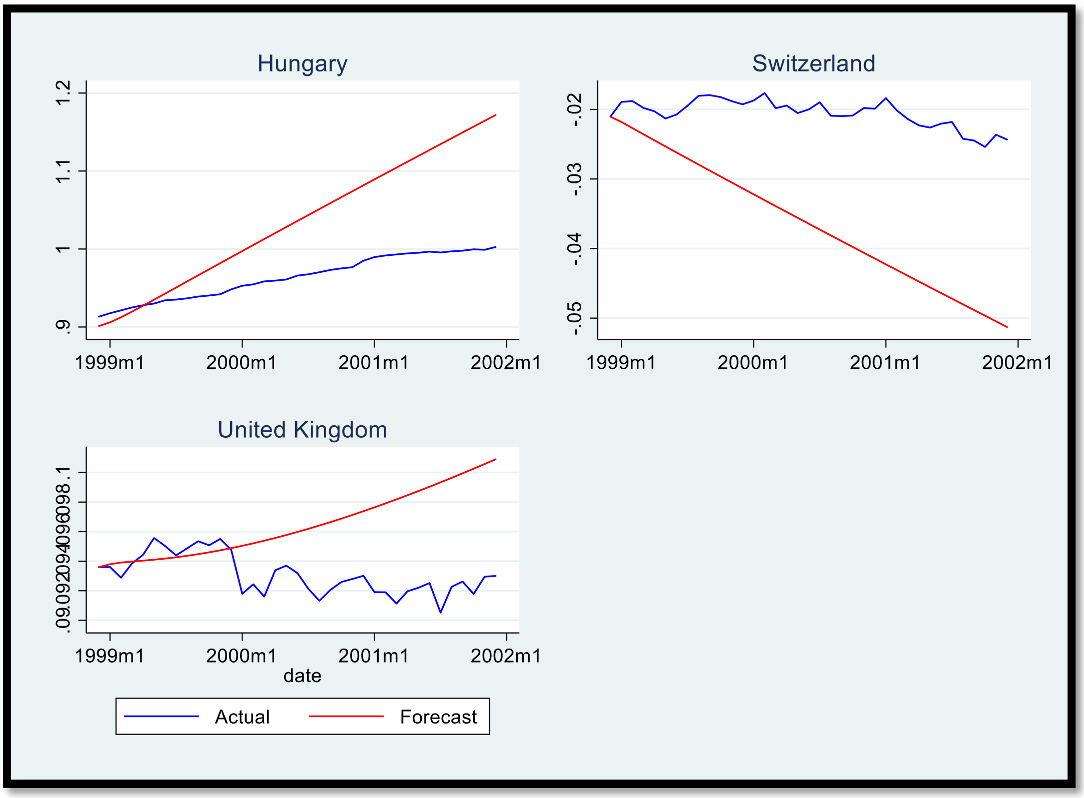
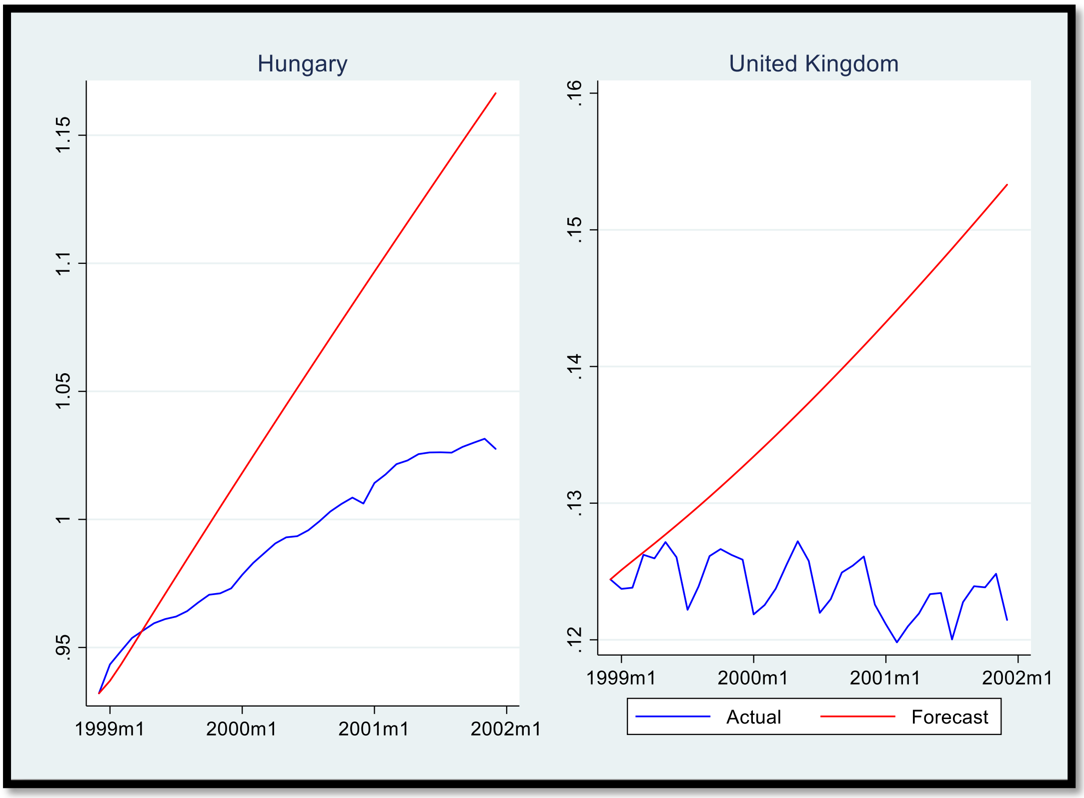


Figure 2.30: Non-Euro countries - price differential forecasts relative to Germany



Chapter 3: The Transmission Mechanism of the European Central Bank (ECB) Unconventional Monetary Policy

Abstract

During, and after the 2008 financial crisis, most monetary authorities in advanced economies officially adopted Unconventional Monetary Policy (UMP); that involves the mass purchase of treasury and mortgage-backed securities. This policy is intended to serve the purpose of mitigating the effects of crises, especially when the interest rate has reached the so-called zero lower bound. This study attempts to examine the transmission mechanism/channels of ECB UMP, including both domestic and international spill-over effects, employing a Global Vector Autoregressive (GVAR) model. Generally, ECB UMP effects show encouraging and positive responses from economies within the Euro Area region while international spill-over effects are mixed, probably due to the diverse nature of the monetary policy regimes deployed in the different countries, especially the emerging economies.

Key Words: *Unconventional Monetary Policy (UMP), Global Vector Autoregressive (GVAR)*

3.1 Introduction

This study applied the Global Vector Autoregressive (GVAR) model to monthly macroeconomic data of 15 countries/areas over the period 2007-2019, with the aim of investigating the domestic and international/spill-over effects of the European Central Bank UMP. Given the diversity of the countries chosen, the results were just as diverse. The equity indices showed the highest degree of responsiveness to unconventional monetary policy at domestic and international level. The cross-border effects are generally greater than the domestic effects for all chosen spill-over variables. The data is later aggregated, and a regional analysis is conducted. Finally, a monetary policy sensitivity analysis is conducted with the aim of revealing how responsive monetary authorities are to variations in the macroeconomic variables. The findings showed that monetary authorities in the advanced economies, are in general, more sensitive to macroeconomic variations than emerging economies.

Section 3.2 presents a literature review on conventional and unconventional monetary policy. Section 3.3 discusses the GVAR model and the data used, and further presents some preliminary results. Section 3.4 and section 3.5 give detailed discussions on the dynamic analysis and monetary policy sensitivity analysis respectively. Finally, a conclusion is given in section 3.6.

Unconventional Monetary Policy is a form of monetary policy used when the conventional approach of adjusting the central bank rate is not an option anymore, particularly when the central bank rate has reached the so-called Zero Lower Bound (ZLB) or a negative value or a point at which it loses its policy effectiveness. The central bank essentially buys Mortgage-Backed Securities (MBS) or treasury securities and other financial assets in order to inject liquidity into the economy. In addition to purchases of MBS and other securities, the central bank also avails credit, especially to the private sector, with the objective of stimulating economic activity and reducing medium and long-term interest rates. It can also be argued that this has the effect of reducing the spread between the long- and short-term interest rates. In general, unconventional monetary policy directly targets the cost and availability of external finance to banks, households, and non-financial institutions. This approach further ensures that inflation does not fall below the central bank's target rate and may be used to help economies recover during recessions and crises.

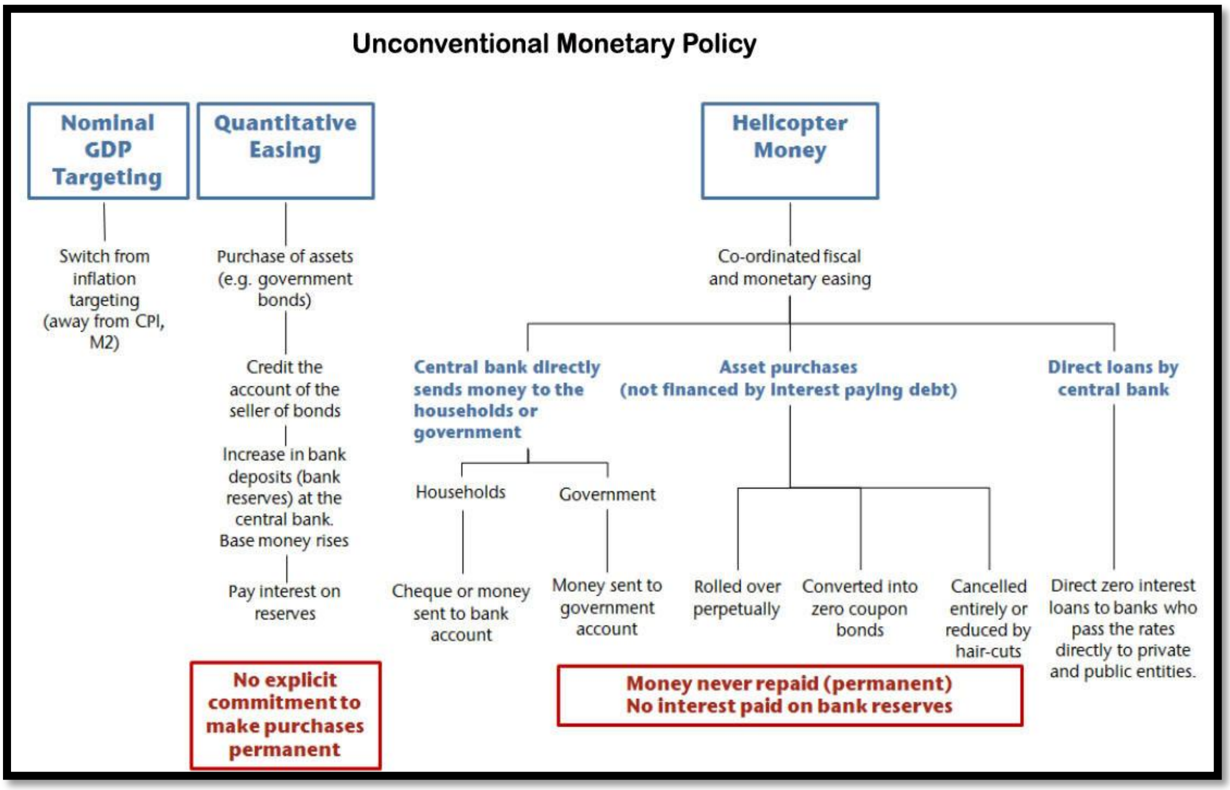
It is argued that this monetary policy approach was first deployed by Japan in the late 1980s in response to the burst of their property and stock markets. Most of the advanced economy central banks only adopted it after the 2007/2008 financial crisis. Emerging markets have long argued that this form of intervention is too costly and cannot be supported by their economies, and are therefore, a reserve for the developed nations. However, some of them seem to be picking interest in this form of monetary action. UMP is essentially an indicator that the central bank is willing to do whatever it takes to help an economy recover.

The four major central banks; European Central Bank (ECB), US Federal Reserve (US Fed), Bank of England (BOE) and Bank of Japan (BOJ) have been the main users of quantitative easing, and this has seen the assets of these banks increase drastically since the 2007/2008 crisis, therefore, the assets growth is used as the unconventional monetary policy variable in this study. Ever since the global financial crisis and sovereign debt crisis, which saw a number of banks and governments experience liquidity squeezes, the ECB has played a pivotal role in stimulating and maintaining financial stability, acting as a Lender of Last Resort (LOLR). The ECB injected liquidity into the economy using three main types of operations; Main Refinancing Operations (MROs), Long-Term Refinancing Operations (LTROs) and Very Long-Term Refinancing Operations (VLTROs). In addition to this form of unconventional monetary policy, the ECB also purchased several government bonds, especially in stressed markets, under the Securities Markets Programme (SMP). Several central banks have also employed a more drastic unconventional approach by lowering the interest rates to below zero as a last resort.

Much as UMP seems an easy process to get into, especially for centrals banks with sufficient financial capacity, an effective exit strategy needs to be designed once the economy rebounds and the central bank has achieved its inflation target. Smagi (2009) argues that this may not be an easy task, especially in two aspects; first, devising the right sequence of phasing out of the conventional and unconventional monetary policy accommodation, and second, deciding on the speed at which the unconventional accommodation is removed. This has proved to be a problem for several central banks.

Quantitative easing is the dominant form of UMP and is the focus of this study. However, it should be noted that there are also other forms of UMP like helicopter money and nominal GDP targeting. These other forms have also been advocated for, especially in the advanced economies. Figure 3.1 below demonstrates a detailed representation of quantitative easing and helicopter money.

Figure 3.1: Main forms of unconventional monetary policy



***Source**: Jefferies*

Figure 3.2 and Figure 3.3 below show how significantly the assets of the four major central banks have increased ever since the 2007/2008 financial crisis. This is a clear indication of more deployment of UMP after the central bank interest rates got to zero or near the ZLB. At this point, the unconventional approach may be the only option since the interest rate may not be effective in stimulating activity as earlier discussed.

Figure 3.2: Central bank interest rates

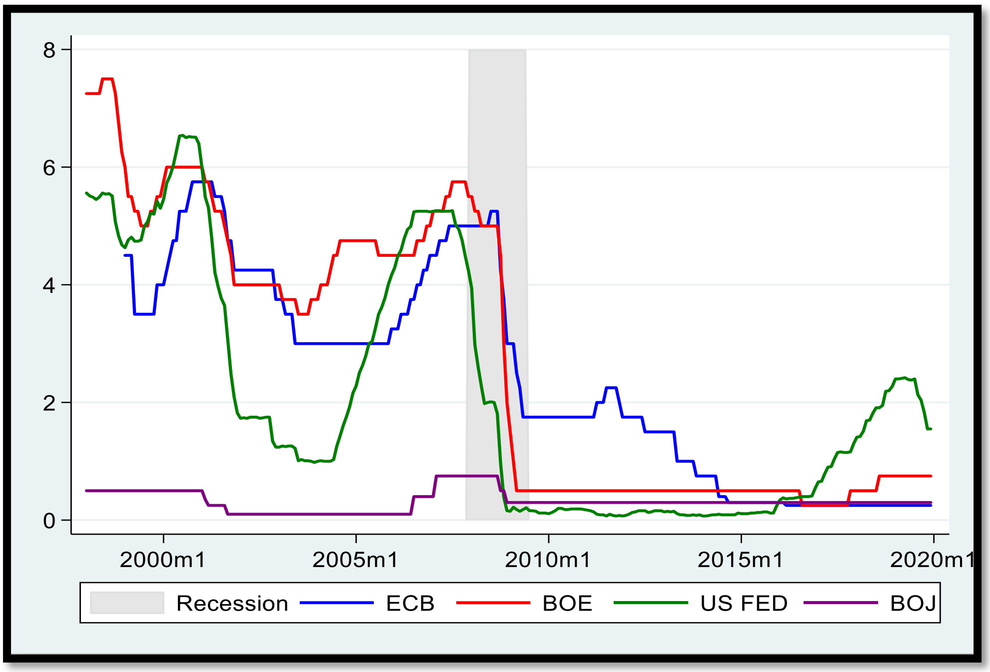


Figure 3.3: Central bank assets index

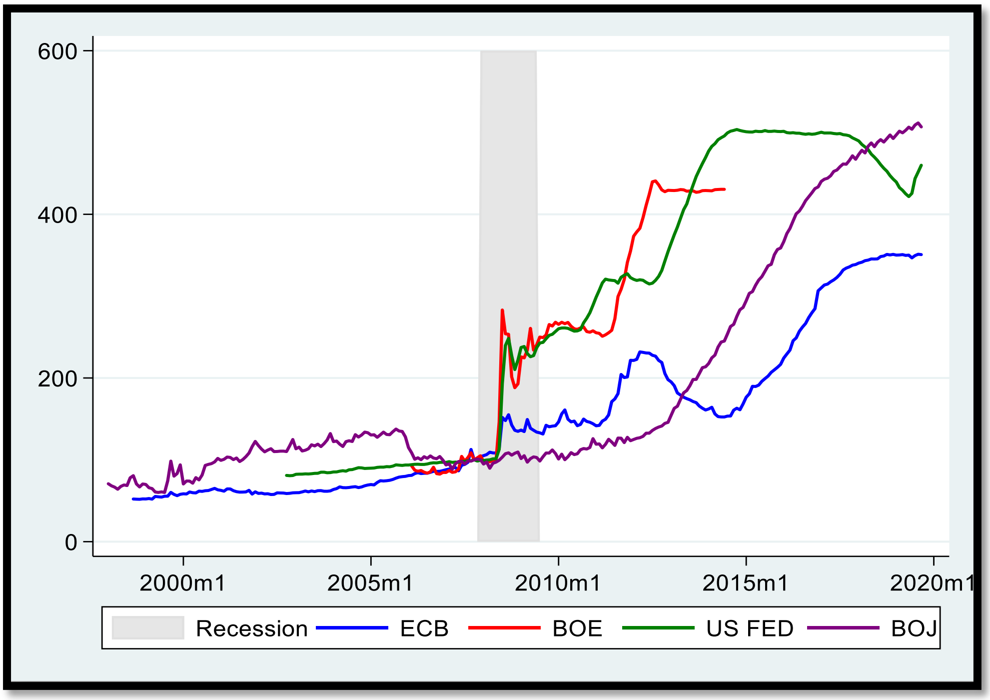
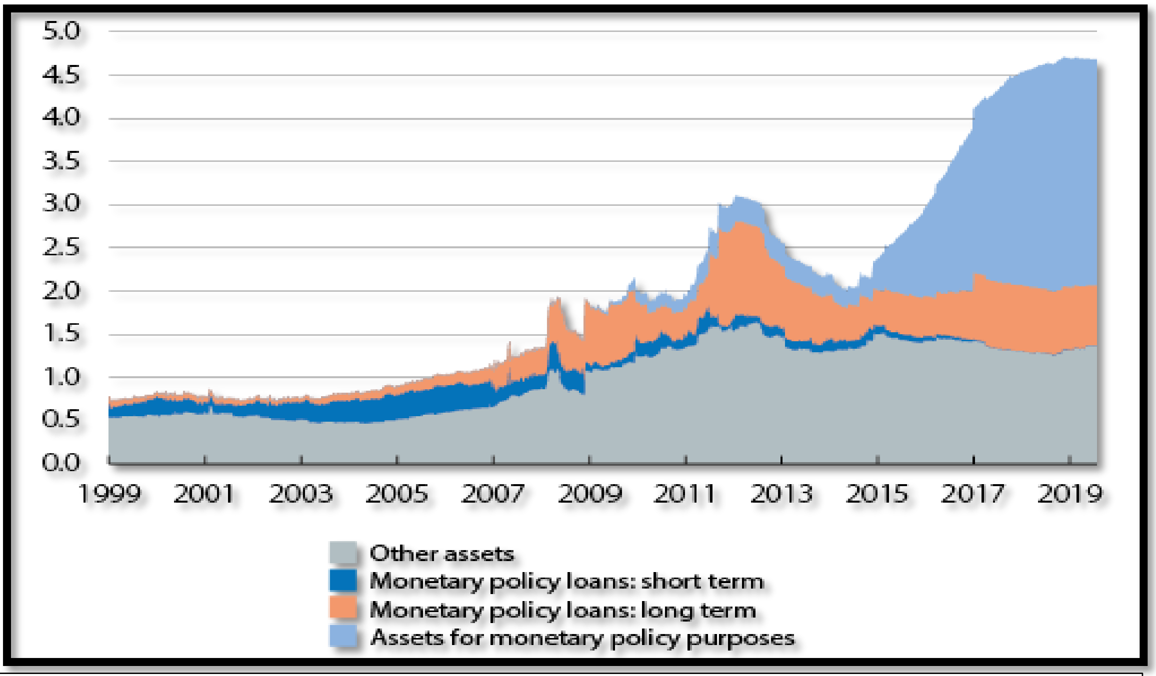
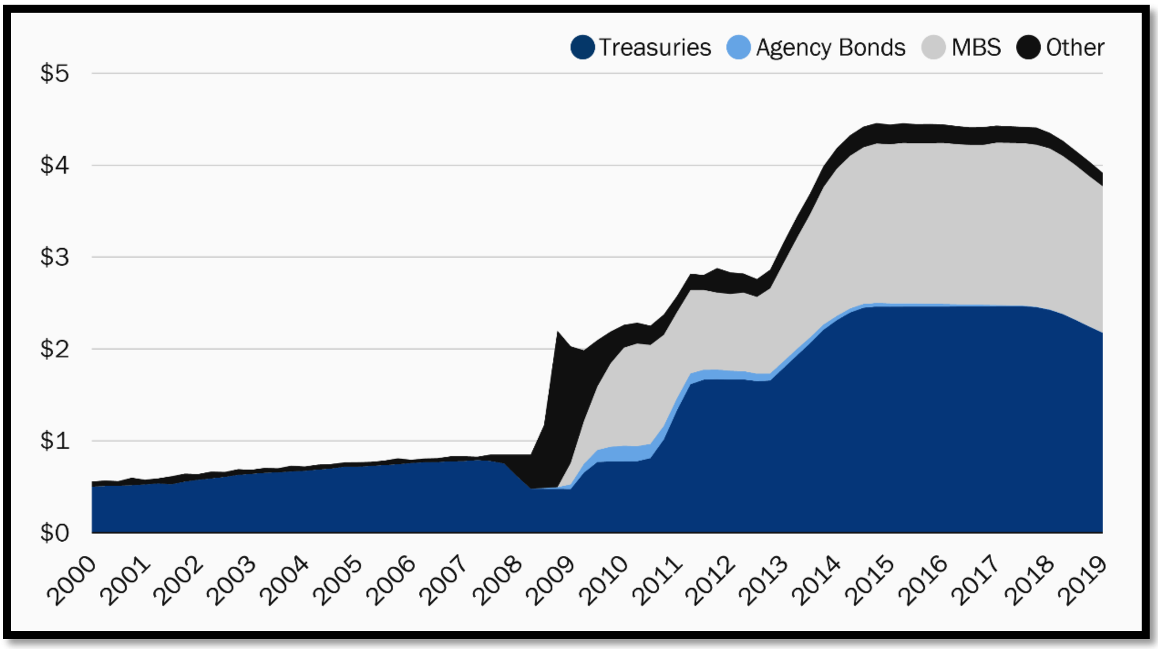


Figure 3.4: Composition of ECB balance sheet assets in trillion EUR



Note: Short-term and long-term loans consist essentially of MROs and LTROs respectively. Assets for monetary policy purposes mostly relate to purchases under the APP (Asset Purchase Programme) and other previous programmes like CBPP (Covered Bond Purchase Programme) and SMP (Securities Markets Programme). Other assets category includes gold, cash, foreign reserves, other monetary policy operations etc.
Source: *CaixaBank research, based on data from the ECB*

Figure 3.5: Composition of US Fed balance sheet assets in trillion USD



Source: *Federal Reserve H.4.1 via Haver Analytics*

Table 3.1: US Federal Reserve Large Scale Asset Purchases

The Federal Reserve's Large-Scale Asset Purchase (LSAP) Programs				
	Announcement	Termination	Assets Purchased	Amount[1]
LSAP1	Nov. 2008		Agency mortgage-backed securities (MBS) and agency debt	$600 billion
	Mar. 2009		Agency securities	$850 billion
		Mar. 2010	Longer-term US Treasury securities	$300 billion
LSAP2	Nov. 2010	Jun. 2011	Longer-term US Treasury securities	$600 billion
Maturity extension programme (MEP)	Sep. 2011		US Treasury securities with remaining maturities of six to 30 years	$400 billion
	Jun. 2012	Dec. 2012	US Treasury securities with remaining maturities of six to 30 years	
LSAP3	Sep. 2012	Oct. 2014	Agency MBS	$40 billion per month[2]
	Dec. 2012	Oct.2014	Longer-term US Treasury securities	$45 billion per month[2]

[1]Initially announced amount of asset purchases for each program or program expansion.
[2]The purchases were open-ended when they were announced. The Federal Reserve started to taper the asset purchases in January 2014, and eventually halted the purchases altogether in October 2014.
Source: *US Federal Reserve*

3.2 Literature Review

3.2.1 Conventional monetary policy and the economy

Monetary policy shocks resulting from a change in money supply and adjustment of the interest rate may have ripple effects on other economic variables ranging from; stock prices, inflation, exchange rate, GDP, and others. As stated by Kim (1999), monetary policy shocks have significant short-run real effects, these effects allow the authorities to change price fluctuations significantly. There is a vast and detailed literature on conventional monetary policy effects and adjustment mechanisms, some of which are discussed in this section.

