Asymmetry and Multiscale Dynamics in Macroeconomic Time Series Analysis

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Abstract

This doctoral thesis consists of an introductory chapter and three articles. The first two articles focus on asymmetries and nonlinearities in the exchange rate adjustment that are potentially due to (i) frictions that impede goods arbitrage, and (ii) official intervention in the foreign exchange market. The third article is devoted to the analysis of the effects of money supply at different time horizons.

The first article investigates the purchasing power parity (PPP) hypothesis in a panel of Sub-Saharan African (SSA) countries. We apply methods that allow for nonlinearities and asymmetries in real exchange rate adjustment towards its equilibrium (mean) value. The results indicate empirical support for the PPP theory. The second article examines the relationship between current account adjustment and exchange rate flexibility in a panel of emerging and developing economies. The purpose is to (i) obtain a measure of exchange rate flexibility that considers autoregressive conditional heteroskedasticity and possible asymmetric responses of the exchange rate to shocks, and (ii) apply suitable dynamic panel data estimators to gauge this relationship. The findings indicate that more flexible exchange rates are associated with faster current account adjustment.

The third article investigates the liquidity effect and the long-run neutrality of money using time series data for Sweden and the US. The objective is to apply wavelets to decompose time series into detailed timescales and then test these two propositions at different time horizons. The findings indicate evidence of the liquidity effect at horizons of one to four years, but we find no evidence of monetary neutrality in any of the analysed economies.

1. Introduction and summary of the thesis

1.1.Background

Macroeconomics is not short of puzzles. A theory becomes a puzzle when its predictions are increasingly unsupported by real-world data. To evaluate an economic theory, hypotheses must be formulated and empirically tested using appropriate data and methods. However, one cannot conclude with certainty that the failure to find support for a given theory invalidates that particular theory. For example, failure to reject a given null hypothesis can be due to less powerful (unable to reject a false null hypothesis) tests that are applied. Moreover, low statistical power can be due to the fact that the applied test is based on a model that is not suitable for the process that generated the data. Thanks to econometric advancements, some puzzles that had become like thorns in macroeconomics are being solved when suitable methods are applied.

An understanding of the behaviour of macroeconomic time series has evolved over time. Since Nelson and Plosser's (1982) seminal work, the presence of unit roots in macroeconomic time series has become a stylized fact and unit root testing has become a standard step in almost every study that deals with macroeconomic time series. Nonstationarity in the series implies that a shock to that particular series will produce effects that will not dissipate over time, and if nonstationary series are used in regression analysis, one tends to find spurious relationships, that is, statistically significant relationships while none in fact exists (Granger & Newbold, 1974).

An important development in partly remediating the problem of spurious relationships has been the development of the cointegration technique. Engle and Granger's (1987) finding that a linear combination of two nonstationary variables with the same order of integration[1] can be stationary[2], revolutionized econometrics and made it possible to study long-run relationships

[1] The order of integration (D) is the number of times a nonstationary variable needs to be differenced to become stationary. Such a variable is said to be integrated of order D, or simply I (D).

[2] Unless otherwise specified, the term "stationarity" throughout this thesis refers to weak stationarity (or covariance-stationarity or second order stationarity). A process x_t with mean μ_t and autocovarince φ_{jt} is said to be weakly stationary or covariance-stationary if:

$E(x_t) = \mu$ for all t

$E(x_t - \mu)(x_{t-j} - \mu) = \varphi_j$ for all t and any j.

These two conditions imply that neither μ_t nor φ_{jt} depend on the date t. (see, Hamilton, 1994, pp. 45-46).

among non-stationary macroeconomic variables without differencing them beforehand to make them stationary[3]. This also meant that together with the error-correction model methodology, it was possible to analyse both the short-run dynamics and long-run equilibrium relationships. These two time horizons have dominated economic literature.

The focus of this thesis is on testing macroeconomic propositions taking into account features of macroeconomic and financial time series that have not been paid enough attention in extant literature. Specifically, we consider (i) asymmetries and nonlinearities in exchange rate adjustment and volatility, and (ii) multiscale (multi-horizon) dynamics in the relationship between money, interest rate and output, beyond just the short and the long-run that have been conventional time horizons in macroeconomic modelling.