Frankel and Hardouvelis (1985) develop a theoretical model of *overshooting*[43] in commodity markets to study the effect of expected money growth (surprises) on commodities. Money surprise effects show up immediately in many commodity prices while other commodity prices are sticky. They find that, generally, the effect of money surprises is statistically significant and of mixed sign for most of the commodities, though at varying levels.

In a rather comprehensive contribution by Bernanke et al. (1997), the scholars add structure[44] to a VAR system, and find that an important part of the effect of oil price shocks on the economy result from the tightening of monetary policy. Specifically, Bernanke et al. (2004) study suggests that a 10% oil price increase is associated with a 150-basis point increase in the US federal funds rate. Anzuini et al. (2012), in their paper, using a standard VAR system found that an expansionary monetary policy shock drives up commodity prices, however, the effect of US expansionary monetary policy does not appear to be overwhelmingly large. Furthermore, their findings suggest that the extraordinarily monetary policy easing deployed to contrast the real effects of the financial crisis is likely to push commodity prices up, albeit to a small extent. Sousa and Zaghini (2007), in a study that covered the G5[45] countries, using a structural VAR and controlling for interactions between variables, find that the effect of monetary policy liquidity shocks may be transmitted to commodity prices at different speeds, with some

[43] A known change in money supply is shown to cause an instantaneous change in commodity prices that is greater than the proportionate change that describes long-run equilibrium.
[44] The researchers argue that it is not possible to infer effects of monetary policy rules from a standard VAR system since this approach gives little or no structural interpretation of the coefficients that make up the lags in the system. They also attempt to sort out the effects of anticipated and partially unanticipated policy changes. The researchers further acknowledge that their approach may be crude and vulnerable to the Lucas critique which argues that it is naive to try to predict the effects of a change in economic policy entirely based on relationships observed in historical data, especially data that is highly aggregated.
[45] USA, Euro Area, Japan, UK and Canada.

countries responding faster than others and adjusting back to equilibrium at different rates. There is indeed a time-lag necessary for these shocks to impact on price dynamics.

Eichenbaum and Evans (1995) attempt to isolate measures of exogenous shocks to monetary policy, and discussing their results based on the Romer and Romer (1989) index measure of monetary policy contractions, using five[46] nominal spot exchange rates, find that a contractionary shock to US monetary policy leads to; (i) a persistent and significant appreciation in the US nominal and real exchange rates. This effect is not contemporaneous though, but appreciations continue for a considerable period of time and (ii) persistent and significant deviations from uncovered interest rate parity in favour of US investments.

Faust et al. (2003), using high frequency data and a VAR system, measure the impact of the surprise component FOMC (Federal Open Market Committee) meetings that were not anticipated by the markets to represent monetary policy shocks. Findings reveal that the peak timing of the exchange rate effect is quite imprecisely estimated, as in, it may come nearly immediately, a phenomenon defined as overshooting or come several years later. It is argued that, generally, the exchange rates might Granger cause money supply because monetary policy makers react to the exchange rate in setting money supply, this is supported by a good number of scholars including Engel and West (2005). However, the reverse may also be true.

Uhlig (2005), while imposing sign restrictions on the impulse responses of prices, unborrowed reserves and federal funds rate, in response to a monetary policy shock, finds that contractionary monetary policy shocks have an ambiguous effect on real GDP, specifically moving it up and down by up to ±0.2%, with a probability of 2/3. In addition, the GDP deflator tends to fall slowly, indicting a possibility of price stickiness. The commodity price index responds quicker, falling much faster. Bernanke et al. (1997) state that identified shocks to monetary policy explain relatively little of the overall variation in output, less than 20%.

Boivin and Giannoni (2006), using a recursive VAR over the pre- and post-1980s in the US, show that unexpected exogenous changes in the federal funds rate have been followed by a smaller response of output and inflation since the beginning of the 1980s. They further add that this phenomenon is mainly attributed to a shift in monetary policy over the years rather than the behaviour of the private sector.

[46] Yen, Deutsche Mark, Lira, French Franc and UK Pound.

Rigobon and Sack (2004), defining a heteroscedasticity-based estimator of the response of asset prices to monetary policy, estimate the response of asset prices and market interest rates to monetary policy from the heteroscedasticity of policy shocks on particular dates, including days of FOMC meetings. Their results show that a 25-basis point increase in the three-month interest rate results in 1.9% decline in the S&P 500 index and a 2.5% decline in the NASDAQ index.

Goodhart and Hofmann (2001) use VAR impulse responses and derive Financial Conditions Indices[47] for the G7 countries to determine the monetary policy stance. Their findings reveal that impulse responses exhibit rather mixed signals for the sampled countries. They further add that monetary policy should also respond to property and equity price movements in order to offset their effect on the output gap.

Zheng (2013) analyses the impact and effectiveness of US conventional monetary policy using a Threshold Vector Autoregressive (TVAR) model to capture switches between the low and high financial stress regimes, and finds that the output response to monetary policy shocks is larger during periods of high financial stress than in periods of low financial stress. In addition, expansionary monetary policy continues to be effective during periods of high financial stress, when the interest rate is at the ZLB, and expansionary monetary policy moves the US economy from high to low financial stress by keeping interest rates and credit spreads low.

3.2.2 Unconventional monetary policy

Gambacorta et al. (2014), applying a panel VAR using monthly data of eight[48] advanced economies over the period covering the onset of the global financial crisis, find that the exogenous increase in central bank balance sheets at the zero lower bound leads to a temporary rise in economic activity and consumer prices. Of great importance, is their conclusion that the results are similar to those expressed in literature to the effects of the more familiar conventional monetary policy.

Schenkelberg and Watzka (2013), using an SVAR approach on Japanese data, report that quantitative easing shocks lead to a significant but temporary/short-term rise in output by about 0.5% and the effect on inflation is not significantly different from zero, thus, it did not lead to

[47] A weighted average of the short-term real interest rate, the effective real exchange rate, real property and real share prices.
[48] Canada, Euro Area, Japan, Norway, Sweden, Switzerland, UK and USA.

an increase in inflation. They further stated that this result is of most high importance to advanced economies, where monetary policy is constrained by the zero lower bound.

Peersman (2011), while comparing the effects of conventional and unconventional monetary policy in the Euro Area using a structural VAR model, finds that the two policies have similar macroeconomic consequences. Both shocks have a hump-shaped impact on economic activity and result in permanent higher level of consumer prices. In addition, the effects of balance sheet policies on output and inflation are more sluggish.

Chen et al. (2016) examine domestic and cross-border effects of the federal fund's unconventional monetary policy using an estimated GVECM, and find that monetary policy and exchange rate responses have been diverse in emerging economies; responses in output, inflation and credit channels have been different too. In addition, they find that US unconventional monetary policy has greater impact on many emerging market economies than on the US economy itself. A phenomenon referred to as overheating, that is, a rapid and very big growth in economic activity and production that is thought to have a negative influence. This was evident in Brazil and China, though the spill-overs supported their recovery.

Miyajima et al. (2014), while studying the spill-over effects of US unconventional monetary policy to Asia, using a panel VAR, focussing on the long-term interest rate, find that the spill-over manifests itself mainly through low domestic bond yields and rapid growth of domestic bank credit. This finding is consistent with the Obstfeld (2015), who concludes that one of the transmission channels of international monetary policy is through long-term rates.

Rogers et al. (2018) use a VAR to study the spill-over effects of unconventional monetary policy measures of four[49] major central banks at the zero lower bound. They report that US monetary policy easing shocks lower domestic and foreign bond risk premia, leading to dollar depreciation and lower foreign exchange risk premia. The UK and Japanese monetary policy shocks significantly lower US ten-year yields for a few quarters.

Gertler and Karadi (2011) develop a quantitative monetary DSGE model with financial intermediaries that face endogenously determined balance sheet constraints, and find that the welfare benefits of unconventional monetary policy may be substantial if the relative efficiency costs of central bank intermediation are modest. They further add that, in a financial crisis,

[49] Bank of England, European Central Bank, US Federal Reserve and Bank of Japan.

there are benefits of credit policy even if the nominal interest rate has reached the zero lower bound.

Cahn et al. (2017) examine whether central bank liquidity injection can induce banks to lend to firms in times of aggregate stress using a difference-in-difference approach, examining the causal effects of a positive credit supply shock to some firms relative to closely comparable non-treated firms, and to show how banks changed their lending to these kind of firms during the crisis. Their results show that the ECB's long-term Refinancing Operations (LTROs) caused an increase in bank lending to firms by around 10%.

Santos and Winton (2008) argue that during crises, banks have an information advantage over potential borrowers and are bound to charge a higher interest rate than is justified by borrower default risk alone. They test their hypothesis by comparing pricing of bank loans for bank-dependent borrowers to that of borrowers with access to public debt markets in good and bad times. Findings revealed that indeed, banks do charge higher rates to customers with limited outside funding options by a magnitude that is significant. This acts as a deterrent to the primary objective of unconventional monetary policy in times of need.

Regarding unemployment, it is argued that unconventional monetary policy may indeed have little or only a sluggish effect. This is supported by the fact that unemployment rates in most western nations have remained persistently high, even after the implementation of QE measures after the 2008 financial crisis. This is further supported by Farmer (2012).

Rosa (2014), while studying the effect of monetary policy on the level, the volatility and trading volumes of energy futures using an event study with intraday data, finds that the unanticipated Large Scale Asset Purchases (LSAPs) by the US Federal Reserve has a negative effect on oil prices. On average, a hypothetical unanticipated 100-basis point hike in the Federal Reserve rate target is associated with a 3% decrease in WTI oil prices. In addition, in a narrow window around the FOMC meeting, the cumulative financial market impact of the Federal Reserve LSAP on crude oil is equivalent to an unanticipated cut in the Federal Reserve target rate of 155 basis points. Furthermore, the channel through which monetary policy affects oil prices is mostly through the value of the US Dollar.

Kucharčuková et al (2016), applying a block-restricted VAR model, study the macroeconomic impact of ECB unconventional monetary policy on Euro Area economies and six non-EMU countries. The standard monetary VAR findings revealed that the transmission of unconventional monetary policy in the Euro Area is quite different than under the conventional approach; prices seem to react fast while output generally remains muted. The block-restricted VAR shows that Euro Area monetary policy does in fact spill-over to the economies of non-EMU countries; exchange rates respond fast, the output effect is found for a few countries and inflation is generally unaffected.

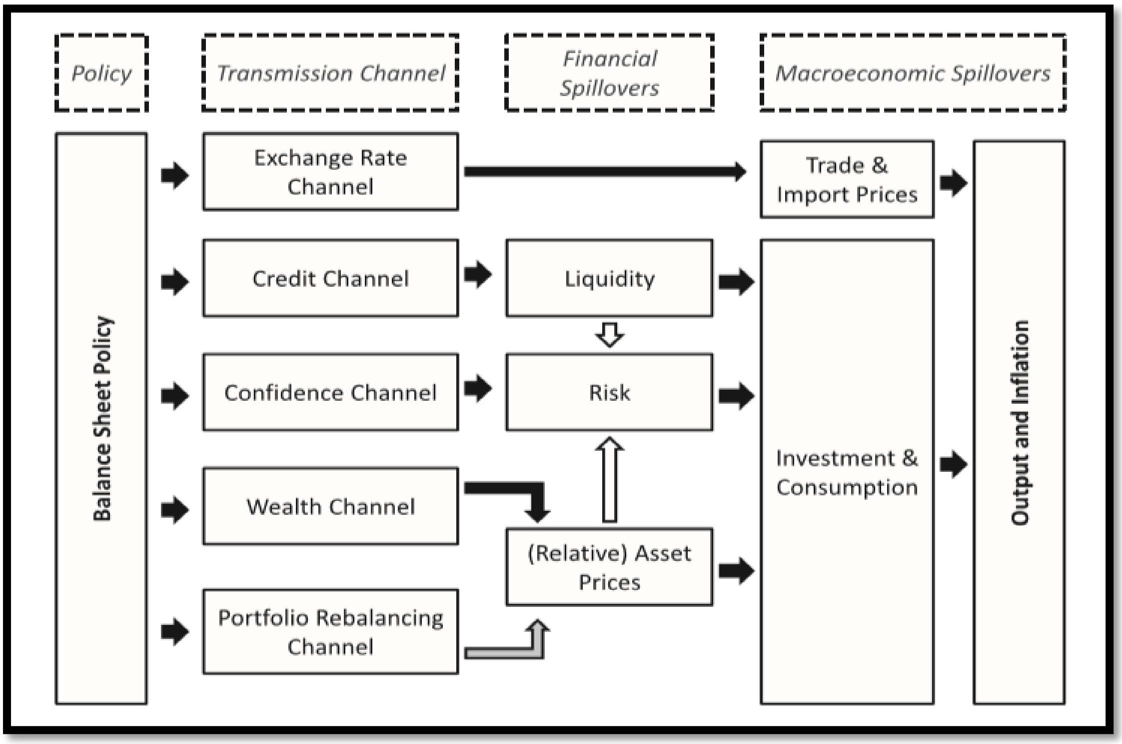
Bluwstein and Canova (2016) examine the effect of conventional and unconventional ECB monetary policy on nine non-Euro European countries using a novel Bayesian mixed-frequency structural VAR, and find that the unconventional disturbances generate a number of fluctuations; the credit channel of transmission does not play a big part, however, international spill-overs are larger in countries with more advanced financial systems and a larger share of domestic banks. Important to note was that, while unconventional monetary policy disturbances induce significant inflation, conventional monetary policy disturbances primarily affect output. This means that a combination of conventional and unconventional measures may help to better control output and inflation dynamics.

Meinusch and Tillmann (2016), examining the effect of US unconventional monetary policy using a Qual VAR linking standard business cycle dynamics with binary information on QE announcement days, show that QE has significant effects on interest rates, real economic activity, stock prices and market uncertainty. Furthermore, QE is found to be more effective in influencing real activity than conventional monetary policy.

Bowman et a. (2014) use an event study approach to analyse the effect of US unconventional monetary policy on sovereign yields, foreign exchange rates and stock prices in emerging markets. Their findings reveal that EME asset prices, especially sovereign yields in local currency, experienced large fluctuations around unconventional monetary policy announcements by the US Federal Reserve. Furthermore, US monetary policy shocks that lower US sovereign yields also lower sovereign yields in most emerging markets. In some cases, the effect on EME sovereign yields is even larger than the effect on US sovereign yields and is clearly significant and persistent. Also, several country-specific variables drive the vulnerability of countries to changes in US monetary policy. In particular, countries with high interest rates, CDS spreads, inflation rates, or current account deficits and those with more-vulnerable banking systems seem to be more affected by changes in US financial variables.

Inoue and Okimoto (2019), while applying a smooth-transition GVAR to study the effects of UMP by BOJ and the US Fed on the financial markets, taking spill-overs and a possible regime change into account, find that the BOJ and US Fed expansionary UMP have had a significant positive effect on domestic financial markets, especially in recent years. Furthermore, regarding spill-over effects, results suggested that BOJ actions had limited effects on international financial markets. Subsequently, the US Fed's international spill-over effect was approximately ten times larger than that of BOJ.

Figure 3.6: International transmission channels of unconventional monetary policy



Source: *Bluwstein and Canova (2016)*

3.3 The Global Vector Autoregressive (GVAR) Model

To investigate the effect of unconventional monetary policy on a global scale, it is important to explore a model that tries to capture the linkages between and among countries chosen in the sample. The GVAR model is a novel technique which serves this purpose well; this is a move away from the traditional VAR analysis. The theory behind this kind of model is primarily explained in Chudik and Pesaran (2016) and Dees et al. (2007). Take a panel of N cross-section units, each with k_i variables observed over the time $t = 1, 2, \ldots, T$. Individual country-specific foreign variables can be estimated using;

$$\boldsymbol{X}_{it}^{*} = \widetilde{\boldsymbol{W}}_{i}'\boldsymbol{X}_{t} \tag{1}$$

It is only reasonable that countries are globally connected through trade and the financial system or capital flows. Trade data alone can serve this purpose, and so, the weights, $\widetilde{\boldsymbol{W}}$, representing the degree of importance and interconnectedness countries have with each other is constructed to estimate the foreign variable counterparts of the domestic ones.

$\boldsymbol{X}_{it}$ is modelled as a VARX* model augmented by star or foreign variables.

$$\boldsymbol{X}_{it} = \sum_{l=1}^{p_i} \boldsymbol{\Phi}_{il}\boldsymbol{X}_{i,t-l} + \boldsymbol{\Lambda}_{i0}\boldsymbol{X}_{it}^{*} + \sum_{l=1}^{q_i} \boldsymbol{\Lambda}_{il}\boldsymbol{X}_{i,t-l}^{*} + \boldsymbol{u}_{it} \tag{2}$$

Introducing common variables, then Equation 2 becomes;

$$\boldsymbol{X}_{it} = \sum_{l=1}^{p_i} \boldsymbol{\Phi}_{il}\boldsymbol{X}_{i,t-l} + \boldsymbol{\Lambda}_{i0}\boldsymbol{X}_{it}^{*} + \sum_{l=1}^{q_i} \boldsymbol{\Lambda}_{il}\boldsymbol{X}_{i,t-l}^{*} + \boldsymbol{D}_{i0}\omega_t + \sum_{l=1}^{s_i} \boldsymbol{D}_{il}\omega_{t-l} + \boldsymbol{u}_{it} \tag{3}$$

Where $\boldsymbol{X}_{it}$ is a domestic variables vector, $\boldsymbol{X}_{it}^{*}$ is the foreign variable vector, ω_t represents the common variables, p_i, q_i and s_i are lag lengths of domestic, foreign and common variables respectively. $\boldsymbol{\Phi}_{il}$, $\boldsymbol{\Lambda}_{il}$ and $\boldsymbol{D}_{il}$ are coefficient matrices of order l and $\boldsymbol{u}_{it}$ is a vector of idiosyncratic country-specific shocks, $\boldsymbol{u}_{it} \sim iid\ (0, \sigma^2)$.

The marginal model of the dominant variables can be estimated without feedback effects from $\boldsymbol{X}_t$ as explained below.

$$\omega_t = \sum_{l=1}^{p_\omega} \boldsymbol{\Phi}_{\omega l}\omega_{t-l} + \eta_{\omega t} \tag{4}$$

In error correction form;

$$\Delta\omega_t = -\alpha_\omega\beta'_\omega\omega_{t-1} + \sum_{l=1}^{p_\omega-1} \boldsymbol{H}_{\omega l}\Delta\omega_{t-l} + \eta_{\omega t} \tag{5}$$

Where $\alpha_\omega\beta'_\omega = \sum_{l=1}^{p_\omega} \boldsymbol{\Phi}_{\omega l}, \boldsymbol{H}_{\omega l} = -(\boldsymbol{\Phi}_{\omega,l+1} + \boldsymbol{\Phi}_{\omega,l+2} + \cdots + \boldsymbol{\Phi}_{\omega,l+p_\omega-1}),$

for $l = 1,2, \ldots, p_\omega - 1$.

In order to allow feedback effects from variables in the GVAR back to the dominant variables via cross-section averages, then, Equation 4 can be augmented with lags of $\boldsymbol{X}^*_{\omega t}$ giving;

$$\omega_t = \sum_{l=1}^{p_\omega} \boldsymbol{\Phi}_{\omega l}\omega_{i,t-l} + \sum_{l=1}^{q_\omega} \boldsymbol{\Lambda}_{\omega l}\boldsymbol{X}^*_{i,t-l} + \eta_{\omega t} \tag{6}$$

With no co-integration among the common variables, ω_t, and the foreign or star variables, $\boldsymbol{X}^*_{i,t-l}$, Equation 6 can be rewritten in error correction form as;

$$\Delta\omega_t = -\alpha_\omega\beta'_\omega\omega_{t-1} + \sum_{l=1}^{p_\omega-1} \boldsymbol{H}_{\omega l}\Delta\omega_{t-l} + \sum_{l=1}^{q_\omega-1} \boldsymbol{B}_{\omega l}\Delta\boldsymbol{X}^*_{\omega,t-l} + \eta_{\omega t} \tag{7}$$

$\boldsymbol{B}_{\omega l} = -(\boldsymbol{\Lambda}_{\omega,l+1} + \boldsymbol{\Lambda}_{\omega,l+2} + \cdots + \boldsymbol{\Lambda}_{\omega,l+q_\omega-1})$

Let $\boldsymbol{y}_t = (\omega'_t, \boldsymbol{X}'_t)'$, vector of observable variables and stacking country-specific models in Equation 3 together with the model for common variables in 6 gives;

$$\boldsymbol{G}_{y,0}\boldsymbol{y}_t = \sum_{l=1}^{p} \boldsymbol{G}_{y,l}\boldsymbol{y}_{t-l} + \boldsymbol{u}_{yt} \tag{8}$$

$u_{yt} = (u'_t, \eta'_{\omega t})'$

$$\boldsymbol{G}_{y,0} = \begin{bmatrix} \boldsymbol{I}_{m_\omega} & \boldsymbol{0}_{m_\omega \mathrm{x} k} \\ \boldsymbol{D}_0 & \boldsymbol{G}_0 \end{bmatrix}, \boldsymbol{G}_{y,l} = \begin{bmatrix} \Phi_{\omega l} & \boldsymbol{\Lambda}_{\omega l}\grave{\mathrm{W}}_\omega \\ \boldsymbol{D}_l & \boldsymbol{G}_l \end{bmatrix}$$

Where $l = 1,2, \ldots, p$. $\boldsymbol{D}_l = (\boldsymbol{D}'_{1l}, \boldsymbol{D}'_{2l}, \ldots, \boldsymbol{D}'_{Nl})'$ for $= 0,1, \ldots, p$. $p = max_i\{p_i, q_i, s_i, p_\omega, q_\omega\}$

Note that matrix $\boldsymbol{G}_{y,0}$ is invertible if and only if $\boldsymbol{G}_0$ is invertible. If $\boldsymbol{G}_0^{-1}$ exists, then;

$$\boldsymbol{G}_{y,0}^{-1} = \begin{bmatrix} \boldsymbol{I}_{m_\omega} & \boldsymbol{0}_{m_\omega \mathrm{x} k} \\ -\boldsymbol{G}_0^{-1}\boldsymbol{D}_0 & \boldsymbol{G}_0^{-1} \end{bmatrix}$$

This is a block-lower triangular matrix. Multiplying both sides of 8 by $\boldsymbol{G}_{y,0}^{-1}$, one can obtain the following solution to the GVAR.

$$\boldsymbol{y}_t = \sum_{l=1}^{p} \boldsymbol{F}_{y,l}\boldsymbol{y}_{t-l} + \boldsymbol{G}_{y,0}^{-1}u_{yt} \tag{9}$$

Where $\boldsymbol{F}_{y,l} - \boldsymbol{G}_{y,0}^{-1}\boldsymbol{G}_{y,l}$ for $l = 1,2,\ldots,p$.

3.3.1 Model specification

As noted earlier, the GVAR primarily requires the estimation of domestic variables, $\boldsymbol{X}_{it}$, and the foreign counterpart, $\boldsymbol{X}_{it}^{*}$, using a predetermined weight. In this case, the fixed trade weight matrix. The chosen domestic variables are industrial production (ip), unemployment (ur), monetary policy indicator (mp), equity price ($eqty$), private sector credit ($credit$), real effective exchange rate ($reer$). Two global variables to control for global business cycles, global price of Brent crude oil ($poil$) and global price of agricultural raw material index ($pmat$). All the variables are log transformed.

$$\boldsymbol{X}_{it} = [ip_{it}, ur_{it}, mp_{it}, eqty_{it}, credit_{it}, reer_{it}]' \tag{10}$$

$$\boldsymbol{X}_{it}^{*} = [ip_{it}^{*}, ur_{it}^{*}, mp_{it}^{*}, eqty_{it}^{*}, credit_{it}^{*}, reer_{it}^{*},\ p_t^{oil},\ p_t^{mat}]' \tag{11}$$

The sample includes five advanced economies: Euro Area (EA), United Kingdom (GB), United States (US), Canada (CA) and Japan (JP). Emerging economies: Hungary (HU), Czech Republic (CZ), Romania (RO), Turkey (TR), Brazil (BR), Chile (CL), Colombia (CO), Hong Kong (HK), South Korea (KR) and Thailand (TH).

3.3.2 Trade weights matrix

The fixed weight matrix to recover the foreign variables is constructed using bilateral trade flows data by employing Equation 12 below.

$$TW_{ij} = \frac{X_{ij} + M_{ij}}{TT_i} \tag{12}$$

TW_{ij} is the weight of bilateral trade between country i and country j. X_{ij} *and* M_{ij} are the values of exports and imports between the two countries and TT_i is the total trade between country i and the partners included in the sample.

Table 3.2 shows the weight each country/area attaches to its partners in the sample. The Euro Area, for instance, attaches a weight of 28.1% and 25.0% to its trade with the United States and United Kingdom respectively. Likewise, the most important trade partners for the United States are Canada and the Euro Area, reporting weights of 31.7% and 31.2% respectively. For the emerging markets in Europe, the Euro Area is the most important trade partner by far compared to the other countries, accounting for 61.4% to 81.9%. The United States is the dominant trade partner in Latin America and Asia, followed closely by the Euro Area.

3.3.3 Country-specific models

A weighted symmetric estimation of the ADF unit root test for stationarity found that most of the domestic and foreign variables are $I(1)$, with only a few $I(0)$, though some are found to be $I(2)$. The unit root tests are a pre-requisite for the estimation of short-run and long-run co-integrating relationships in the country-specific models presented in Table 3.6. The lag length criteria for the ADF tests are chosen based on the Akaike Information Criteria. Unit root test results are presented in Table 3.3, Table 3.4 and Table 3.5.

3.3.4 Test for weak exogeneity of country-specific foreign variables

The weak exogeneity of $\boldsymbol{X}_{it}^{*}$ with respect to the long-run parameters of the conditional models is a key assumption underlying the GVAR, that is, foreign variables are weakly exogenous with respect to long-run parameters of the error correction model. In other words, there must be no long-run feedback from $\boldsymbol{X}_{it}$ to $\boldsymbol{X}_{it}^{*}$. $\boldsymbol{X}_{it}^{*}$ is said to be long-run forcing for $\boldsymbol{X}_{it}$. The weak exogeneity test is applied to the country-specific foreign variables and global variables as described below.

$$\Delta\boldsymbol{X}_{it,l}^{*} = \mu_{il} + \sum_{j=1}^{r_i} \gamma_{ij,l}\boldsymbol{ECM}_{i,t-1}^{j} + \sum_{k=1}^{s_i} \varphi_{ik,l}\Delta\boldsymbol{X}_{i,t-k} + \sum_{m=1}^{n_i} \Gamma_{im,l}\Delta\breve{\boldsymbol{X}}_{i,t-m}^{*} + \varepsilon_{it,l} \qquad (13)$$

$\boldsymbol{ECM}_{i,t-1}^{j}, j = 1,2,\dots,r_i$ are estimated error correction terms corresponding to the r_i co-integrating relations found for the i^{th} country model, with $\Delta\breve{\boldsymbol{X}}_{it}^{*} = (\Delta\boldsymbol{X}_{it}^{\prime *}, \Delta p_t^{oil}, \Delta p_t^{mat})'$. This is an F-test joint hypothesis that $\gamma_{ij,l} = 0, j = 1,2,\dots,r_i$.

The results in Table 3.7 show that the weak exogeneity assumption is rejected for some of the foreign variables in the country-specific VARX* models. The assumption does not hold for industrial production and private sector credit in the Euro Area, the only country in the sample that completely passes the test is Turkey.

3.3.5 Contemporaneous effect of foreign variables on domestic counterpart variables

This relationship can be interpreted as describing the international linkages between domestic and foreign variables. A good number of the coefficient elasticities are positive and significant. It is essential that there be some form of relationship between the foreign and original domestic variables, though this may not be the case. The results are presented in Table 3.8. Take the Euro Area, for instance, a 1% increase in foreign industrial production leads to a 0.228% increase in domestic industrial production and a 1% increase in foreign equity prices results to a 1.075% increase in domestic equity prices. All elasticities in the equity variable are relatively high and significant, indicating a strong co-movement between domestic and foreign equity markets. Foreign unemployment too seems to have a high effect on domestic unemployment for most of the economies. For example, take Colombia, a 1% increase in foreign unemployment increases its domestic unemployment by 0.961%. The monetary policy variable elasticities are generally not significant.

3.3.6 Average pair-wise cross-section correlations

A key issue to investigate is the correlation between domestic and counterpart foreign variables for the individual countries. An important assumption of the GVAR is that the idiosyncratic shocks of the individual country-specific models are cross-sectionally weakly correlated, allowing for $Cov(\boldsymbol{X}_{it}^{*}, u_{it}) \rightarrow 0$ as $N \rightarrow \infty$. This assumption ensures that weak exogeneity of the foreign variables, which is another important assumption, actually holds. The average pair-wise cross-section correlation test measures the extent to which country-specific foreign variables have been able to reduce cross-section correlation in the GVAR. Table 3.9, Table 3.10 and Table 3.11 present the pair-wise cross-section correlation results. As a general observation, the cross-section correlation is high in the variables at level and falls in the first differences. The monetary policy variable shows the highest degree of cross-section correlation, averaging at 96.1%, however, first differencing drastically reduces cross-sectional correlation in this variable, taking it down to only 6.2%. The real effective exchange rate shows the lowest degree of cross-section correlation, reporting an average of only 7.3%. Residual results are also presented, which are quite small. Residual interdependencies could be an indicator of spill-overs.

3.3.7 Nyblom variable structural stability tests

Nyblom (1989) proposes a test of parameter stability, which is considered a very big problem for VAR models, especially when dealing with emerging market economies that are always characterized by uncertainty, with variables constantly shifting over time. The results from applying the Nyblom tests presented in Table 3.12 indicate that the parameters are generally stable, with only a few indicating instability. The monetary policy variable is unstable for about half the number of countries in the sample. USA, Brazil and South Korea are the only countries with all parameters showing perfect stability. These instabilities can be dealt with by using robust standard errors and using bootstrap means and confidence bands when performing the dynamic analysis. This is done in the next section.

3.4 Dynamic Analysis

To perform the dynamic analysis, a Generalised Impulse Response Function (GIRF) model, proposed by Koop et al. (1996) is now used. The GIRF is a good alternative to the Orthogonalised Impulse Response Function (OIRF) model developed by Sims (1980). The advantage of the GIRF over the OIRF is that it is invariant to the ordering of the variables and countries in the GVAR. The variable ordering may be easy to identify based on economic theory or other reasoning in some cases, but with a big number of countries in the sample, it becomes difficult to arrive at a proper or correct country ordering.

$$GIRF(\boldsymbol{X}_t; u_{ilt}, n) = E\left(\boldsymbol{X}_{t+1} \middle| u_{ilt} = \sqrt{\sigma_{ii,ll}}, I_{t-1}\right) - E(\boldsymbol{X}_{t+1}|I_{t-1}) \quad (14)$$

I_{t-1} is the information set at time $t-1$, $\sigma_{ii,ll}$ is the diagonal element of the variance-covariance matrix Σ_u corresponding to the l^{th}equation in the i^{th} country and n horizon.

Assuming that $\boldsymbol{u}_t$ has a multivariate normal distribution, then the GIRFs of a unit shock at time t to the l^{th} equation in the above model on the j^{th} variable at time $t+n$ is given by the j^{th} element of;

$$GIRF(\boldsymbol{X}_t; u_{lt}, n) = \frac{\boldsymbol{e}_j' \boldsymbol{A}_n \boldsymbol{G}_0^{-1} \boldsymbol{\Sigma}_u \boldsymbol{e}_l}{\sqrt{\boldsymbol{e}_l' \boldsymbol{\Sigma}_u \boldsymbol{e}_l}}, n = 0,1,2, \ldots ; l, j = 1,2, \ldots, k \quad (15)$$

$\boldsymbol{e}_l = (0,0, \ldots ,0,1,0, \ldots 0)'$ is a selection vector with unity as the l^{th} element in the case of a country-specific shock. For a regional shock, $\boldsymbol{e}_l$ has PPP-GDP weights that sum to one, corresponding to the shocks of each of the countries that belong to the chosen region, and zeroes elsewhere. For a global shock, $\boldsymbol{e}_l$ has PPP-GDP weights that sum to one, corresponding to particular variable shocks of each of the $N+1$ countries and zeroes elsewhere. The GVAR GIRFs allow for correlation of the error terms; the error terms are not orthogonal.

3.4.1 Domestic effects of ECB unconventional monetary policy

To study the domestic effect of ECB UMP, consider a one standard error positive shock to the Euro Area monetary policy variable, in this case, the asset purchases by the ECB. The results are presented in Figure 3.7 and discussed as follows.

This one standard error positive shock, on impact, results to a 0.2% appreciation in the real effective exchange rate of the Euro, peaking at about 0.5% within the first 3 months, and then a gradual depreciation thereafter.

The Euro Stoxx 50 equity index is rather very responsive to the UMP shock compared to other variables, reporting a response of about 0.7% on impact and peaking at approximately 3.5% within the first 12 months.

As expected, private sector credit responds positively due to an increase in the monetary base or reserves of the commercial banks that are now able lend out more. This response peaks at about 0.5% after the first 28 months and remains that way throughout the projection period.

On to the general macroeconomic variables, unemployment responds rather slowly, steadily oscillating about the zero point until after 8 months when it starts to fall up to a maximum of about 0.7%, remaining stable along that line.

Industrial production generally responds positively, peaking at 0.7% after the first 13 months and gradually declining after that.

The domestic results are all statistically significant and reflect a positive impact of UMP; instilling confidence in the financial markets, creating more credit, creating jobs and encouraging production.

3.4.2 International/cross-border spill-over effects of ECB unconventional monetary policy

To study the international/cross-border spill-overs of ECB UMP, and for better comparison of the responses in different countries/regions, the maximum impulse response of each individual economy is reported in a bar graph form as shown in Figure 3.8. The responses are diverse and in either direction, except for equity prices. The diversity in responses may be due to the significant differences in the nature of advanced and emerging market economies, some regional economies may be linked in several ways. The results are discussed as follows.

Among the advanced economy currencies, the British Pound shows the highest response, appreciating by about 1.1%. The Canadian Dollar and Japanese Yen move in the opposite direction in comparison to the other 3 advanced economy currencies, depreciating instead. The Hungarian Forint registered the highest response to ECB UMP, depreciating by 1.5%. Currency responses in Latin America and Asia are rather modest in either direction, however, all three currencies in emerging Asia depreciate in response to ECB UMP.

The equity index variable shows the highest elasticity for all countries, though emerging European economies respond more than the rest, with the Hungarian BUX and Czech PX indices registering the highest maximum responses with gains of about 5.3% and 4.3%

respectively. Latin America equities respond the least, and remain conservative compared to the other economies.

Private sector credit growth is observed for all advanced economies. Emerging markets register responses in either direction, with credit increasing in Romania by about 2.5% and an opposite reaction in Colombia, seeing a credit fall of up to 1.8%.

The monetary policy variable, defined by broad money supply, too shows mixed reactions. Monetary policy practices may be very diverse in several countries, especially emerging markets, thus, the diversity in responses is rather expected. Generally, emerging market economies register higher responses than the advanced economies, with money supply in Romania growing by up to 1.6% and falling in Colombia by 1.4%. The United Kingdom registers a significant response, an increase of 0.6% compared to the other three advanced economies that seem to keep money supply at a rather controlled level, showing only minuscule responses.

Unemployment in advanced economies generally falls, except for Canada. In emerging Europe, Czech Republic registers the highest drop in unemployment at about 3.1%. All Latin America countries see an increase in unemployment. Overall, Thailand registers the highest drop in unemployment at about 3.4%.

Finally, an increase in industrial production is observed in all advanced economies. The Euro Area reports an increase of 0.7%, and diverse responses are seen in the emerging markets. Thailand reports a fall in industrial production of almost 1.5%, it is the most elastic.

It is important to note that for all variables, emerging markets seem to respond much more than the advanced economies, an indicator of more control employed in the advanced economies.

3.4.3 Regional effects of ECB unconventional monetary policy

Countries are aggregated into regions, and the weights each country contributes to a variable are computed based on the PPP-GDP contribution of that particular country to a region. Table 3.13 shows the weight contribution by each of the countries/area. Japan, Euro Area, Brazil and USA contribute the highest weights in each of their regions. Figure 3.9 and Figure 3.10 show the regional impulse response functions for ECB UMP shock.

The real effective exchange rate of currencies in Asia generally show signs of depreciation of up to 0.4%. European currencies appreciate by up to about 0.4%, and this effect dies out after about 28 months. Latin American currencies do not show significant movements, with oscillations around zero while in North America, the Dollar currencies of Canada and USA are the most sensitive, with appreciations of up to 0.7%.

The equity markets generally show positive and high sensitivity responses, most especially European indices, with positive responses of utmost 3.2%. Again, Latin America shows the least response.

Private sector credit growth in Europe peaked at 0.5%. On impact, there is generally a positive response for all four regions. Growth is reported for all regions except for Latin America that registered a positive response on impact and eventually, a gradual decline.

The monetary policy variable in Asia does not show any significant responses with oscillations about zero while Europe and Latin America show a positive response on impact. In North America, however, there is clearly a negative response on impact, and this negative effect persists until the end of the projection period.

Unemployment shows the strongest negative effect on impact in Asia where unemployment fell by up to 0.7%. Europe and North America generally respond with a fall in unemployment while Latin America responds with a gradual increase in unemployment.

On impact, Asia shows the highest growth in industrial production at about 0.5%. Europe and North America also signal a positive response on impact while Latin America shows a negative response on impact with industrial production falling by up to 0.7%.

3.4.4 Persistence profiles

Persistence profiles of the first co-integrating vectors of the individual countries are presented in Figure 3.11 and Figure 3.12 to give a view of how the long-run relationships in the variables respond to a shock to the unconventional monetary policy variable. This long-run relationship does not, in particular, represent the relationship between particular variables but is rather general. As shown in the figures, persistence profiles have an initial value of unity on impact and should tend to zero as $n \to \infty$, where n is the time horizon. This is a good test of whether the identified co-integrating vector is valid or not. Persistence profiles further provide a good indication of the speed of adjustment back to equilibrium. The persistence profiles generally indicate stable return to equilibrium although the speeds may differ substantially. All co-integrating relationships return to or are close to equilibrium by the 40th month after impact with the exception of Colombia that shows a sluggish return and requires a longer period of time for adjustment, but there is definitely a sign of return.

3.4.5 Global oil price shock effects

In addition to the impulse responses to UMP shock, it is also important to study results of a shock to a global variable, in this case, the oil price. Maximum impulse responses to a one standard error negative shock to the oil price are shown in Figure 3.13. The results also indicate a diversity of responses from the countries in the sample.

The Japanese Yen and Hungarian Forint are the most sensitive to oil price shocks, exhibiting depreciations of up to 4.2% and 4.4% respectively. The British Pound and Canadian Dollar were the least responsive to oil price shocks, appreciating by less than 1%.

As in the global responses to a UMP shock, the equity variable is the most responsive. The ROSNP index of Romania responds with a huge drop of up to 11.5%. The advanced economies' equity market responses are within the same uniform range of 1.8% (FTSE 100) to 3% (S&P 500), all in the same direction (a drop).

Private sector credit growth in advanced economies shows a more conservative response compared to the emerging economies. For instance, considering the two extremes, private credit in Japan grows by only 0.1% while in Hungary it falls by up to 2.3%.

Advanced economies generally show an increase in money supply except for the Euro Area whose monetary policy is described by the UMP variable/ECB assets. Sensing a fall in the oil price, the ECB reduces its aggressiveness in applying UMP by up to 1.3%. Emerging economies show a diversity of responses with money supply in Brazil falling by up to 2.9% and increasing by 0.5% in Hong Kong.

Unemployment in the Euro Area and United Kingdom fall by 0.8% and 4.6% respectively while Brazil registers an increase of 6.9%, the highest response.

Lastly, industrial production too registers a variety of responses, with Brazil, again showing the highest degree of responsiveness, falling by 3.7% compared to Colombia's increase of 0.5%. All advanced economies with the exception of the United Kingdom (increase of 0.5%) show a fall in industrial production.

3.4.6 Robustness check

Several researchers have argued that unconventional monetary policy can be measured by the term spread between long- and short-term treasury yields, and the corporate spread between AAA rated bond yields and the effective central bank rate. As a robustness check, the central bank assets variable is replaced with the term spread between the long- and short-term bond yields, the results change for some of the variables and remain unchanged for some. Generally, results do not remain the same but do not change drastically either.

It would also be helpful to allow the trade weights used to construct the foreign variables to change over time, instead of keeping it fixed. The trade weight matrix can also be replaced with another indicator of country interconnectedness, for instance, the extent to which commercial banks trade with each other.