Linear models have long been conventional in economic modelling. "Linear approximations to nonlinear economic phenomena have served macroeconomic modelers well, but in many cases nonlinear specifications have turned out to be useful" (Teräsvirta, 2004, p.222). A linear data generating process implies that the speed of adjustment of the time series towards the equilibrium is constant. For real-world data, however, the adjustment may not take place at a constant speed. For example, policymakers may not find it necessary to intervene when the exchange rate is misaligned, but they may start intervening when the misalignment reaches a certain level. As a result, there are two regimes. One regime that is mean reverting whereby large deviations require the intervention of the monetary authority thus making some corrections. Another regime that is not mean reverting because of small deviations that do not necessitate the intervention of the authorities. Moreover, small deviations do not attract arbitrageurs because, due to transaction costs, the marginal cost of arbitrage may exceed the marginal benefit. Therefore, this scenario suggests that the speed of adjustment is higher further from the equilibrium and a method that is based on a suitable data generating process is necessary to model such an adjustment.

Moreover, not only does the magnitude of the deviations from the equilibrium value matter, but so do the signs of these deviations. At some point in time, countries may react differently to currency appreciation or depreciation depending on their policy agendas. For example, policymakers may tolerate depreciation in a certain range to regain competitiveness, and if necessary the central bank will intervene vigorously in the foreign exchange market to prevent

[3] This is important because when a series is differenced, the level information is lost.

excessive currency appreciation. The opposite is also possible, especially in developing countries that are import-dependent and where currency appreciation means that imports become more expensive and this has eventual repercussions for the economy. Further, for countries with a high proportion of debt that is denominated in a foreign currency, a depreciated currency results in expensive foreign debt and thus more debt servicing. This implies that these countries may have incentives to vigorously defend the value of their own currencies vis-à-vis the major currencies.

Another source of asymmetries does not come from policymakers' actions but from agents in financial markets. Financial markets do not react in the same way to positive and negative news or shocks. When one is modelling variables like the exchange rate, it is necessary to recognize the possibility that a negative shock can generate more uncertainty (volatility) in the foreign exchange market than a positive shock of the same magnitude.

Another focus of this thesis is recognizing that there may exist different scales of variations in macroeconomic time series. The idea here is that economic agents simultaneously make decisions at different time horizons. Ramsey (2014) uses the term "planning horizons" that are likely to affect the structure of macroeconomic relationships so that such relationships might vary over different time horizons or hold at some time scales but not at others. Moreover, these "planning horizons" are important to policymakers. For example, a central bank's actions to achieve price stability depend on the time horizon; monetary authorities may react to inflation news in the short run, while at long horizons the price level is essentially determined by money supply (Aguiar-Conraria et al., 2008). The implication for economic modelling is that to fully understand the relationship among macroeconomic variables it is necessary to be able to decompose the data into detailed timescales.

The rest of this introductory chapter is organized as follows. The second section describes the purchasing power parity (PPP) theory and recent theoretical developments in modelling nonlinear and asymmetric adjustments towards PPP. The third section discusses the role of flexible exchange rates in external adjustment and the fourth section briefly discusses the rationale of wavelet analysis in economics and the timescale effects of monetary policy. The fifth section provides a summary and an outline of the remaining chapters.

1.2.Nonlinear and asymmetric deviations from purchasing power parity

The intellectual origins of the proposition that nominal exchange rates adjust to differences in price levels across countries, known as (relative) purchasing power parity (PPP), can be traced to the writings of Wheatley (1803, 1807, 1819) and Ricardo (1810, 1817) in the early part of the 19th century (see Frenkel, 1978, for a thorough discussion of the origins of the PPP theory). However, its modern formulation starts with the Swedish economist Karl Gustav Cassel's (1918) seminal work. He wrote:

> "At every moment the real parity between two countries is represented by this quotient between the purchasing power of the money in the one country and the other. I propose to call this parity *the purchasing power parity*" Cassel (1918, p.413).

The PPP proposition has long been the cornerstone of models of exchange-rate determination and a basis for international comparisons of national account statistics. Moreover, the PPP condition can be used to assess the degree of misalignment and its empirical validity can be understood as a measure of economic integration among countries (Cuestas & Regis, 2013).

The absolute PPP hypothesis, known as the law of one price (LOP), posits that the price of identical goods in different countries should be the same when converted to the same currency. This implies that if one selects two identical baskets of goods in two different countries with two different currencies, the cost should be the same using the exchange rate. Realistically, however, LOP is less likely to hold since it is based on the idea of frictionless goods arbitrage. The presence of tariffs, transport costs and other nontariff barriers and duties would induce a violation of the non-arbitrage condition. Moreover, internationally produced goods are not always perfect substitutes, thus the difference between domestic and foreign prices can also be due to product differentiation[4] (Sarno & Taylor, 2002, p.52).

On the other hand, the relative PPP hypothesis asserts that a change in the nominal exchange rate between two currencies is determined by a change in the relative price levels of the two countries. This implies that when PPP holds there exists a relationship between the nominal exchange rate and domestic and foreign prices. Therefore, the real exchange rate, computed as

[4] Consider, for example, two goods: gold and McDonald's hamburgers. LOP can be expected to hold for the former but not for the latter because, unlike gold, McDonald's hamburgers are differentiated across countries (see Rogoff, 1996; Sarno & Taylor, 2002, p.52).

the nominal exchange rate adjusted for relative price, can be interpreted as a deviation from PPP. Unless otherwise specified, throughout this thesis PPP refers to relative PPP.

However, it is worth mentioning here that PPP is not expected to hold in the short run; instead it is a long-run phenomenon because at short horizons the relative price levels (inflation differentials) are unlikely to explain changes in nominal exchange rates because the latter are relatively more volatile (Sjölander, 2007).

Several variants of relative PPP have been suggested and tested; we list a few of them here. The qualified PPP (QPPP) hypothesis holds when there is mean reversion in real exchange rates after allowing for a shift in the intercept. That is, PPP may hold before and after a given event that caused structural changes, but not for the continuous period (Dornbusch & Vogelsang, 1991; Habimana et al., 2018; Hegwood & Papell, 1998). Trend PPP (TPPP) holds when there is mean reversion in real exchange rates after allowing for a time trend in the sense of the Balassa–Samuelson effect that causes long-run deviations from PPP (Balassa, 1964 and Samuelson, 1964).[5] Trend qualified PPP (TQPPP) holds when there is mean reversion in real exchange rates after allowing for a time trend and one or two changes in the intercept (Papell & Prodan, 2006). The generalized PPP (GPPP) holds when there is cointegration among individual nonstationary real exchange rates. GPPP is one of the criteria used to assess whether or not a group of countries form an optimum currency area (Caporale et al., 2011; Enders & Hurn, 1994). Judging by these definitions, it is fair to say that the effort to rescue the PPP doctrine has resulted in many "weak" and "weaker" reformulations of this concept.

To further define relative PPP, let S be the nominal exchange rate (defined as domestic currency units per a foreign currency unit) and P *and* P^* denote domestic and foreign price levels respectively. The real exchange rate (RER) is defined as:

$$Q_t = \frac{S_t P_t^*}{P_t} \tag{1}$$

If we take the natural logarithm of both sides of Eq. (1), RER is given by:

[5] The Balassa–Samuelson effect (Balassa, 1964; Samuelson, 1964) is another argument put forward to explain the empirical failure of PPP. According to this effect, "low wages in a low-productivity, labour-endowed country will cause prices to be low in its non-traded sector, whereas high wages will drive prices up in a more productive economy. Higher productivity will thus cause an appreciation in a country's real exchange rate and can lead to a breakdown in PPP" (Bahmani-Oskooee & Hegerty, 2009, p.618).

$$q_t = s_t + p_t^* - p_t \qquad (2)$$

where lower-case letters denote the variables in logarithmic form.

The relative PPP condition contends that s_t adjusts to offset changes in $p_t^* - p_t$ so that in the long-run q_t is stationary and converges to a constant mean. A stationary q_t implies that deviations from PPP will dissipate over time (Hegwood & Papell, 1998). A non-stationary q_t, on the other hand, implies that deviations from PPP are not corrected.