3.5 Monetary Policy Sensitivity

To examine the monetary policy sensitivity, a pooled OLS and 2 panel data techniques, fixed-effects and random-effects estimators, are used. The specifications of the 3 models are briefly discussed below.

$$mp_{it} = \beta_1 reer_{it} + \beta_2 eqty_{it} + \beta_3 credit_{it} + \beta_4 ur_{it} + \beta_5 cpi_{it} + \beta_6 ip_{it} + \alpha_i + u_{it} \quad (1)$$

α_i is the unobserved heterogeneity, and $\varphi_{it} = \alpha_i + u_{it}$.

$$(mp_{it} - \overline{mp}_i) = \beta_1(reer_{it} - \overline{reer}_i) + \beta_2(eqty_{it} - \overline{eqty}_i) + \beta_3(credit_{it} - \overline{credit}_i) + \beta_4(ur_{it} - \overline{ur}_i) + \beta_5(cpi_{it} - \overline{cpi}_i) + \beta_6(ip_{it} - \overline{ip}_i) + \alpha_i - \alpha_i + (u_{it} - \bar{u}_i) \quad (2)$$

The fixed-effects within group model in Equation 3 below de-means[50] the dependent and independent variables, and gets rid of the unobserved heterogeneity that features in the pooled OLS model in Equation 1, thus, the estimated coefficients of the fixed-effects model cannot be biased because of omitted time invariant characteristics.

$$(mp_{it} - \overline{mp}_i) = \beta_1(reer_{it} - \overline{reer}_i) + \beta_2(eqty_{it} - \overline{eqty}_i) + \beta_3(credit_{it} - \overline{credit}_i) + \beta_4(ur_{it} - \overline{ur}_i) + \beta_5(cpi_{it} - \overline{cpi}_i) + \beta_6(ip_{it} - \overline{ip}_i) + (u_{it} - \bar{u}_i) \quad (3)$$

Unlike the fixed-effects model that fully time de-means the variables, the random-effects model only quasi de-means the variables. The random-effects model in Equation 4 below is estimated by GLS.

$$(mp_{it} - \gamma\overline{mp}_i) = \beta_0(1-\gamma) + \beta_1(reer_{it} - \gamma\overline{reer}_i) + \beta_2(eqty_{it} - \gamma\overline{eqty}_i) + \beta_3(credit_{it} - \gamma\overline{credit}_i) + \beta_4(ur_{it} - \gamma\overline{ur}_i) + \beta_5(cpi_{it} - \gamma\overline{cpi}_i) + \beta_6(ip_{it} - \gamma\overline{ip}_i) + (\varphi_{it} - \gamma\bar{\varphi}_i) \quad (4)$$

$$\gamma = 1 - \left(\frac{\sigma_u^2}{\sigma_u^2 + T\sigma_\alpha^2}\right)^{\frac{1}{2}} \quad (5)$$

[50] Thus, variations in the independent variables are interpreted as changes above the individual means/averages.

If $\gamma = 0$, then random-effects → pooled OLS. If $\gamma = 1$, then random-effects → fixed-effects. If $0 < \gamma < 1$, then the model is purely a random-effects one. $\gamma = 0$ if $\sigma_\alpha^2 = 0$ and $\gamma = 1$ if $\sigma_\alpha^2 \to \infty$.

If $Cov(\alpha_i, X_{it}) = 0$, then the fixed and random-effects estimators are consistent, that is, $\hat{\beta}_{FE}$ and $\hat{\beta}_{RE}$ are consistent. In addition, random-effects has lower variations than fixed-effects, that is, $se(\hat{\beta}_{RE}) < se(\hat{\beta}_{FE})$. However, if $Cov(\alpha_i, X_{it}) \neq 0$, then $\hat{\beta}_{FE}$ is consistent while $\hat{\beta}_{RE}$ is not consistent anymore. The fixed-effects estimator will always be consistent, but may not be the most efficient. The Hausman test is therefore conducted to determine which model best suites the data.

Hausman test; $H_0 =$ random-effects appropriate, $Cov(\alpha_i, X_{it}) = 0$ and $H_1 =$ fixed-effects is appropriate, $Cov(\alpha_i, X_{it}) \neq 0$.

The Hausman statistic is computed as;

$$H = \frac{\left(\hat{\beta}_{FE} - \hat{\beta}_{RE}\right)^2}{Var\left(\hat{\beta}_{FE}\right) - Var\left(\hat{\beta}_{RE}\right)} \sim \chi^2 \tag{6}$$

3.5.1 Fixed-effects heterogeneity

Figure 3.14 and Figure 3.15 report the within-group mean heterogeneity across the countries for the log transformed variables under consideration. The monetary policy variable for the advanced economies lies more or less within the same range compared to the emerging markets that display more heterogeneity. There is also a lot of heterogeneity in the real effective exchange rate variation. The ROSNP equity index of Romania is an extreme outlier among the equity indices. The Japanese credit variable too is an outlier compared to the rest of the countries. The unemployment rate variations have a few outliers; Thailand, as an outlier, is easily noticeable. Consumer price index and industrial production variations lie within the same range, with US and Hong Kong reporting outlier variations in the consumer price index and industrial production respectively.

3.5.2 Advanced economies

The central banks of the advanced economies chosen for this analysis are the ECB, BOE, US Fed and BOJ. The monetary policy indicator for the advanced economies is strictly described by the central bank assets variable, an unconventional form of monetary policy intervention.

Table 3.14 shows that the monetary policy variable is negatively correlated with all the variables except the consumer price index. In addition, the consumer price index shows the highest magnitude of correlation at 0.443, while industrial production reported the lowest magnitude at 0.022. The correlation matrix generally serves as a primary checker for variable multi-collinearity before regressions are performed. There are no extreme correlation values of up to 0.8 that may cause regression problems. The highest correlation reported is 0.764 between equity and private sector credit.

The Hausman test indicated that the fixed-effects model best suits the advanced economies' data. Table 3.15 reports the regression results from the pooled OLS, fixed-effects and random-effects models. Pooled OLS and random-effects results are exactly identical, indicating that, as discussed in the in the previous section, $\gamma = 0$ under the random-effects model. Under pooled OLS and random-effects, the monetary policy indicator is most sensitive to industrial production and the real effective exchange rate, reporting significant negative coefficients of 2.211 and 2.048 respectively. Monetary policy is least sensitive to private sector credit, reporting a significant negative coefficient of 0.170. However, monetary authorities are not responsive to the unemployment rate. For instance, a 1% increase in industrial production tends to lower the monetary authorities' appetite to engage in financial market asset purchases by 2.211%.

Fixed-effects results are quite different, all regressors are significant. A 1% increase in the consumer price index above the average increases the monetary authorities' desire to engage in financial market asset purchases by 5.415% and a 1% increase in the real effective exchange rate lowers the monetary authorities' asset purchases by 1.850%. Equities, private sector credit, unemployment and industrial production affect the authorities' asset purchase appetite by 0.247%, 1.433%, -0.220% and -2.568% respectively.

3.5.3 Emerging economies

Unlike the advanced economies, it makes more sense to describe the monetary policy indicator in emerging markets by the broad money supply. Emerging markets tend to intervene in the financial markets using a variety of monetary policy tools and are not consistent with their monetary policy practises. In addition, currency notes may be printed for various economic and political reasons, which may not necessarily be the case in advanced economies.

Table 3.16 shows that the monetary policy variable is negatively correlated with most of the variables except the real effective exchange rate and industrial production. Furthermore, the unemployment rate shows the highest magnitude at 0.459 while consumer price index reported the lowest magnitude at 0.131. There are no extreme correlation values of up to 0.8 that may cause regression problems. The highest correlation reported is 0.615 between the real effective exchange rate and consumer price index.

For the emerging economies, the data failed to meet the asymptotic assumptions of the Hausman test. Table 3.17 reports the regression results from the pooled OLS, fixed-effects and random-effects models. Unlike the advanced economies where pooled OLS and random-effects results were exactly the same, they differ in this case. Consequently, $0 < \gamma < 1$ under the random-effects model. However, it is important to note that the fixed and random-effects results are very close in comparison to each other, implying that γ is very close to 1. Pooled OLS results are generally much higher than those from the fixed and random-effects models. As an illustration, take for instance the real effective exchange rate coefficients, pooled OLS reports a significant positive result of 7.950 while fixed and random-effects report significant positive results of only 0.183 and 0.184 respectively. Interpreting the fixed-effects results, a 1% increase in private sector credit increases money supply by up to 0.413% while a 1% increase in the real effective exchange rate increases money supply by 0.183%. Unemployment, consumer price index and industrial production affect money supply by -0.180%, 1.229% and 0.0488% respectively. The monetary policy indicator is most sensitive to private sector credit and does not respond to changes in equity prices.

Pooled OLS ignores the panel nature of the data and does not try to reduce the bias caused by unobserved heterogeneity, so it makes more sense to consider the fixed and random-effects results when drawing any inference and interpreting the results. In conclusion, considering the fixed and random-effects results, one can easily conclude that, in general, the monetary policy variable in the advanced economies is more sensitive to changes in any of the regressor variables compared to the emerging economies.

3.5.4 Regional analysis

Table 3.18 reports the fixed-effects results per region for all the four regions under consideration. The monetary authorities in Europe are very responsive to changes in the consumer price index and the real effective exchange rate, responding by up to 1.922% and -1.015% respectively. The equity market and the unemployment rate have limited effects at -0.159% and -0.197% respectively. Private sector credit and industrial production statistics are not significant. Of note in North America is the high response of monetary policy to changes in the consumer price index by 9.238%, the highest coefficient reported if compared to other panels. Except for the real effective exchange rate, the other variables in this region are significant. The monetary authorities in Latin America show the highest degree of sensitivity to variations in private sector credit, reporting a coefficient of 0.793. The unemployment rate and industrial production variations seem to have no effect on monetary policy actions, reporting coefficients that are not significant. Asia is the only region where the monetary authorities are responsive to variations in all the chosen regressors, with most sensitivity to the consumer price index (1.990%) and least sensitivity to the unemployment rate (-0.178%). As a general observation, it is clear that monetary policy in all the respective regions is responsive to variations in the equity markets and the consumer price index, where the stability of the latter is the primary objective of central banks.

Some of the results make economic sense when viewed from the perspective of academic theory, however, it is important to note the diversity in the regions and countries in the sample. The different authorities have different tools at their disposal, some, especially the advanced, have both conventional and unconventional tools at their disposal while the emerging may only have the conventional tools available. The emerging markets have very underdeveloped financial markets. In addition, the emerging market monetary authorities do not target only inflation, but rather the exchange rate too, given that most of them are dependent on international trade.

3.5.5 Aggregated sample

Table 3.19 shows that the monetary policy variable, as before, is again negatively correlated with most of the variables except the real effective exchange rate and industrial production. Again, the unemployment rate shows the highest magnitude at 0.450, while consumer price index reported the lowest magnitude at 0.125. There are no extreme correlation values of up to 0.8 that may cause regression multicollinearity problems. The highest correlation reported is 0.450 between the monetary policy variable and unemployment rate.

The Hausman test indicated that the fixed-effects model best suites the aggregated data. Table 3.20 reports the regression results from the pooled OLS, fixed-effects and random-effects models. The random-effects results are different from pooled OLS and fixed-effects results, thus, $0 < \gamma < 1$. However, the fixed and random-effects results are very close in comparison to each other, indicating that γ is very close to 1. As in the previous regression that reported results from the three models, pooled OLS results are generally much higher than those from the fixed and random-effects models. As an example, consider the equity coefficients, pooled OLS reports a significant negative result of 0.605 while fixed and random-effects report significant positive results of only 0.245 and 0.241 respectively. In addition, all the fixed and random-effects results are significant.

Looking at the fixed-effects results, a 1% increase in the real effective exchange rate reduces the monetary policy indicator by up to 0.622% while a 1% increase in the consumer price index increases the monetary policy indicator by 1.346%. Equities, private sector credit, unemployment and industrial production affect the monetary policy indicator by 0.245%, 0.310%, -0.252% and -0.289% respectively. The monetary policy indicator is most sensitive to consumer price index and least responsive to equity index changes.

3.6 Conclusion

Using a GVAR model, this study investigated the domestic and international spill-over effects of ECB unconventional monetary policy, where the ECB UMP is defined by the ECB total asset purchases. To study the extent of shock effects to ECB UMP, Generalised Impulse response functions are presented, and the results indicated a richness of responses exhibited by the different countries/regions. Generally, ECB UMP effects showed encouraging and positive responses from economies within the Euro Area region while international spill-over effects were mixed, probably due to the different nature of the monetary policy regimes deployed in the different countries, especially the emerging economies. Some countries seem to be conservative while others allow their responses to spiral away. In addition, persistence profiles indicate that the long-run co-integrating relationships are stable and valid, with adjustment to equilibrium by the 40^{th} month for all countries except Colombia. Furthermore, country-specific responses to a global oil price shock are also studied and findings revealed that the equity indices are the most responsive in comparison to the other variables. As a robustness check, ECB UMP is described by the spread between short- and long-term bond yields; results change for certain variables, but not drastically.

Lastly, a panel data approach is deployed to examine the sensitivity of monetary policy to the regressor variables included in the model. Final results indicated that monetary policy in advanced economies is more sensitive to changes in the regressor variables if compared to responses in the emerging economies. And on aggregation, taking the fixed and random-effects results, most of the regressors are significant in analysing monetary policy sensitivity.

Table 3.2: Trade weights matrix

	EA	GB	US	CA	JP	HU	CZ	RO	TR	BR	CL	CO	HK	KR	TH
EA	0.000	0.660	0.312	0.085	0.215	0.767	0.819	0.740	0.614	0.361	0.232	0.219	0.219	0.211	0.185
GB	0.250	0.000	0.064	0.030	0.036	0.037	0.050	0.042	0.095	0.033	0.018	0.021	0.063	0.033	0.038
US	0.281	0.176	0.000	0.810	0.369	0.028	0.026	0.019	0.108	0.332	0.321	0.507	0.262	0.320	0.241
CA	0.026	0.029	0.317	0.000	0.034	0.002	0.002	0.002	0.014	0.030	0.028	0.029	0.017	0.026	0.014
JP	0.057	0.026	0.111	0.032	0.000	0.012	0.009	0.006	0.024	0.055	0.122	0.036	0.183	0.202	0.320
HU	0.061	0.008	0.004	0.001	0.005	0.000	0.038	0.085	0.013	0.003	0.001	0.002	0.007	0.006	0.004
CZ	0.104	0.014	0.004	0.001	0.004	0.060	0.000	0.039	0.019	0.003	0.001	0.001	0.005	0.008	0.005
RO	0.042	0.006	0.002	0.001	0.002	0.055	0.017	0.000	0.032	0.003	0.001	0.003	0.002	0.003	0.002
TR	0.062	0.025	0.010	0.004	0.006	0.017	0.012	0.050	0.000	0.014	0.009	0.030	0.006	0.018	0.008
BR	0.030	0.008	0.035	0.008	0.019	0.002	0.002	0.005	0.016	0.000	0.129	0.079	0.014	0.023	0.021
CL	0.008	0.002	0.013	0.003	0.014	0.000	0.000	0.000	0.003	0.050	0.000	0.035	0.006	0.015	0.006
CO	0.006	0.002	0.015	0.002	0.003	0.000	0.000	0.001	0.009	0.024	0.027	0.000	0.002	0.004	0.001
HK	0.017	0.020	0.023	0.004	0.065	0.002	0.008	0.001	0.004	0.018	0.003	0.003	0.000	0.099	0.083
KR	0.040	0.017	0.066	0.016	0.137	0.014	0.012	0.007	0.040	0.052	0.090	0.028	0.133	0.000	0.073
TH	0.015	0.008	0.023	0.005	0.092	0.004	0.004	0.002	0.009	0.020	0.017	0.007	0.081	0.032	0.000

The matrix is constructed based on average monthly trade data over the period 2015-2019.

Table 3.3: Unit root tests-global variables

Variable	WS statistic	t-statistic
$poil$	-3.24	-2.54
$\Delta poil$	-2.55	-6.64*
$pmat$	-3.24	-2.59
$\Delta pmat$	-2.55	-5.76*

*Indicates statistical significance, and so, the null hypothesis of unit root presence is rejected.

Table 3.4: Unit root tests-domestic variables

Variable	WS statistic	EA	GB	US	CA	JP	HU	CZ	RO	TR	BR	CL	CO	HK	KR	TH
ip	-3.2	-2.7	-1.3	-2.4	-1.5	-2.8	-1.9	-2.3	-3.9*	-2.1	-5.8*	-2.0	-2.0	-13.5*	-2.6	-3.9*
Δip	-2.6	-4.5*	-9.9*	-5.7*	-7.7*	-7.5*	-9.9*	-12.0*	-12.0*	-8.7*	-7.8*	-9.8*	-13.5*	-11.9*	-10.6*	-8.0*
ur	-3.2	-1.21	-0.49	0.44	-2.13	-0.86	-0.51	-0.90	-1.08	-2.93	-1.26	-1.94	-2.64	-3.68*	-7.03*	-2.54
Δur	-2.6	-6.7*	-6.0*	-5.4*	-9.4*	-10.5*	-5.3*	-12.7*	-8.4*	-5.7*	-4.6*	-7.4*	-9.4*	-5.8*	-8.9*	-13.0*
mp	-3.2	-1.9	-0.6	-2.0	-1.9	0.6	-0.9	-1.6	0.4	-3.2	-1.0	-1.6	0.0	-1.8	-2.2	-1.0
Δmp	-2.6	-8.1*	-4.1*	-5.5*	-7.4*	-3.4*	-4.3*	-3.5*	-4.9*	-10.3*	-4.3*	-8.6*	-2.4	-10.7*	-3.7*	-7.1*
$eqty$	-3.2	-1.9	-2.9	-2.0	-3.4*	-1.1	-1.7	-3.3*	-2.9	-2.9	-2.0	-2.2	-2.1	-3.7*	-4.0*	-2.8
$\Delta eqty$	-2.6	-9.6*	-9.2*	-8.7*	-6.7*	-8.3*	-7.8*	-6.1*	-5.7*	-8.4*	-8.6*	-8.5*	-9.4*	-7.8*	-5.0*	-5.7*
$credit$	-3.2	-1.5	-1.2	-1.6	-2.1	-0.7	-0.2	-0.8	-0.6	-1.4	-0.4	-1.4	-0.6	-2.8	-1.0	-1.3
$\Delta credit$	-2.6	-1.9	-8.4*	-6.0*	-3.6*	-5.5*	-4.4*	-3.4*	-1.9	-4.9*	-2.2	-5.7*	-3.1*	-5.4*	-4.1*	-3.7*
$reer$	-3.2	-2.7	-1.3	-1.8	-2.1	-2.0	-4.8	-1.7	-3.1	-2.1	-2.4	-3.3*	-2.1	-2.0	-1.8	-2.5
$\Delta reer$	-2.6	-8.4*	-8.1*	-7.9*	-5.6*	-6.8*	-7.9*	-8.0*	-8.5*	-9.8*	-7.9*	-8.7*	-6.6*	-5.4*	-8.6*	-9.7*

*Indicates statistical significance, and as a result, the null hypothesis of unit root presence is rejected.

Table 3.5: Unit root test-foreign variables

Variable	WS statistic	EA	GB	US	CA	JP	HU	CZ	RO	TR	BR	CL	CO	HK	KR	TH
$ip*$	-3.2	-2.4	-3.3†	-2.8	-2.9	-4.8†	-2.0	-2.5	-1.8	-2.5	-3.5†	-3.3†	-3.0	-3.3†	-3.1	-3.1
$\Delta ip*$	-2.6	-11.1†	-5.0†	-5.3†	-4.7†	-6.9†	-5.2†	-5.0†	-8.5†	-5.4†	-4.4†	-6.0†	-5.1†	-5.5†	-8.7†	-7.5†
$ur*$	-3.2	-0.1	-0.9	-1.3	0.3	-1.3	-1.0	-1.1	-1.0	-0.8	-0.5	-1.0	-0.2	-1.3	-0.6	-0.7
$\Delta ur*$	-2.6	-4.6†	-7.2†	-8.8†	-5.2†	-9.7†	-6.3†	-6.2†	-6.5†	-7.9†	-5.2†	-9.9†	-5.0†	-8.7†	-4.9†	-4.9†
$mp*$	-3.2	-0.4	-1.9	-1.7	-2.8	-1.9	-1.8	-1.8	-1.8	-1.7	-1.8	-2.1	-2.2	-2.3	-1.8	-1.8
$\Delta mp*$	-2.6	-5.7†	-8.1†	-8.0†	-5.2†	-7.5†	-8.0†	-8.1†	-8.1†	-8.0†	-7.9†	-5.7†	-5.7†	-7.6†	-7.7†	-7.8†
$eqty*$	-3.2	-3.1	-2.2	-2.2	-2.1	-3.1	-2.2	-2.1	-2.2	-2.3	-2.5	-2.7	-2.4	-2.6	-1.7	-1.6
$\Delta eqty*$	-2.6	-4.8†	-9.2†	-8.2†	-8.8†	-6.2†	-5.0†	-9.4†	-5.0†	-5.0†	-8.9†	-5.0†	-8.8†	-8.7†	-8.6†	-8.6†
$credit*$	-3.2	-1.2	-1.9	-1.7	-1.6	-2.1	-1.8	-1.5	-1.0	-1.7	-2.0	-1.2	-2.1	-2.0	-2.3	-2.0
$\Delta credit*$	-2.6	-4.1†	-2.7†	-2.2	-5.7†	-3.3†	-1.6	-2.2	-2.4	-1.8	-2.9†	-2.9†	-3.5†	-3.0†	-3.6†	-4.6†
$reer*$	-3.2	-1.4	-2.3	-2.8	-1.4	-0.6	-2.6	-2.7	-2.8	-2.4	-1.2	-2.2	-1.3	-1.5	-2.3	-2.7
$\Delta reer*$	-2.6	-6.9†	-8.6†	-4.9†	-7.9†	-6.5†	-8.6†	-8.5†	-8.5†	-8.6†	-8.6†	-7.0†	-8.2†	-7.2†	-7.3†	-6.9†

†Indicates statistical significance, and as a result, the null hypothesis of unit root presence is rejected.

Table 3.6: Country-specific VARX* order and number of long-run co-integrating relationships

	$VARX^*(p_i, q_i)$		
	p_i	q_i	Co-integrating relationships
Euro Area	2	2	2
United Kingdom	2	1	4
USA	2	2	3
Canada	1	2	3
Japan	1	2	5
Hungary	2	2	4
Czech Republic	2	1	5
Romania	2	2	5
Turkey	2	1	3
Brazil	2	1	5
Chile	2	1	4
Colombia	2	1	4
Hong Kong	2	2	3
South Korea	2	2	4
Thailand	1	2	4

p_i and q_i are the lag lengths of the domestic and foreign variables respectively.

Table 3.7: F-statistic tests for weak exogeneity of country-specific foreign variables and global variables

	$Fcrit$	ip^*	ur^*	mp^*	$eqty^*$	$credit^*$	$reer^*$	p^{oil}	p^{mat}
EA	3.063	7.827†	2.837	2.028	0.353	3.984†	0.177	0.901	2.692
GB	2.439	4.161†	1.084	5.060†	1.364	3.375†	0.549	2.285	0.426
US	2.675	1.880	0.919	0.344	1.097	2.982†	2.479	0.591	0.283
CA	2.672	6.498†	3.019†	1.161	1.302	1.353	2.256	1.432	0.351
JP	2.282	1.421	3.810†	1.009	2.215	2.774†	0.638	0.259	0.916
HU	2.439	1.673	2.012	0.027	0.367	2.763†	2.187	3.232†	1.165
CZ	2.282	2.616†	2.394†	0.510	0.313	3.053†	2.137	2.119	1.509
RO	2.282	3.521†	1.144	1.849	0.872	3.891†	1.210	3.640†	3.551†
TR	2.672	0.944	1.138	1.325	2.140	0.652	1.121	0.735	0.649
BR	2.282	3.250†	3.990†	2.345†	1.254	0.411	0.544	0.972	0.563
CL	2.439	4.234†	1.660	1.999	0.483	5.538†	1.078	1.365	1.112
CO	2.439	0.705	3.370†	0.978	0.413	0.717	1.405	1.323	0.800
HK	2.672	2.912†	0.673	1.149	1.883	1.780	1.073	2.171	2.342
KR	2.439	3.089†	2.773†	2.561†	1.363	5.093†	1.025	0.607	0.258
TH	2.439	1.223	0.896	2.723†	1.625	1.461	0.279	0.701	1.957

†Indicates statistical significance, and as a result, the null hypothesis of weak exogeneity is rejected.

Table 3.8: Contemporaneous effect of foreign variables on their domestic counterparts

	Domestic variables					
	ip	ur	mp	$eqty$	$credit$	$reer$
Euro Area	0.228*	0.173*	1.559	1.075*	0.104*	-1.130*
	[5.789]	[2.917]	[0.961]	[16.512]	[2.124]	[-4.810]
United Kingdom	0.399*	0.310*	-0.017	0.661*	0.080	-0.477*
	[6.112]	[4.408]	[-0.871]	[19.694]	[0.135]	[-3.434]
USA	0.380*	0.670*	0.025	0.047*	0.238	-1.116*
	[5.463]	[5.197]	[0.985]	[17.209]	[0.813]	[-10.17]
Canada	0.251*	0.578*	-0.010	0.646*	0.027	-0.776*
	[4.980]	[6.202]	[-0.137]	[11.970]	[1.269]	[-4.990]
Japan	0.042	0.146	-0.018	0.915*	-0.283*	-2.909*
	[0.557]	[1.673]	[-1.894]	[12.510]	[-3.220]	[-6.460]
Hungary	3.997*	0.322*	-0.010	0.821*	1.976*	0.507*
	[11.415]	[2.544]	-0.642	[11.802]	[3.628]	[5.570]
Czech Republic	3.152*	0.658*	0.023	0.856*	0.302*	0.557*
	[7.908]	[2.576]	[1.920]	[10.947]	[2.316]	[5.540]
Romania	2.872*	0.808*	0.090	1.130*	1.475*	0.394*
	[9.565]	[3.737]	[1.349]	[8.107]	[4.288]	[4.450]
Turkey	0.411*	0.909*	0.020	0.973*	0.385	-0.895*
	[3.014]	[8.059]	[0.455]	[7.955]	[1.009]	[-3.375]
Brazil	2.500*	-0.026	0.318*	0.704*	-0.148	-2.319*
	[8.504]	[-0.280]	[4.282]	[6.994]	[-1.080]	[-3.516]
Chile	2.090*	0.039	0.380*	0.535*	0.137	-0.170
	[5.508]	[0.470]	[3.817]	[5.663]	[0.939]	[-0.419]
Colombia	0.178*	0.961*	-0.019	0.990*	0.170	-0.413
	[2.072]	[4.778]	[-0.467]	[6.542]	[1.072]	[-0.936]
Hong Kong	1.850*	0.090	-0.103	1.133*	2.991*	-0.588
	[5.135]	[1.509]	[-0.689]	[10.183]	[2.524]	[-1.948]
South Korea	0.428*	0.345	-0.010	0.893*	0.161	-2.339*
	[2.354]	[1.946]	[-0.322]	[11.738]	[1.672]	[-7.974]
Thailand	2.877*	1.756*	0.096	0.834*	-0.341*	-0.633*
	[6.359]	[2.938]	[1.221]	[8.384]	[-3.399]	[-2.876]

White robust t-ratios in parentheses.
*Indicates statistical significance.

Table 3.9: Average pair-wise cross-section correlations

	Industrial production			Unemployment		
	Levels	First differences	VARX* residuals	Levels	First differences	VARX* residuals
Euro Area	0.460	0.217	-0.086	0.135	0.200	-0.050
United Kingdom	0.260	0.134	-0.027	0.361	0.221	0.037
USA	0.510	0.080	-0.080	0.411	0.269	-0.008
Canada	0.510	0.103	-0.018	0.415	0.231	0.031
Japan	0.262	0.081	-0.040	0.419	0.098	-0.023
Hungary	0.381	0.227	0.022	0.363	0.215	-0.010
Czech Republic	0.499	0.255	0.014	0.356	0.190	0.045
Romania	0.456	0.212	0.028	0.305	0.104	-0.006
Turkey	0.449	0.131	-0.006	-0.071	0.232	-0.023
Brazil	-0.117	0.252	-0.024	-0.309	0.070	-0.036
Chile	0.288	0.141	-0.014	0.276	0.071	-0.017
Colombia	0.487	0.057	0.000	0.227	0.236	0.021
Hong Kong	0.069	0.125	-0.062	0.375	-0.006	0.031
South Korea	0.350	0.203	0.002	0.048	0.211	-0.027
Thailand	0.118	0.172	-0.018	0.022	0.110	-0.024
Average	**0.332**	**0.159**	**-0.020**	**0.222**	**0.163**	**-0.004**

Table 3.10: Average pair-wise cross-section correlations

	Monetary policy			Equity		
	Levels	First differences	VARX* residuals	Levels	First differences	VARX* residuals
Euro Area	0.918	0.095	-0.032	0.463	0.630	-0.245
United Kingdom	0.915	0.026	-0.030	0.711	0.633	0.018
USA	0.976	0.095	0.001	0.660	0.656	-0.147
Canada	0.976	0.039	-0.032	0.713	0.630	0.056
Japan	0.969	-0.080	0.027	0.592	0.559	-0.137
Hungary	0.942	0.038	-0.013	0.616	0.601	0.068
Czech Republic	0.970	0.132	-0.008	0.122	0.626	0.041
Romania	0.972	0.134	0.020	0.353	0.584	0.085
Turkey	0.977	0.076	0.017	0.656	0.529	0.061
Brazil	0.956	0.117	-0.016	0.509	0.577	0.104
Chile	0.973	0.148	0.016	0.562	0.452	0.076
Colombia	0.969	0.080	-0.006	0.408	0.502	0.086
Hong Kong	0.967	-0.052	-0.023	0.699	0.649	0.093
South Korea	0.979	0.022	0.023	0.672	0.631	0.080
Thailand	0.958	0.057	0.013	0.625	0.598	0.103
Average	**0.961**	**0.062**	**-0.003**	**0.557**	**0.590**	**0.023**

Table 3.11: Average pair-wise cross-section correlations

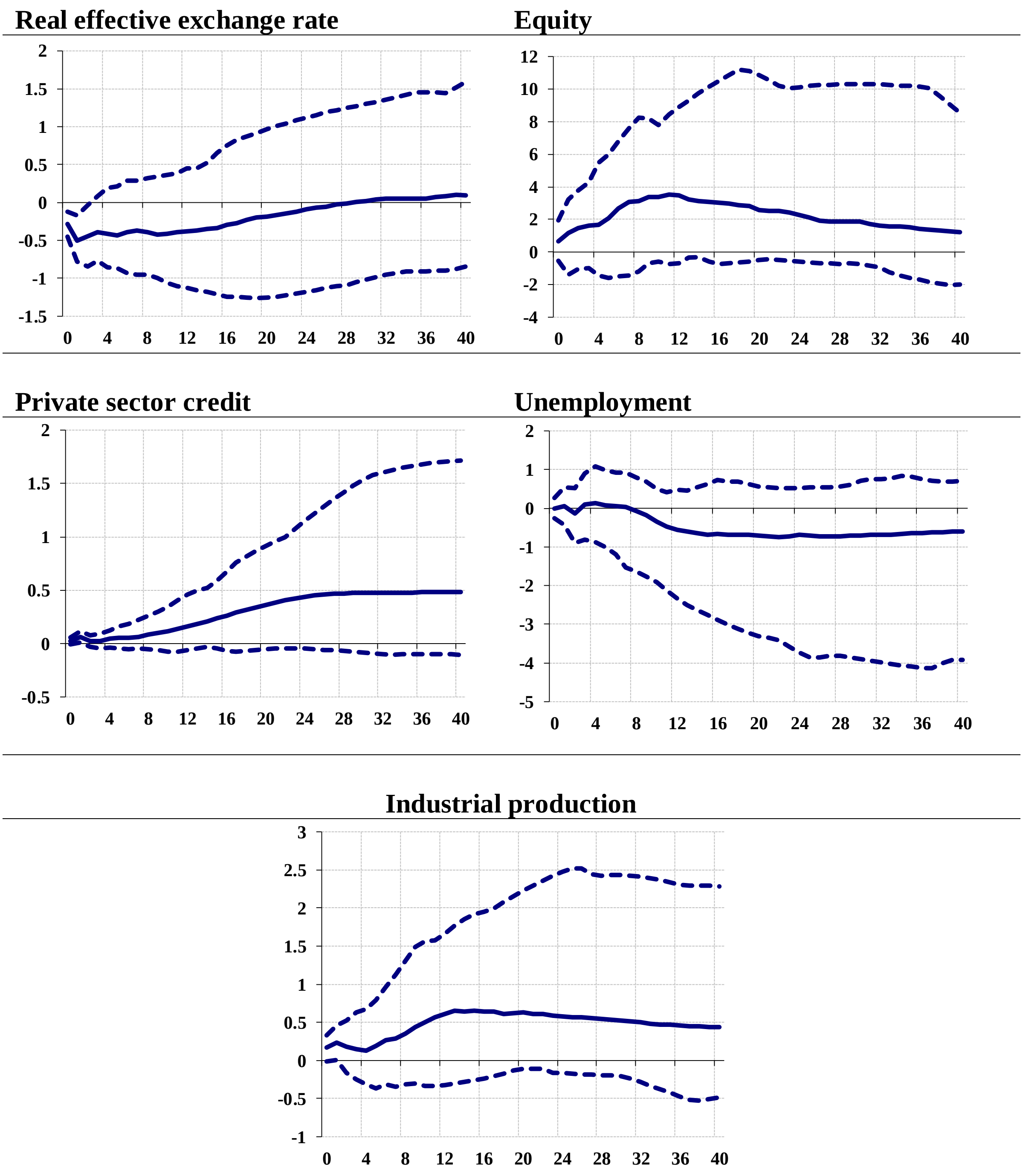
	Private sector credit			Real effective exchange rate		
	Levels	First differences	VARX* residuals	Levels	First differences	VARX* residuals
Euro Area	0.628	0.255	-0.028	0.202	-0.060	-0.032
United Kingdom	0.745	-0.015	-0.042	0.095	-0.028	-0.009
USA	0.768	0.146	-0.037	-0.359	-0.209	0.104
Canada	0.821	0.192	-0.002	0.275	0.091	0.035
Japan	0.752	-0.100	-0.049	0.123	-0.198	0.011
Hungary	-0.275	0.124	-0.039	0.276	0.081	0.014
Czech Republic	0.840	0.274	-0.011	0.086	0.006	-0.066
Romania	0.709	0.286	0.018	0.229	0.059	0.050
Turkey	0.806	0.108	0.003	0.179	0.039	0.010
Brazil	0.778	0.229	0.063	0.241	0.093	0.043
Chile	0.817	0.270	0.012	0.199	0.042	0.037
Colombia	0.804	0.242	0.020	0.231	0.077	0.008
Hong Kong	0.810	0.032	-0.007	-0.404	-0.159	0.033
South Korea	0.836	0.181	-0.031	-0.152	0.090	0.068
Thailand	0.789	0.068	0.008	-0.128	0.026	0.078
Average	**0.708**	**0.153**	**-0.008**	**0.073**	**-0.003**	**0.025**

Table 3.12: Nyblom stability tests

	ip	ur	mp	$eqty$	$credit$	$reer$
Euro Area	3.496*	3.829*	4.728	3.235*	2.956*	3.618*
	[4.439]	[4.291]	[4.387]	[4.464]	[4.145]	[4.375]
United Kingdom	2.385*	1.976*	3.685	3.417*	2.652*	2.059*
	[3.265]	[3.481]	[3.339]	[3.572]	[3.509]	[3.377]
USA	2.916*	3.272*	2.889*	2.720*	3.611*	3.715*
	[4.419]	[4.449]	[4.548]	[4.696]	[4.290]	[4.492]
Canada	1.602*	3.541	2.464*	2.662*	2.933*	2.839*
	[3.835]	[3.382]	[3.625]	[3.873]	[3.726]	[3.497]
Japan	3.216*	2.529*	2.530*	2.967*	2.584*	4.387
	[3.970]	[3.813]	[3.618]	[3.911]	[3.848]	[3.944]
Hungary	3.368*	3.696*	2.649*	3.673*	4.463	3.446*
	[4.472]	[4.459]	[4.425]	[4.451]	[4.360]	[4.192]
Czech Republic	2.408*	2.249*	3.895	3.421*	2.620*	2.252*
	[3.515]	[3.327]	[3.624]	[3.423]	[3.267]	[3.581]
Romania	2.742*	2.886*	4.471	4.486	4.254*	3.832*
	[4.409]	[4.600]	[4.354]	[4.193]	[4.743]	[4.769]
Turkey	2.423*	2.436*	3.447	3.205*	2.929*	3.031*
	[3.356]	[3.265]	[3.374]	[3.537]	[3.294]	[3.498]
Brazil	2.593*	2.455*	3.392*	3.426*	2.466*	2.827*
	[3.409]	[3.564]	[3.490]	[3.536]	[3.365]	[3.575]
Chile	3.302*	2.413*	3.673	3.744*	2.615*	2.654*
	[3.509]	[3.412]	[3.462]	[3.785]	[3.608]	[3.562]
Colombia	1.713*	3.798	2.601*	2.644*	1.619*	4.362
	[3.320]	[3.271]	[3.503]	[3.558]	[3.432]	[3.323]
Hong Kong	3.188*	2.748*	5.175	3.820*	5.680	4.704
	[4.261]	[4.695]	[4.534]	[4.549]	[4.378]	[4.501]
South Korea	3.933*	2.388*	2.909*	4.153*	3.727*	3.524*
	[4.242]	[4.329]	[4.746]	[4.670]	[4.093]	[4.529]
Thailand	3.362*	2.145*	3.551*	2.743*	2.950*	4.232
	[3.813]	[3.765]	[3.800]	[3.974]	[3.621]	[3.577]

*Indicates stability since the Nyblom statistic is less than the Nyblom critical value in parentheses, H_0 = Stability.

Figure 3.7: Euro Area impulse responses to a one standard error positive shock to UMP variable



Solid lines are bootstrap median estimates, and the dotted lines represent a 90% bootstrap confidence interval band.

Figure 3.8: Maximum cross-border impulse responses to a positive shock to ECB UMP

Table 3.13: Regional weights for impulse response analysis

Region	Country	ip	ur	mp	$eqty$	$credit$	$reer$
Asia	Hong Kong	0.050	0.050	0.050	0.050	0.050	0.050
	Japan	0.596	0.596	0.596	0.596	0.596	0.596
	South Korea	0.220	0.220	0.220	0.220	0.220	0.220
	Thailand	0.134	0.134	0.134	0.134	0.134	0.134
Europe	Czech Republic	0.018	0.018	0.018	0.018	0.018	0.018
	Euro Area	0.707	0.707	0.707	0.707	0.707	0.707
	Hungary	0.013	0.013	0.013	0.013	0.013	0.013
	Romania	0.023	0.023	0.023	0.023	0.023	0.023
	Turkey	0.101	0.101	0.101	0.101	0.101	0.101
	United Kingdom	0.138	0.138	0.138	0.138	0.138	0.138
Latin America	Brazil	0.733	0.733	0.733	0.733	0.733	0.733
	Chile	0.102	0.102	0.102	0.102	0.102	0.102
	Colombia	0.165	0.165	0.165	0.165	0.165	0.165
North America	Canada	–	–	–	–	–	–
	USA	1.000	1.000	1.000	1.000	1.000	1.000

Figure 3.9: Regional impulse responses to a one standard error positive shock to ECB UMP variable

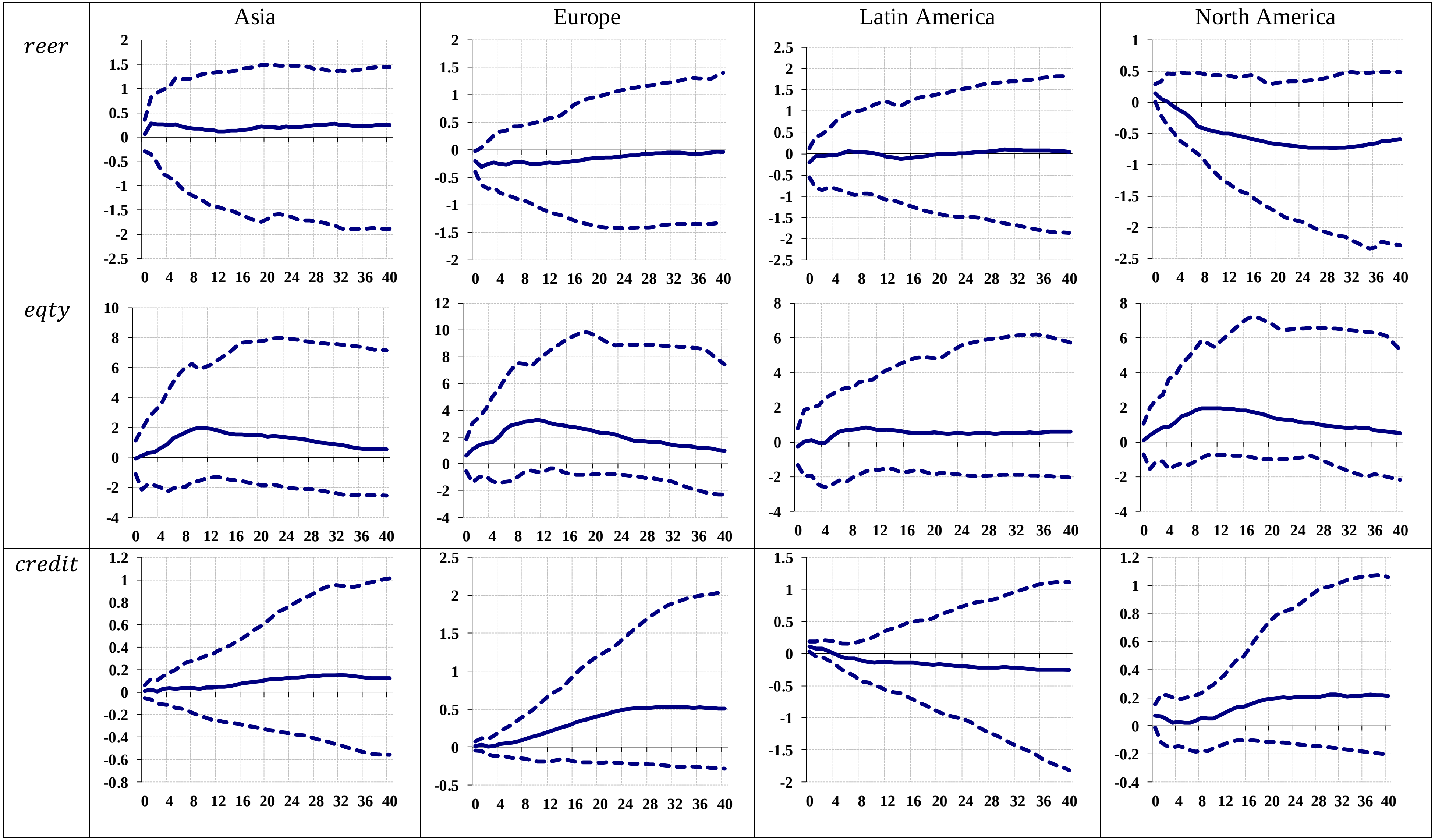


Figure 3.10: Regional impulse responses to a one standard error positive shock to ECB UMP variable

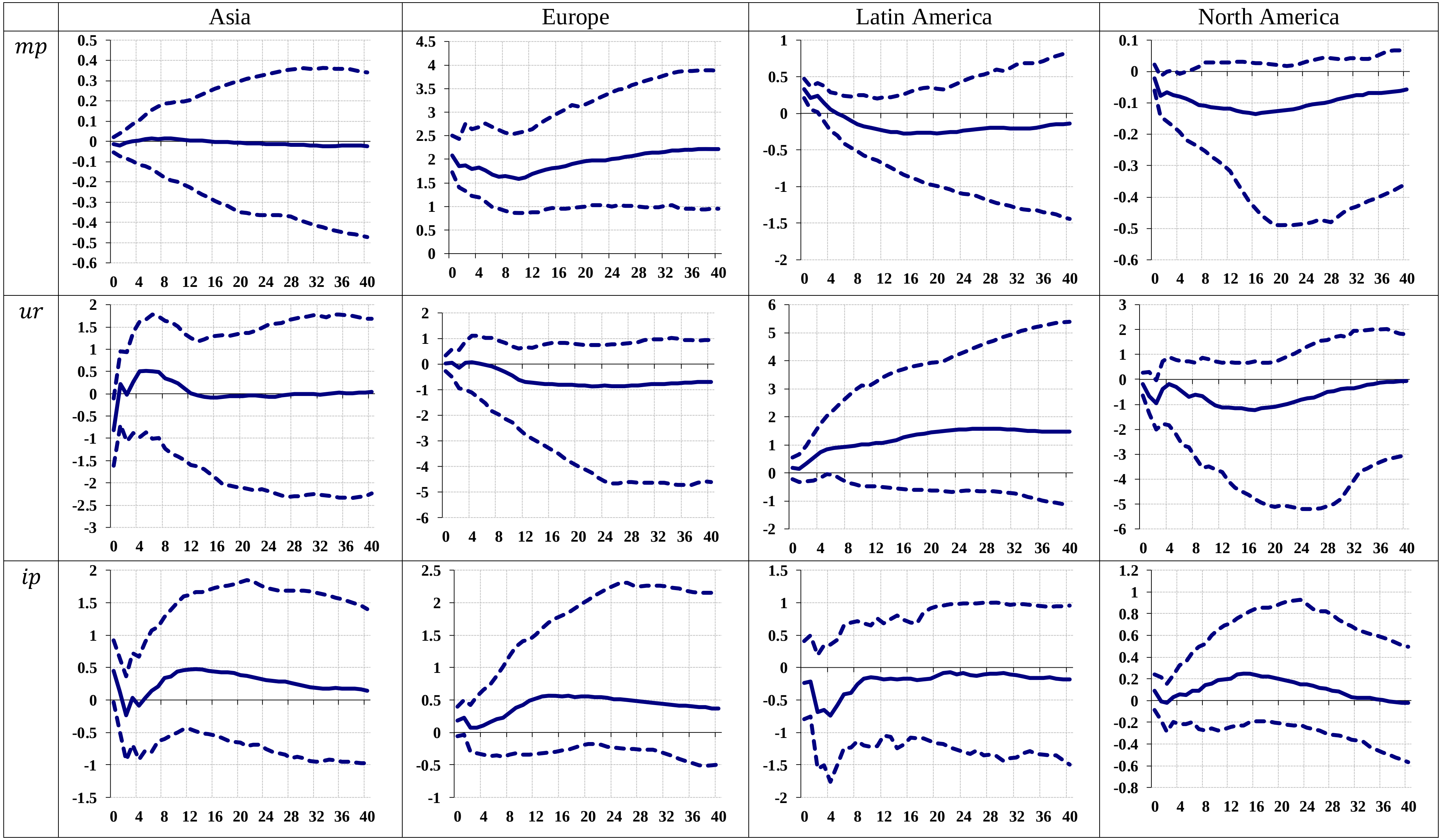


Figure 3.11: Impulse responses of long-run relationships to a shock to the ECB UMP variable

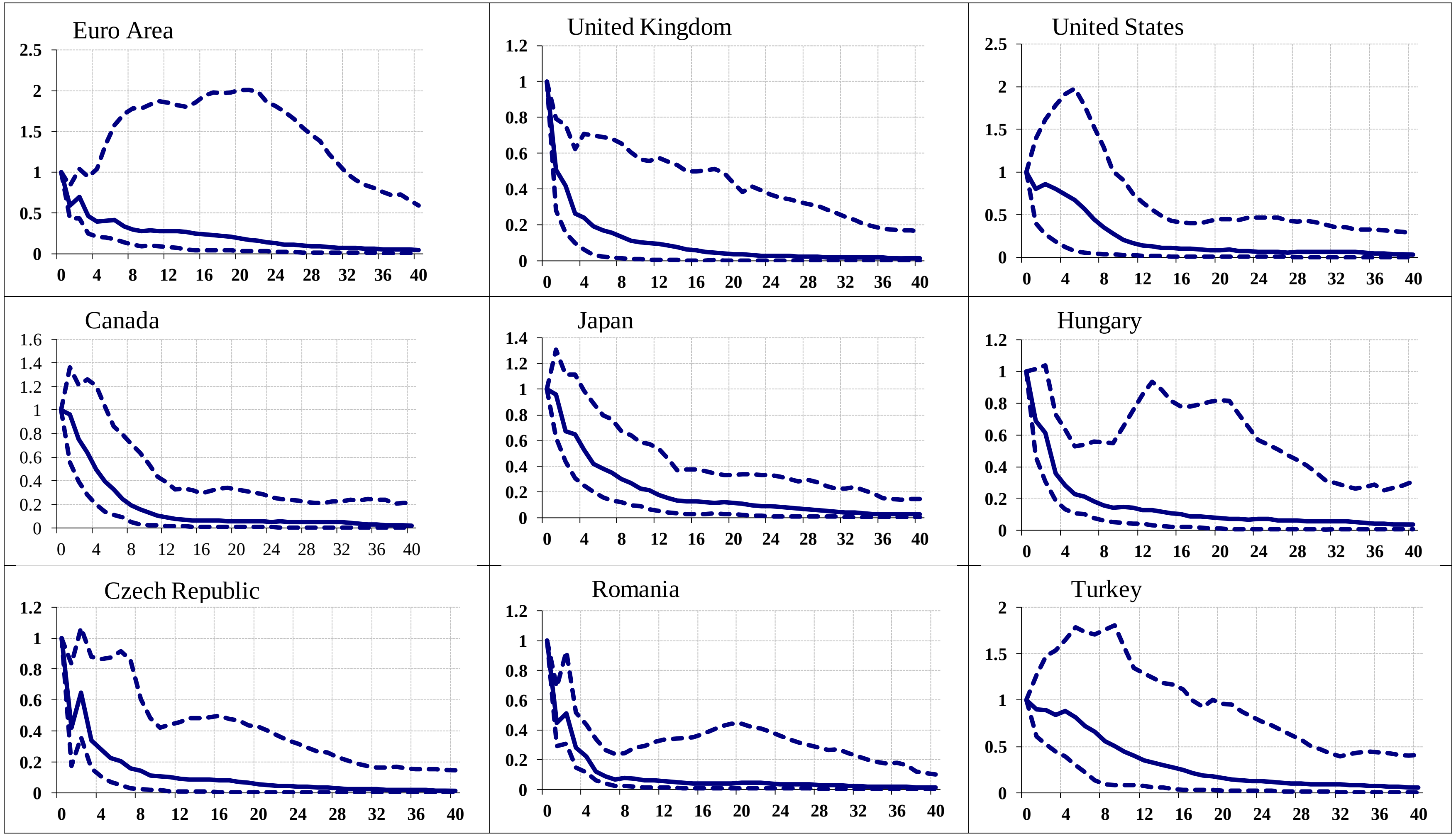


Figure 3.12: Impulse responses of long-run relationships to a shock to the ECB UMP variable

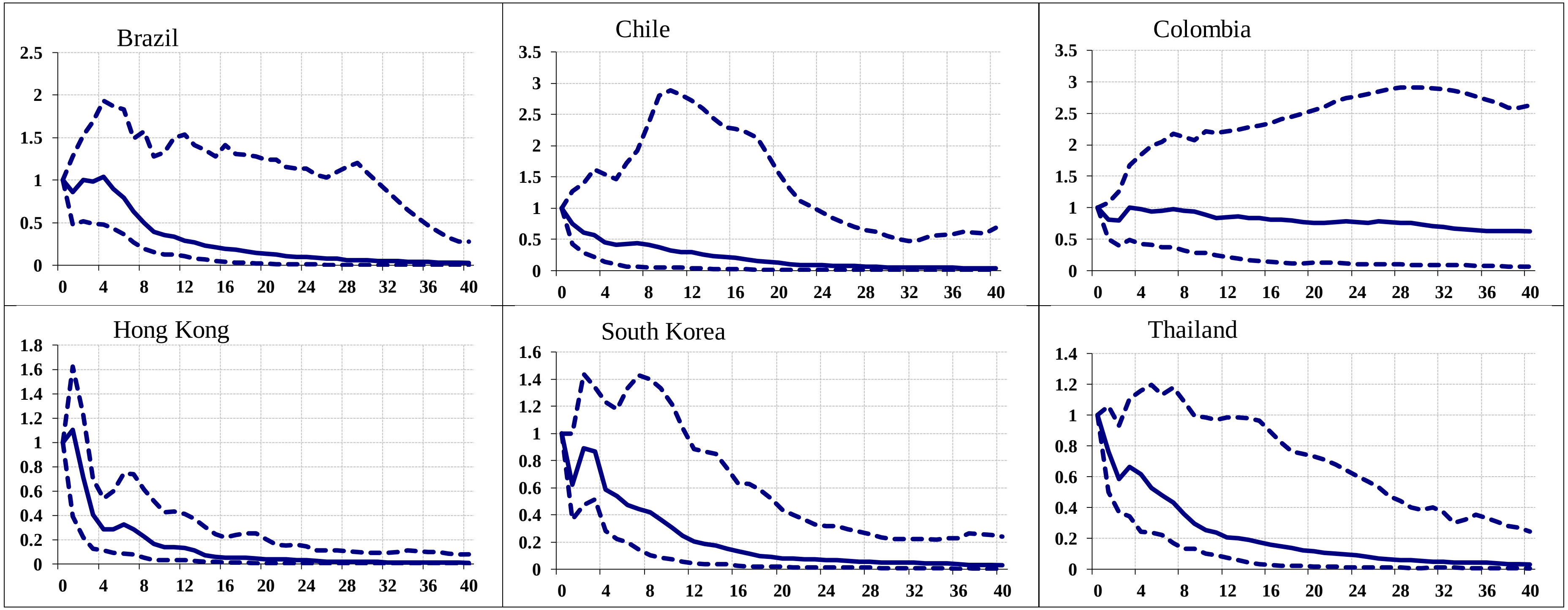


Figure 3.13: Maximum impulse responses to a one standard error negative shock to oil price

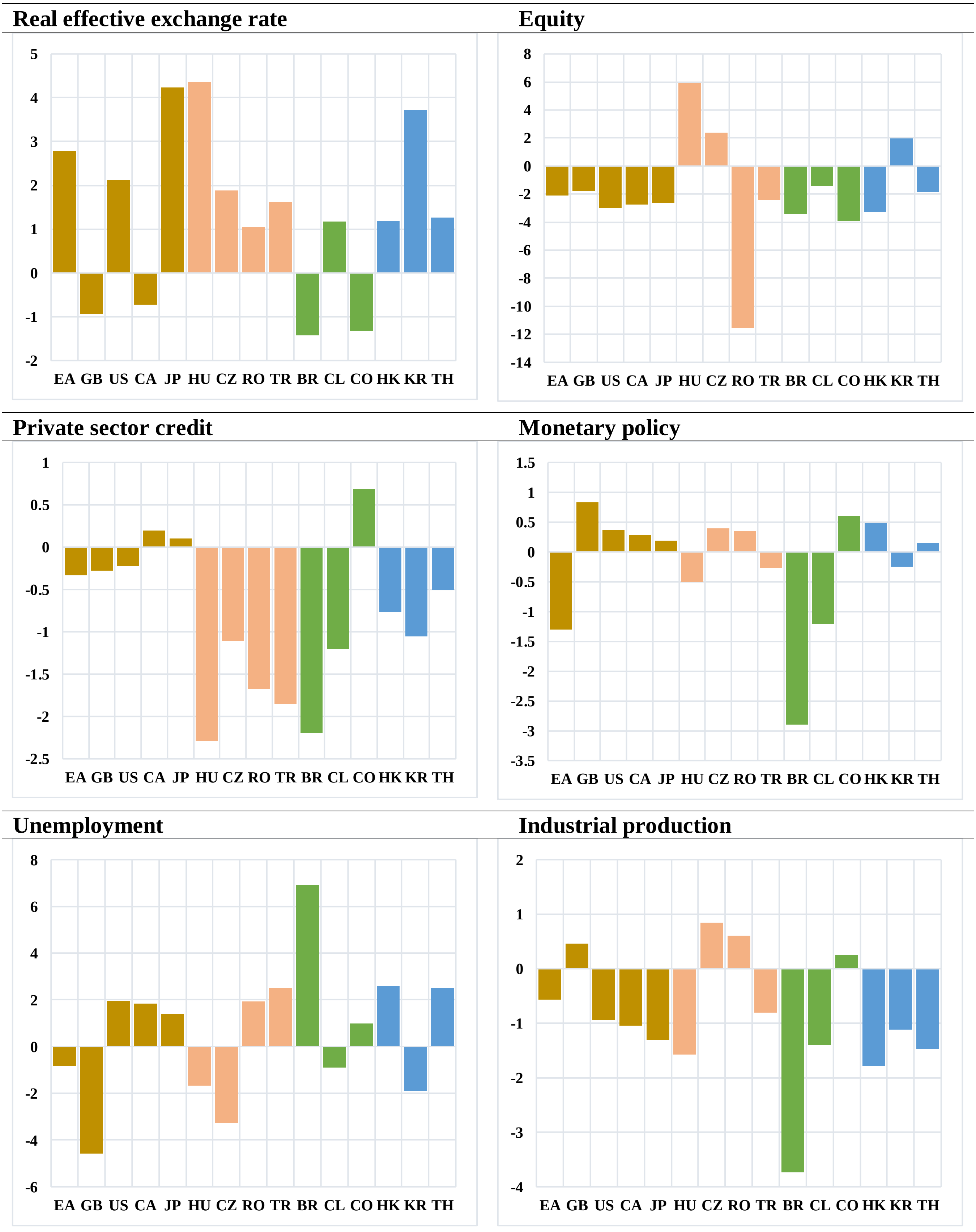


Figure 3.14: Variable heterogeneity across countries

Figure 3.15: Variable heterogeneity across countries

Table 3.14: Variable correlation matrix - advanced economies

	mp	$reer$	$eqty$	$credit$	ur	cpi	ip
mp	1.000						
$reer$	-0.145	1.000					
$eqty$	-0.061	-0.612	1.000				
$credit$	-0.148	-0.688	0.764	1.000			
ur	-0.176	0.378	-0.664	-0.688	1.000		
cpi	0.443	0.336	-0.625	-0.311	-0.081	1.000	
ip	-0.022	-0.011	0.235	0.088	-0.399	0.054	1.000

Table 3.15: Monetary policy sensitivity - advanced economies

	POLS	FE	RE
	mp	mp	mp
$reer$	-2.048^{***}	-1.850^{***}	-2.048^{***}
	(0.174)	(0.120)	(0.174)
$eqty$	0.762^{***}	0.247^{**}	0.762^{***}
	(0.0645)	(0.0758)	(0.0645)
$credit$	-0.170^{***}	1.433^{***}	-0.170^{***}
	(0.0102)	(0.243)	(0.0102)
ur	0.189	-0.220^{**}	0.189
	(0.101)	(0.0788)	(0.101)
cpi	1.629^{***}	5.415^{***}	1.629^{***}
	(0.104)	(0.347)	(0.104)
ip	-2.211^{***}	-2.568^{***}	-2.211^{***}
	(0.317)	(0.235)	(0.317)
N	561	561	561

Standard errors in parentheses.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ significance level.

Table 3.16: Variable correlation matrix - emerging economies

	mp	$reer$	$eqty$	$credit$	ur	cpi	ip
mp	1.000						
$reer$	0.430	1.000					
$eqty$	-0.361	-0.155	1.000				
$credit$	-0.427	-0.095	0.111	1.000			
ur	-0.459	-0.403	0.065	-0.103	1.000		
cpi	-0.131	-0.615	0.132	0.038	0.209	1.000	
ip	0.341	0.373	0.192	-0.120	-0.083	-0.274	1.000

Table 3.17: Monetary policy sensitivity - emerging economies

	POLS	FE	RE
	mp	mp	mp
$reer$	7.950***	0.183***	0.184***
	(0.936)	(0.0269)	(0.0271)
$eqty$	-0.532***	0.00697	0.00616
	(0.0244)	(0.00914)	(0.00922)
$credit$	-0.796***	0.413***	0.411***
	(0.0323)	(0.0136)	(0.0137)
ur	-3.232***	-0.180***	-0.180***
	(0.130)	(0.00805)	(0.00812)
cpi	6.902***	1.229***	1.234***
	(0.609)	(0.0388)	(0.0392)
ip	1.172***	0.0488**	0.0500**
	(0.0632)	(0.0176)	(0.0178)
N	1557	1557	1557

Standard errors in parentheses.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ significance level.

Table 3.18: Monetary policy sensitivity - regions

	Europe	North America	Latin America	Asia
	mp	mp	mp	mp
$reer$	-1.015***	0.251	0.0905**	-1.165***
	(0.130)	(0.191)	(0.0294)	(0.110)
$eqty$	-0.159***	0.293*	0.0478***	0.471***
	(0.0309)	(0.118)	(0.0108)	(0.0511)
$credit$	-0.0422	-0.941***	0.793***	0.353**
	(0.0482)	(0.198)	(0.0251)	(0.133)
ur	-0.197***	0.426***	0.0167	-0.178***
	(0.0291)	(0.0902)	(0.0184)	(0.0473)
cpi	1.922***	9.238***	0.406***	1.990***
	(0.137)	(0.707)	(0.0643)	(0.403)
ip	-0.0536	-1.468***	0.0347	-0.259***
	(0.0843)	(0.347)	(0.0313)	(0.0684)
N	873	312	465	624

Standard errors in parentheses.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 3.19: Variable correlation matrix - aggregated sample

	mp	$reer$	$eqty$	$credit$	ur	cpi	ip
mp	1.000						
$reer$	0.303	1.000					
$eqty$	-0.386	-0.172	1.000				
$credit$	-0.355	-0.234	0.147	1.000			
ur	-0.450	-0.235	0.052	-0.199	1.000		
cpi	-0.125	-0.145	0.027	-0.053	0.114	1.000	
ip	0.373	0.293	0.160	-0.111	-0.103	-0.191	1.000

Table 3.20: Monetary policy sensitivity - aggregated sample

	POLS	FE	RE
	mp	mp	mp
$reer$	-2.745***	-0.622***	-0.618***
	(0.576)	(0.0570)	(0.0572)
$eqty$	-0.605***	0.245***	0.241***
	(0.0222)	(0.0213)	(0.0214)
$credit$	-0.674***	0.310***	0.301***
	(0.0257)	(0.0356)	(0.0355)
ur	-3.759***	-0.252***	-0.253***
	(0.110)	(0.0204)	(0.0205)
cpi	-0.438	1.346***	1.368***
	(0.274)	(0.0975)	(0.0975)
ip	1.421***	-0.289***	-0.282***
	(0.0568)	(0.0472)	(0.0473)
N	2274	2274	2274

Standard errors in parentheses.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ significance level.

Table 3.21: Data description

Variable	Description	Source	Other details
Central bank interest rates	FRED		
Central bank assets	FRED		
Real effective exchange rate		IMF-IFS, Bruegel	
Equity prices	Stock price index	Yahoo Finance, Investing.com	
Private sector credit	Credit extended by commercial banks and other deposit-taking institutions (excluding central banks) to private non-financial firms and households.	theGlobalEconomy.com, Bank of Japan	
Money supply	The total amount of currency and other liquid instruments circulating in the economy.	OECD, theGlobalEconomy.com	
Unemployment rates		IMF-IFS, OECD, FRED	
Consumer price index	IMF-IFS, OECD, FRED		
Industrial production		IMF-IFS, FRED, OECD.	Due to lack of monthly data, for Hong Kong, data on electricity consumption[1] is used as a proxy. For Thailand, Business Sentiments Index (BSI)[2] is used.
Global oil price	Brent Crude	FRED	
Global price of raw material	Agricultural raw material index	FRED	
Trade flows		IMF-DOTS	
GDP (PPP)		World Bank	

[1]Data sourced from CLP Power Hong Kong Limited and The Hong Kong Electric Company Ltd.
[2]Data sourced from Bank of Thailand.

Table 3.22: Stock indices

Country	Index
United States	S&P 500
Japan	Nikkei 225
Euro Area	Euro Stoxx 50
Canada	S&P/TSX Composite
United Kingdom	FTSE 100
Brazil	IBOVESPA
Chile	S&P/CLX IGPA
Colombia	Bancolombia SA CIB[1]
Hong Kong	Hang Seng
South Korea	KOSPI
Thailand	SET
Turkey	BIST 100
Hungary	BUX
Czech Republic	PX
Romania	ROSNP

[1]Used as a proxy for COLCAP (the national index) due to limited data.

Chapter 4: Forecasting Exchange Rates Using Artificial Neural Networks

Abstract

This analysis uses the science of a single hidden layer perceptron neural network structure to forecast daily, weekly and monthly exchange rate data on CHF/EUR, GBP/EUR and USD/EUR. The results show good accuracy of the model as evidenced by the low mean absolute error and root mean square error, especially for the daily frequency data. Furthermore, the neural network performs best in out-of-sample predictions for the CHF/EUR currency pair for daily and weekly predictions, and best for the GBP/EUR pair when it comes to monthly frequency data. The USD/EUR pair proves more difficult to model, performing worst, especially in the validation period. The non-linear nature of the neural network goes a long way in learning and capturing complex movements in the exchange rates as shown in the in-sample and out-of-sample graphs; a clear advantage when compared to the traditional linear prediction models.

Key Words: *Artificial neural network, predicting/forecasting, exchange rate*

4.1 Introduction

This research applied the single hidden layer Artificial Neural Network (ANN) to model and forecast the daily, weekly and monthly frequency CHF/EUR, GBP/EUR and USD/EUR exchange rate data. The results reported showed good accuracy of the model as evidenced by the low mean absolute error and root mean square error, especially for the daily frequency data.

Section 4.2 presents a literature review on some of the studies that applied the ANN technique and some modifications. Section 4.3 discusses the structure of ANNs and how they work. Section 4.4 gives a detailed discussion of the ANN's performance and section 4.5, a conclusion of the study.

Exchange rate movements are of keen interest to monetary authorities, however, it is also of great importance to large firms, especially multinationals, that conduct transactions in huge amounts of foreign currency, thus, several scholars have tried to develop and apply forecasting techniques like the ARIMA, ARMA, ARCH, GARCH and VAR models (all autoregressive in nature), just to mention but a few, to exchange rate data. Artificial Neural Networks, a form of artificial intelligence, still remain an area worth exploring when it comes to exchange rate forecasting. According to Huang et al. (2004), an ANN is a system loosely modelled on the human brain, which can detect underlying functional relationships within a dataset and performs tasks such as pattern recognition, classification, evaluation, modelling, prediction and control. ANNs are well suited to finding accurate solutions in an environment characterized by complex, noisy, irrelevant or partial information. A number of reasons have been put forward as advantages for the use of ANNs which include; ANNs are data-driven self-adaptive techniques in that there are few a priori assumptions about the models, ANNs can generalize, ANNs are universal functional approximators and finally, ANNs are nonlinear, and for these reasons, ANNs are very much applicable to time series data, particularly exchange rates.

According to Meese and Rogoff (1983), econometric models used to forecast exchange rates based on economic fundamentals have had limited success, especially when the forecast horizon is at a 1 to 12-month period. Time series models produce plausible point estimates in exchange rate prediction but are poor at predicting the direction in which the rates move. Machine learning methods such as shallow ANNs and support vector machines may be marginally better at predicting the direction of change, but their success depends critically on the input features used to train the models. This improvement comes at a cost; obtaining a good set of features from raw input data may require significant efforts from domain experts (Galeshchuk and Mukherjee, 2017).

When it comes to the inputs used in the ANNs, there are generally two ways to approach the problem; one may use the lags of the exchange rate variable as inputs or use the economic fundamentals believed to be important in the determination of exchange rates, these fundamentals[51] are; relative money supply, relative GDP, nominal interest rate differential, and the long-run expected inflation differential. One may also add the current account as a possible variable.

The structure of the ANN determines the nature of the output; the structure may be characterized by the number of hidden layers and the number of neurons per layer. It is important to note that if there is no hidden layer in the system, this may be similar to a simple OLS regression type model, particularly when the activation function is linear in nature. Of course, the more complex the structure of the ANN, the higher the model's ability to capture complex relationships and key turning points. However, there may also be a problem of over-fitting if the structure is too complex, thus, it is important to strike a balance when dealing with ANNs. Another important consideration is that the output produced by an ANN changes each time the model is run despite the fact that key input parameters remain fixed; this perhaps may be one of the downsides of ANN models.

[51] The combination of these variables form the monetary or macroeconomic type models. When applied to ANNs, then we have a non-linear monetary model.

4.2 Literature Review

Scholars have shown interest in ANNs in recent times; others have modified the ANNs or applied them in combination with other models and most have reported the superiority of such models. Neural networks were originally developed in cognitive or biological science and were later used in engineering for pattern recognition and classification. They have also been used in the tourism industry, energy, especially renewables (Markova, 2019). Adewole et al. (2011) applied daily data on NGN/USD, NGN/EUR, NGN/GBP and NGN/JPY to an ANN and a hidden Markov model and found that the multi-layer perceptron ANN reported an accuracy rate of 81.2% compared to the hidden Markov model that reported a rate of 69.9%. Panda and Narasimhan (2007) apply ANNs to INR/USD weekly data comparing its forecast performance to the linear AR and RW models and their results showed that the neural network has a superior in-sample performance compared to the other two models, reporting a more convincing evaluation result regardless of the evaluation criteria used in the study. Furthermore, the ANN also beats the linear autoregressive model in four out of the six evaluation criteria in their out-of-sample comparison.

Aydin and Cavdar (2015) applied the Multi-Layered Feed Forward Neural Network (MLFFNN) and VAR models to monthly data on USD/TRY, gold prices and the Borsa Istanbul (BIST). On comparing the forecast results, it was evident that the ANN technique performed better compared to the VAR model. Lasheras et al. (2015) compared the performance of the MLFFNN and the Elman neural network to the ARIMA using copper spot prices data and concluded that the performance of the MLFFNN and Elman Recurrent Neural Network (RNN) are better than the ARIMA when evaluated in terms of Root Mean Square Error (RMSE) values.

Koprinska et al. (2018) show that Convolutional Neural Networks (CNN) and the Multi-Layered Perceptron Neural Networks performed similarly in terms of accuracy and training time, and outperformed other models used in their study; highlighting the potential of CNNs for energy time series forecasting. See also Matyjaszek et al. (2019), Eskandari et al. (2021) and Yang et al. (2021) for similar studies in the energy sector.

Borovykh et al. (2017) show that the CNN can effectively learn dependencies in and between a series without the need for long historical data. Their study subjected data on the S&P 500, volatility index, the CBOE interest rate, and many exchange rates to a CNN and VAR model.

Lai et al. (2018) proposed a deep learning framework, the Long- and Short-term Time-series Network (LSTNet), that combines the methods of the CNN and RNN to extract short-term local dependency patterns among variables and to discover long-term patterns for trends; complementing the CNN and RNN with an AR model to solve the scale insensitivity problem that neural network models suffer from. The LSTNet model was applied to data on traffic, solar power production, electricity consumption and exchange rates. Their findings showed that by combining the strengths of CNN, RNN and AR models, the LSTNet significantly improved the state-of-the-art results in time series forecasting on multiple benchmark datasets.

Leung et al. (2000) use the non-parametric General Regression Neural Network (GRNN) to predict the monthly exchange rate movements of the GBP, CAD and JPY. Their results revealed that the GRNN performed better than the Multi-Layered Feed Forward Neural Network, the parametric multivariate transfer function and the RW model included in their study. Their findings revealed that except for the GBP, the GRNN reported significantly lower Mean Absolute Error (MAE) and Root Mean Square Error compared to the other approaches. Ni et al. (2019) propose a Convolution Recurrent Neural Network (C-RNN) applying the model to exchange rate data of nine major currencies; findings revealed that the C-RNN model has better applicability and higher accuracy.

Alizadeh et al. (2020) use an Adaptive Neural-Fuzzy Inference System (ANFIS) to forecast USD/JPY exchange rates and find that the ANFIS is superior in terms of prediction error minimization, robustness and flexibility when compared to the Sugeno-Yasukawa model, MLFFNN and multiple regression models. They further argue that the ANFIS can be used to better explain solutions when compared to the black-box neural networks. A similar argument is put forward by Sharma et al. (2016) who applied an ANFIS to daily CNY/USD, INR/USD and JPY/USD data and reported that ANFIS based models outperformed the ANN based models when evaluated based on Mean Absolute Percentage Error (MAPE) values.

Galeshchuk and Mukherjee (2017) argue that time series models and shallow neural networks provide acceptable point estimates for future rates but are poor at predicting the direction of change. They advocate for the use of deep networks that may have the ability to learn abstract features in the data. In their study, they investigate the ability of Deep Convolution Neural Networks (DCNN) to predict the direction of change in EUR/USD, GBP/USD and JPY/USD, and they state that trained deep networks produce satisfactory out-of-sample accuracy. They further point out that the Absolute Percentage Error rate for forecasts in the ARIMA, Exponential Smoothing (ETS) and ANN models were less than 2.4% in all instances, which are generally acceptable error rates that imply the point estimates are acceptable and satisfactory.

Shen et al. (2015) in their study, while modifying a Deep Belief Network (DBN), applied weekly exchange rate data on GBP/USD, BRL/USD and INR/USD to a DBN, MLFFNN, RW and ARMA models. The findings in the study reported that the DBN outperformed the MLFFNN and the traditional forecasting techniques by all evaluation criteria used in the study.

Henríquez and Kristjanpoller (2019) propose a hybrid model that uses Independent Component Analysis (ICA) as a deconstruction model and then employs neural networks to predict the future values of the deconstructed series. The hybrid model was applied to five daily frequency currencies with respect to the USD; EUR, GBP, JPY, CHF and CAD. Their results revealed a significant performance improvement in the Mean Square Error (MSE) and MAPE when compared to the RW model and the econometric models of the ARMA and GARCH family.

Markova (2019) presents a Nonlinear Autoregressive with Exogenous Input (NARX) neural network using three different training algorithms[52] applying the model to EUR/USD. Results reported were convincing and the study concluded that ANNs are an effective method of forecasting exchange rates; there was a close relationship between the outputs and the targets after.

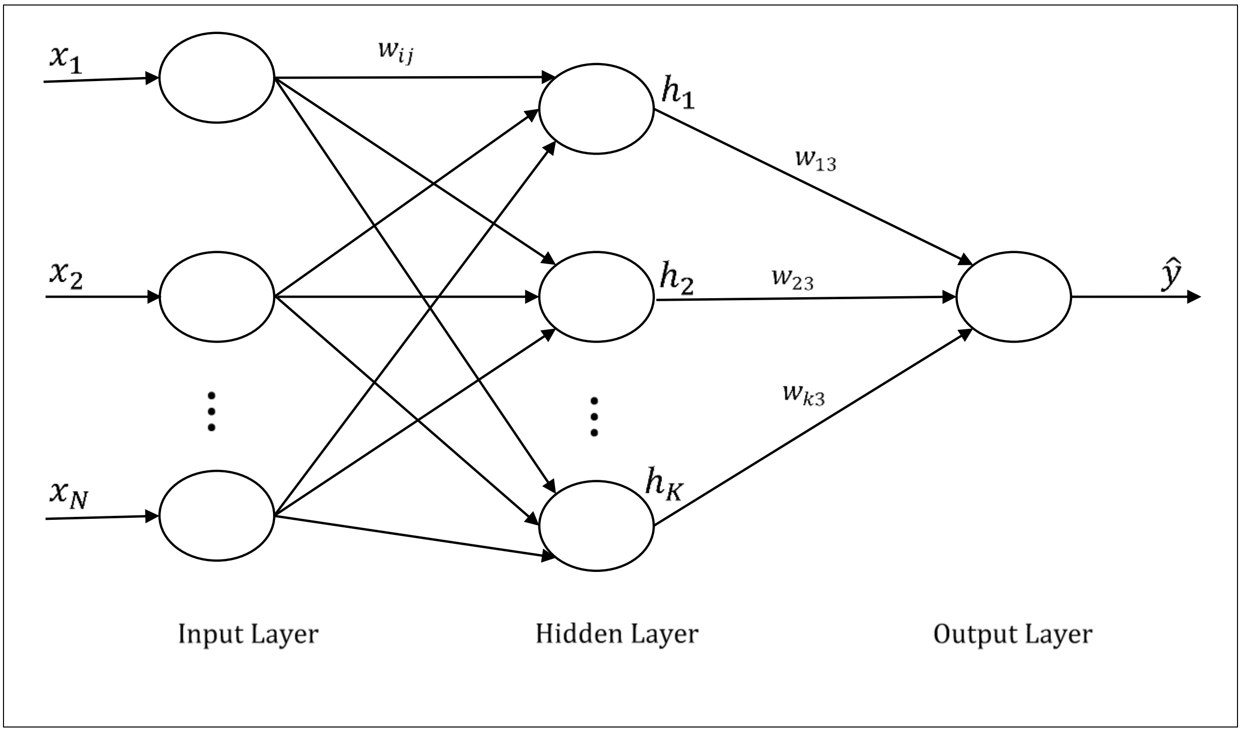
There are many other hybrid adaptations and modifications to the neural network structures using a number of functions; see for example Sermpinis et al. (2012, 2013, 2019), Dunis et al. (2011) and Stasinakis et al. (2016).

[52] Levenberg-Marquardt, Bayesian regularisation and Scaled Conjugate Gradient.

4.3 The Model and Data

4.3.1 The model

Figure 4.1: The structure of a single hidden layer neural network



The input variables in this model, that is the x variables, are the lags of the exchange rate series. The output of any neuron j in the hidden layer is given by;

$$h_j = \sigma(b_j + \sum_{i=1}^{N} w_{ij} x_i) \quad (1)$$

Where σ is the sigmoid logistic activation function[53] which has the important property of being non-linear in nature, b_j is the bias term specific to neuron j, that is to say, every neuron already has a bias term. This bias, sometimes referred to as the threshold term is the value required for the neuron to have a meaningful performance. The bias can be compared to the intercept term in a regression model. w_{ij} is the weight of the synapse from neuron i to neuron j, it may also be looked at as the contribution of neuron i to the output of neuron j. x_i is the input into a neuron in the input layer and N the number of neurons in the input layer.

[53] There has been a movement towards the use of the Rectified Linear Unit (ReLU) activation function. The argument is that this type of function enables the algorithm to detect and learn patterns faster.

The estimate of the output of the final neuron, in the output layer, which is of interest, is evaluated in the same way, only that the final contributions in this case are coming from the hidden layer identified by the hidden neurons, h. The key principle is that the output from one layer is the input into the next layer.

$$\hat{y} = \sigma(b_j + \sum_{i=1}^{K} w_{i3} h_i) \tag{2}$$

The error, which in this case is the Sum Squared Error (SSE) for the training iteration t and training vector p is given by;

$$E^p(t) = \frac{1}{2}(\hat{y}^p(t) - y^p(t))^2 \tag{3}$$

Where $\hat{y}^p(t)$ is the output value and $y^p(t)$ is the target value.

The total error is therefore computed as;

$$E(t) = \sum_{p=1}^{P} E^p(t) \tag{4}$$

The relationship between the weight, w_{ij}, bias, b_j, during each training iteration and the error function is given by;

$$\Delta w_{ij}(t) = -\tau \frac{\partial E^p(t)}{\partial w_{ij}(t)} \tag{5}$$

$$\Delta b_j(t) = -\tau \frac{\partial E^p(t)}{\partial b_j(t)} \tag{6}$$

Where τ is the learning rate[54] and $\frac{\partial E^p(t)}{\partial w_{ij}(t)}$ and $\frac{\partial E^p(t)}{\partial b_j(t)}$ are the gradient terms of the error function with respect to the weights and bias terms at iteration t and training vector p. The model is trained using a gradient descent[55] algorithm which is designed to allow the model to adjust the

[54] The learning rate has to be appropriate; it should not be too high or too low. For instance, if it is too high, the model may not reach the local minimum and may just keep bouncing back and forth between the convex function.
[55] This algorithm is generally used in training machine learning models; it tweaks the parameters iteratively to minimise a loss function to its local minimum.

parameters (the weights and biases) of the ANN in a way that best minimises the loss function, and consequently the output deviation. The gradient of the loss function is computed by the backpropagation algorithm using the chain rule, one layer at a time, iterating backwards right from the output layer.

The errors reported are the Mean Absolute Error and Root Mean Square Error as defined below.

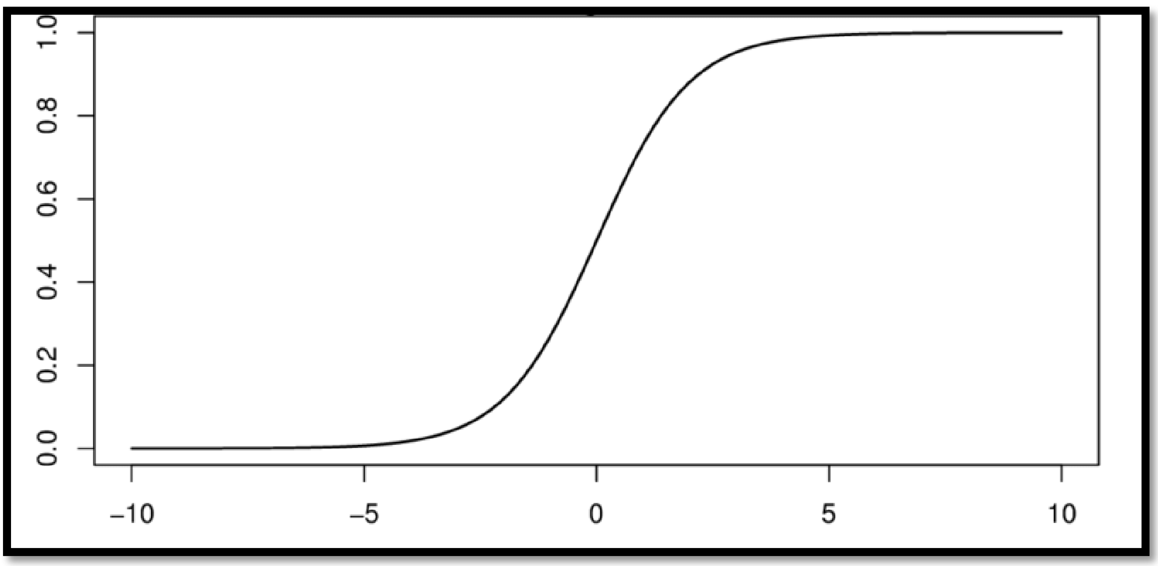
$$MAE = \frac{1}{n}\sum_{i=1}^{n}|y_i - \hat{y}_i| \quad (7)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2} = \sqrt{MSE} \quad (8)$$

Well-behaved activation functions in this case need to be non-linear, continuous, differentiable, monotonic and bounded. Some of these functions are;

- The logistic function; $f(x) = \frac{1}{1+e^{-x}}$
- The hyperbolic tangent; $f(x) = \frac{e^{x}-e^{-x}}{e^{x}+e^{-x}}$
- Gaussian; $f(x) = e^{x^2/2}$
- Sine and Cosine; $f(x) = \sin(x)\,, f(x) = \cos(x)$

Figure 4.2: Sigmoid logistic activation function



4.3.2 Data

The exchange rate data on CHF/EUR, GBP/EUR and USD/EUR covers three frequencies; daily, weekly and monthly and is all downloaded from www.global-view.com/forex-trading-tools/forex-history/index.html. The daily data runs from 02/01/2020 to 03/12/2020, that is, 242 data points. The weekly data runs from the week of 18/04/2016 to 03/12/2020, that is, 242 data points and the monthly data runs from January 2000 to December 2020, that is 252 observations.

The data is then divided into two parts; the training and validation data sets. The daily frequency training data for the CHF/EUR runs from 30/01/2020 to 16/09/2020 (166 observations), GBP/EUR runs from 23/01/2020 to 16/09/2020 (171 observations) and USD/EUR runs from 09/01/2020 to 16/09/2020 (181 observations). The validation data runs from 17/09/2020 to 03/12/2020 (56 observations) for all three currencies.

The weekly frequency training data for the CHF/EUR runs from the week of 15/08/2016 to 08/11/2019 (169 observations), GBP/EUR runs from the week of 05/09/2016 to 08/11/2019 (166 observations) and USD/EUR runs from the week of 05/09/2016 to 08/11/2019 (166 observations). The validation data runs from the week of 11/11/2019 to 03/12/2020 (56 observations) for all three currencies.

The monthly frequency data for the CHF/EUR runs from October 2000 to April 2016 (187 observations), GBP/EUR runs from December 2000 to April 2016 (185 observations) and USD/EUR runs from January 2001 to April 2016 (184 observations). The validation data runs from May 2016 to December 2020 for all three currencies.

4.4 Discussion of Results

4.4.1 Descriptive statistics

Table 4.1, Table 4.2 and Table 4.3 show the key moment summary statistics of the exchange rate data at levels for the daily, weekly and monthly frequencies respectively. For instance, from Table 4.1, it is observable that the CHF/EUR had an average rate of 1.069 with a standard deviation of 0.010, reaching a minimum rate of 1.051 and a maximum rate of 1.086. The tail behaviour, described by the skewness and kurtosis values indicates that the data is negatively skewed. The kurtosis on the other hand is less than 3, implying that the data is platykurtic. All the data have a platykutic distribution except for the GBP/EUR weekly frequency that has a kurtosis greater than 3, making it leptokurtic.

4.4.2 Architecture of the neural network models

Table 4.4 shows the structure of the neural networks by number of neurons per layer. There is no specific formula that gives the optimal number of neurons that may be used by a layer, but the bigger the number of neurons, the more complex the relationships being captured by the model as noted earlier. The model uses a single hidden layer with a single output neuron as illustrated in Figure 4.1.

4.4.3 Error/Accuracy measure and performance of the models

In-sample predictions are associated with the training period while the out-of-sample predictions are associated with the validation period. The validation period is an unbiased period that typically is an evaluation of the model’s performance.

Table 4.5 and Table 4.6 show the Mean Absolute Error and Root Mean Square Error for the training and validation periods of the 3 data frequencies. It is observable that there is a lower error (regardless of the measure) reported during the training period compared to the validation period for all currency pairs and frequencies. For example, looking at Table 4.5 and Table 4.6, GBP/EUR weekly data; the training period reports a MAE and RMSE of 0.00016 and 0.00025 respectively while the validation period reports higher MAE and RMSE of 0.01844 and 0.02168 receptively. This implies that the model performs better for in-sample predictions compared to out-of-sample predictions. It is also important to note that the error reported for daily frequency data is lower than that for both the weekly and monthly frequency data for each of the currency pairs during the validation period. For example, taking the USD/EUR pair; daily, weekly and monthly MAE are 0.00882, 0.02334 and 0.07140 respectively; the model performs best for high frequency data during the validation period. This assertion may not apply to the training period; comparing GBP/EUR daily and weekly frequencies during the training period, it is observable that the weekly data reports a lower MAE and RMSE compared to the daily frequency data.

In-sample daily predictions indicate that the model performed best for the CHF/EUR pair, reporting the lowest MAE and RMSE of 0.00010 and 0.00018 respectively. Weekly estimates show that the model performed best for the GBP/EUR pair, reporting a MAE and RMSE of 0.00016 and 0.00025 respectively. The GBP/EUR currency pair again performed best when it came to monthly frequency, reporting a MAE and RMSE of 0.00673 and 0.00878 respectively.

Out-of-sample daily predictions indicate that the model performed best for the CHF/EUR currency pair, reporting the lowest MAE and RMSE of 0.00377 and 0.00473 respectively. When it came to weekly estimates, the model performed best for the CHF/EUR currency pair too, reporting a MAE and RMSE of 0.00783 and 0.00983 respectively. The GBP/EUR currency pair performed best when it came to monthly frequency, reporting a MAE and RMSE of 0.03649 and 0.04266 respectively. The ANN models did not perform well when it came to the USD/EUR pair, especially during the validation period, where the currency pair reported the highest MAE and RMSE regardless of the data frequency. The performance of the ANN models for the currency pairs and frequencies can be observed graphically in Figure 4.3, Figure 4.4 and Figure 4.5 for daily data; Figure 4.6, Figure 4.7 and Figure 4.8 for weekly data; Figure 4.9, Figure 4.10 and Figure 4.11 for monthly data.

4.5 Conclusion

This study applied the single hidden layer neural network to predict daily, weekly and monthly frequency exchange rates of the CHF/EUR, GBP/EUR and USD/EUR. The results show good accuracy of the model as evidenced by the low MAE and RMSE, especially for the daily frequency data. Furthermore, the neural network performed best in out-of-sample predictions for the CHF/EUR currency pair for daily and weekly predictions and performed best for the GBP/EUR pair when it came to monthly frequency. The USD/EUR pair proved more difficult to model, performing worst, especially in the validation period. The non-linear nature of the neural network went a long way in learning and capturing complex movements in the exchange rates as shown in the in-sample and out-of-sample graphs; a clear advantage when compared to the traditional linear prediction models like the ARMA and ARIMA. Perhaps, a study comparing the results of the neural network model and a linear model could have given a more evidence-based conclusion. Thus, it can be argued that when it comes to risk reduction, especially with the complexity and patterns in exchange rate movements, neural networks may do a much better job when it comes to risk mitigation for the private sector and monetary authorities that are more policy oriented.

Table 4.1: Moment summary statistics of daily exchange rates

	Mean	Std. Dev	Min	Max	Skewness	Kurtosis
CHF/EUR	1.069	0.010	1.051	1.086	-0.335	1.980
GBP/EUR	0.888	0.024	0.831	0.938	-0.806	2.729
USD/EUR	1.135	0.040	1.064	1.214	0.096	1.502

Table 4.2: Moment summary statistics of weekly exchange rates

	Mean	Std. Dev	Min	Max	Skewness	Kurtosis
CHF/EUR	1.108	0.037	1.051	1.197	0.465	2.072
GBP/EUR	0.875	0.028	0.761	0.929	-1.314	5.697
USD/EUR	1.136	0.045	1.043	1.245	0.320	2.654

Table 4.3: Moment summary statistics of monthly exchange rates

	Mean	Std. Dev	Min	Max	Skewness	Kurtosis
CHF/EUR	1.348	0.204	1.032	1.678	-0.065	1.371
GBP/EUR	0.773	0.100	0.586	0.957	-0.218	1.604
USD/EUR	1.207	0.165	0.849	1.578	-0.233	2.608

Table 4.4: Structure of neural networks by number of neurons per layer

	Daily		Weekly		Monthly	
	Input	Hidden	Input	Hidden	Input	Hidden
CHF/EUR	20	10	17	10	9	10
GBP/EUR	15	15	20	10	11	6
USD/EUR	5	10	20	5	12	8

Table 4.5: Training period error measures

	CHF/EUR		GBP/EUR		USD/EUR	
	MAE	RMSE	MAE	RMSE	MAE	RMSE
Daily	0.00010	0.00018	0.00041	0.00065	0.00323	0.00475
Weekly	0.00056	0.00093	0.00016	0.00025	0.00228	0.00286
Monthly	0.00908	0.01562	0.00673	0.00878	0.00992	0.01297

Table 4.6: Validation period error measures

	CHF/EUR		GBP/EUR		USD/EUR	
	MAE	RMSE	MAE	RMSE	MAE	RMSE
Daily	0.00377	0.00473	0.00711	0.00977	0.00882	0.01138
Weekly	0.00783	0.00983	0.01844	0.02168	0.02334	0.03046
Monthly	0.04024	0.05313	0.03649	0.04266	0.07140	0.09152

Figure 4.3: CHF/EUR daily step exchange rate forecasts

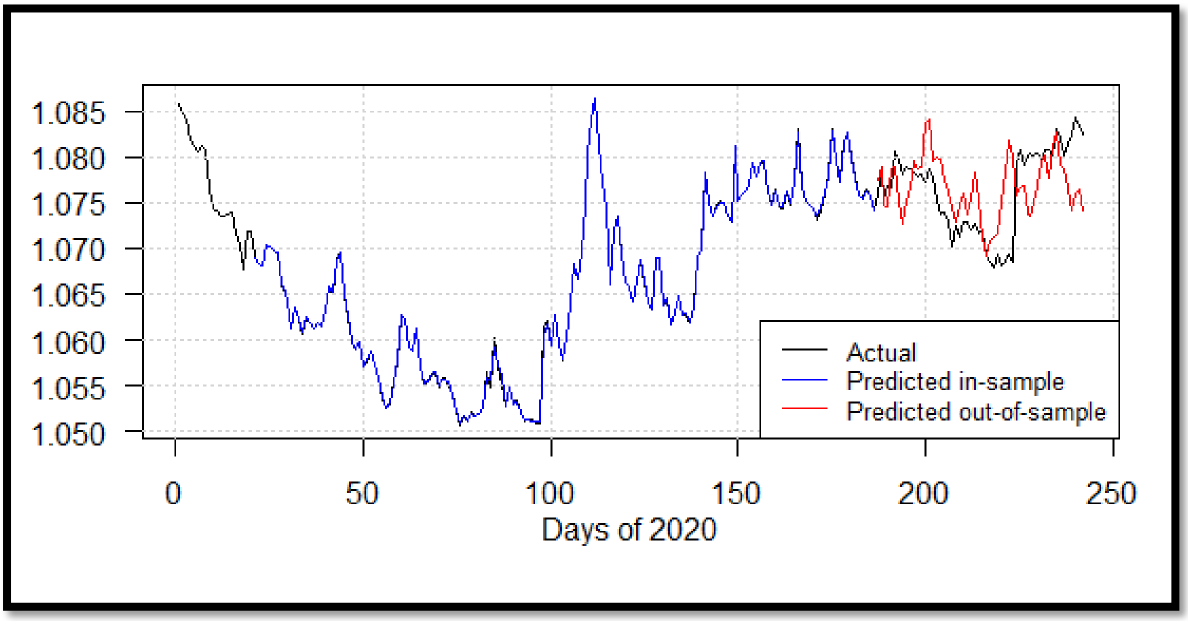


Figure 4.4: GBP/EUR daily step exchange rate forecasts

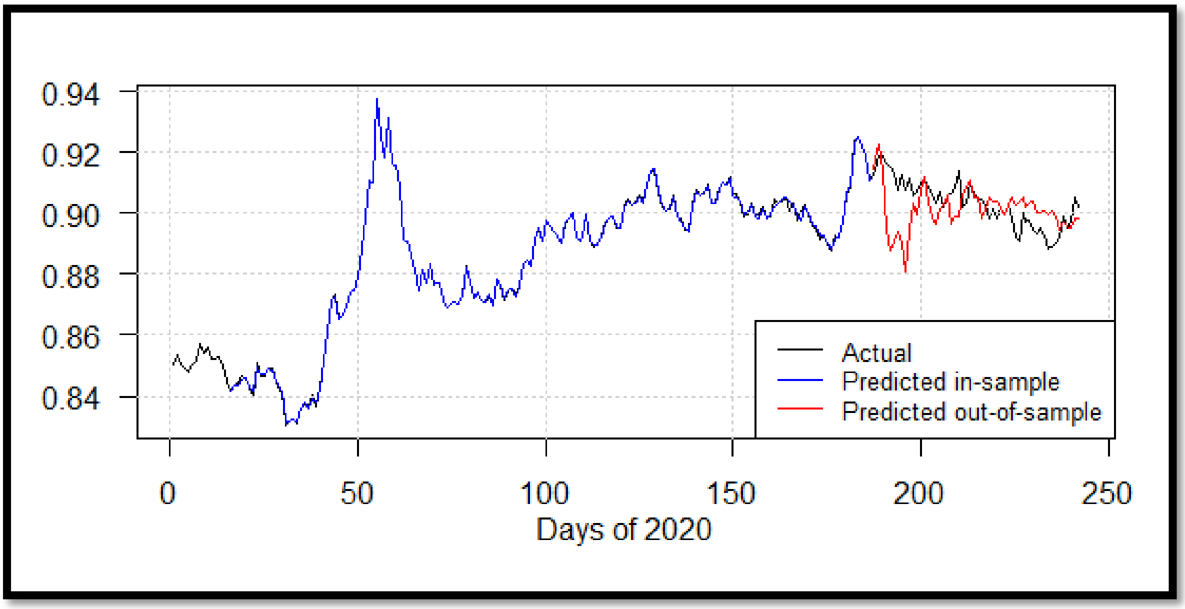


Figure 4.5: USD/EUR daily step exchange rate forecasts

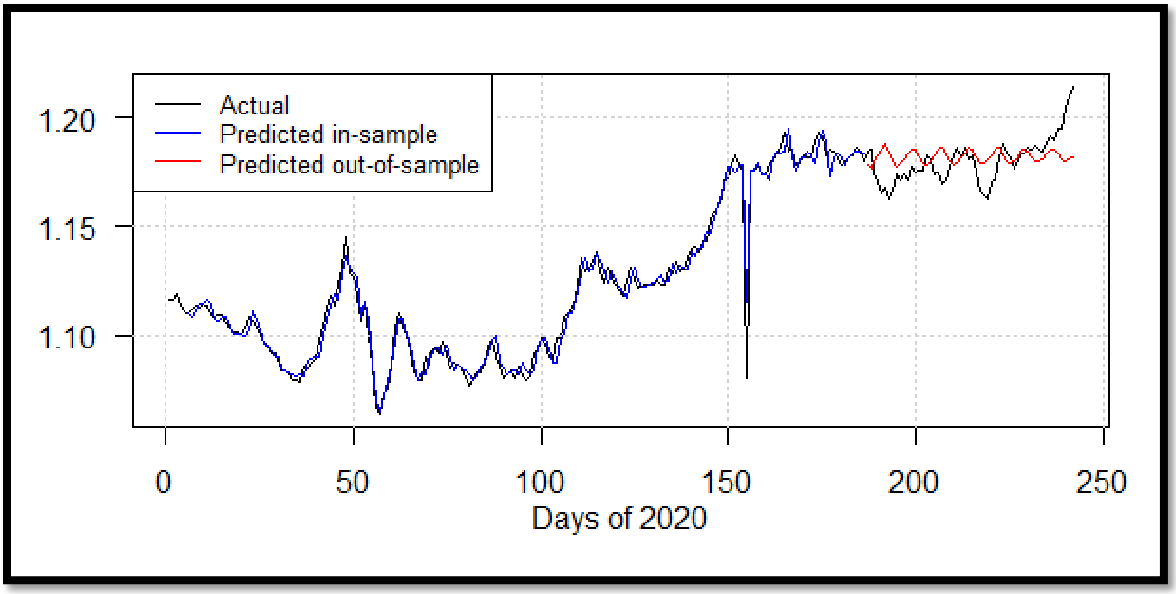


Figure 4.6: CHF/EUR weekly step exchange rate forecasts

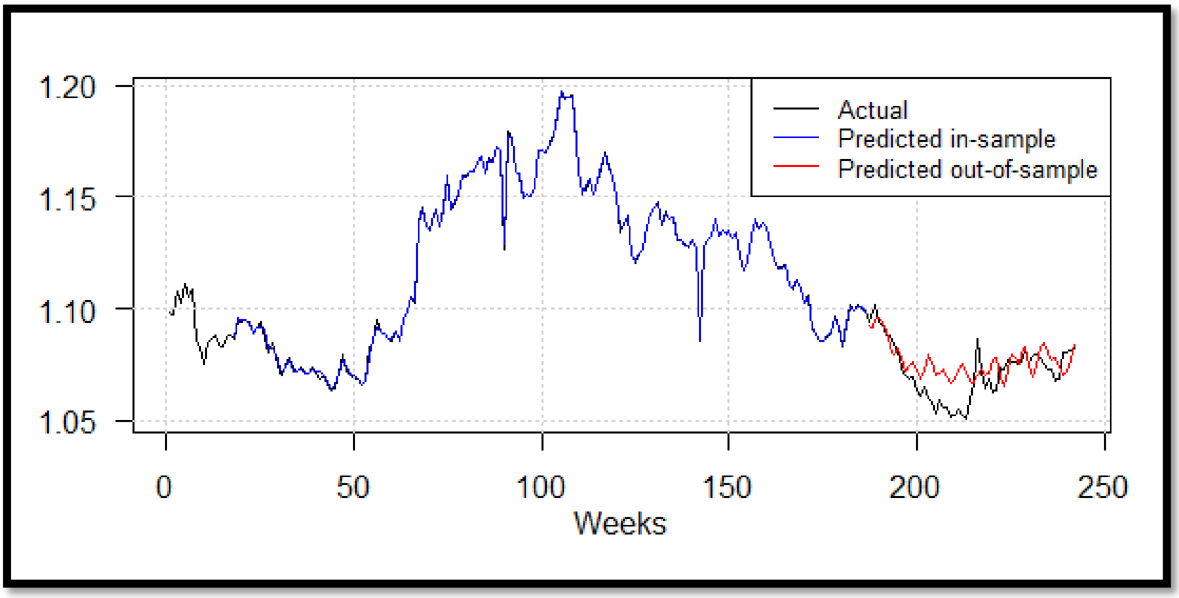


Figure 4.7: GBP/EUR weekly step exchange rate forecasts

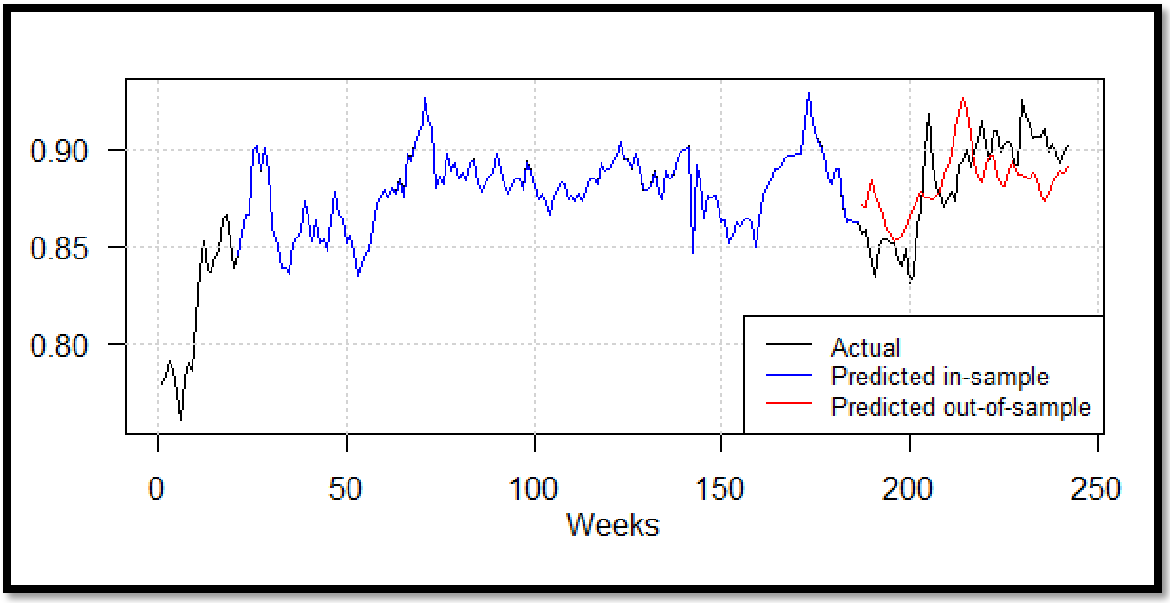


Figure 4.8: USD/EUR weekly step exchange rate forecasts

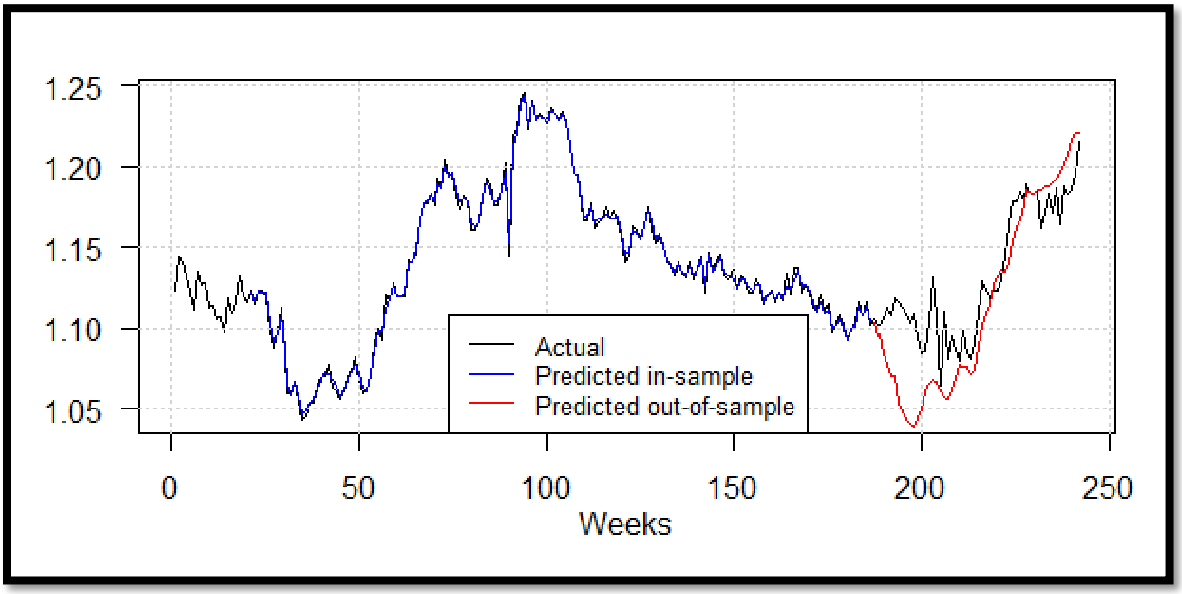


Figure 4.9: CHF/EUR monthly step exchange rate forecasts

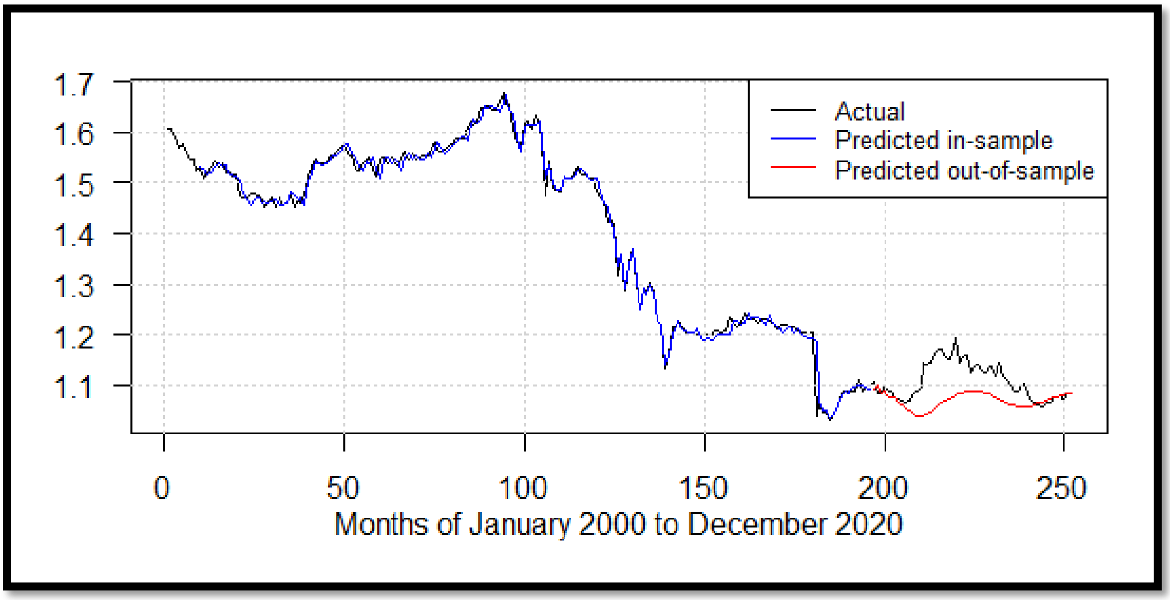


Figure 4.10: GBP/EUR monthly step exchange rate forecasts

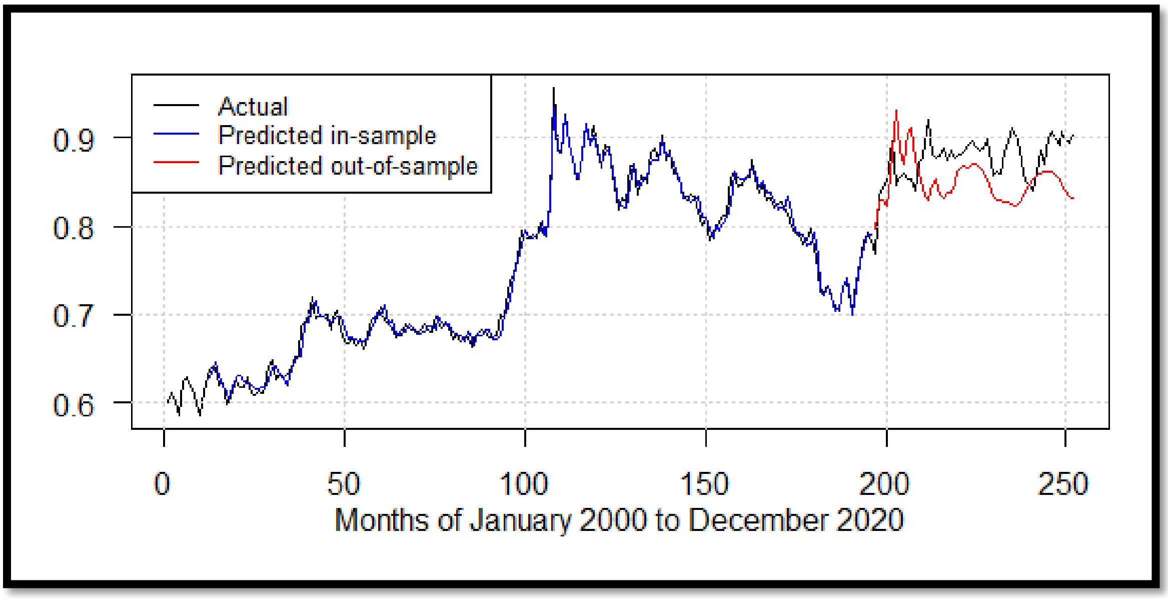
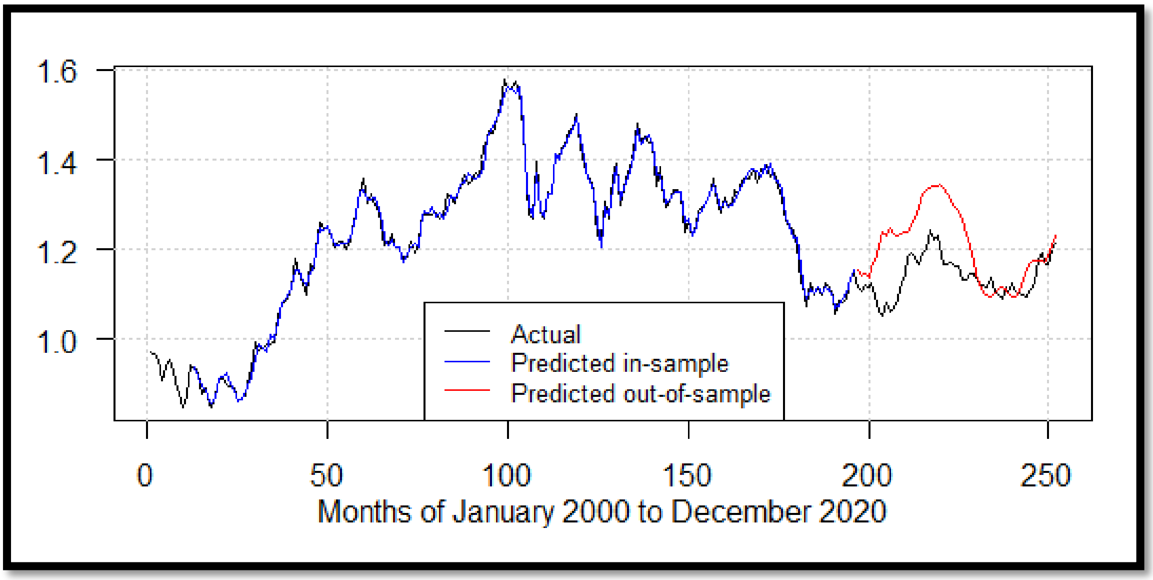


Figure 4.11: USD/EUR monthly step exchange rate forecasts



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