Empirically, early studies could not find strong evidence that RER follows a stationary process (among others, Adler & Lehman, 1983; Frenkel, l981). Moreover, studies have suggested a half-life of PPP deviations of three to five years[6] (Froot & Rogoff, 1995). A half-life of three to five years is far too long[7] to be explained by nominal rigidities (Rogoff, 1996).

PPP's empirical failure has been partly attributed to the lack of power[8] of conventional univariate unit root tests. As a remedy, several studies have applied panel unit root tests to improve the power. Some studies have also suggested that RER adjustment towards long-run equilibrium might be nonlinear (for example, Taylor et al., 2001). That is, RER might be generated by a nonlinear but stationary process. The argument is that for small deviations from the mean (equilibrium) value, real exchange rates are nonstationary due to the presence of market frictions and transaction costs, while larger deviations do exhibit mean reversion (see McMillan, 2009). Other sources of nonlinearities in real exchange rates include speculative attacks on currencies (Flood & Marion, 1999), heterogeneity of buyers and sellers (Taylor & Allen, 1992) and the presence of target zones (Krugman, 1991). On these lines, Kapetanios et al. (2003) propose a unit root test that is based on the following exponential smooth transition autoregressive (ESTAR) data generating process (DGP):

$$\Delta y_t = \gamma y_{t-1}\left[1 - e^{(-\theta y_{t-1}^2)}\right] + \varepsilon_t \qquad (3)$$

[6] Taylor (2001) argues and also demonstrates through Monte Carlo simulations that there is substantial upward bias when half-lives are estimated with linear models while the true data generating process is nonlinear.
[7] A half-life of 5 years, for example, implies that it will take five years for the PPP deviation to decay by half. That is, only 10% of the deviation from PPP is corrected each year.
[8] The power of a statistical test is the probability of rejecting a false null hypothesis.

where ε_t is independently and identically distributed (iid) with zero mean and constant variance, σ^2 ; θ=0 under the null of a unit root, and θ>0 under the alternative of a nonlinear but globally stationary y_t.

The idea behind the application of ESTAR models to modelling exchange rate adjustment is that the speed of adjustment is an increasing function of deviations from PPP. Due to transaction costs, arbitrage is only lucrative when deviations from PPP are large enough to cover these costs. Therefore, the larger the deviations, the greater the incentive for arbitrage, which in turn is expected to accelerate mean reversion unlike in the case of small deviations (Taylor, 2003). This type of nonlinear adjustment results in two distinct regimes in exchange rates with potentially different dynamic properties but the transition between the regimes is smooth (Sarantis, 1999).

Moreover, one would expect that not only is the magnitude of these deviations important but also that the direction (or sign) of the deviations, that is, the adjustment towards the long-run equilibrium is not only nonlinear but also asymmetric. The extant literature suggests different sources of asymmetric adjustments towards PPP as follows. Monetary authorities intervene asymmetrically in the foreign exchange market depending on the direction of RER's misalignment. Because of the effect that this misalignment has on net exports and on foreign debt servicing, the speed of adjustment varies according to whether a currency is over- or under-valued (Baharumshah et al., 2010). Real exchange rate depreciation implies a reduction of the purchasing power of domestic output over foreign claims, and this will make it more difficult to service debt that is denominated in a foreign currency (Eichengreen et al., 2007). Hence, countries whose debt is denominated in a foreign currency may choose to resist depreciations more vigorously than appreciations thereby generating asymmetric behaviour in RER (Dutta & Leon, 2002). Sollis (2009) extends the ESTAR model to the asymmetric ESTAR (henceforth referred to as AESTAR) that employs both an exponential and a logistic function:

$$\Delta y_t = G_t(\gamma_1, y_{t-1})\{S_t(\gamma_2, y_{t-1})\rho_1 + (1 - S_t(\gamma_2, y_{t-1}))\rho_2\}y_{t-1} + \varepsilon_t$$

$$G_t(\gamma_1, y_{t-1}) = 1 - \exp\left(-\gamma_1(y_{t-1}^2)\right),\ \gamma_1 \geq 0 \qquad (4)$$

$$S_t(\gamma_2, y_{t-1}) = \left[1 + \exp\left(-\gamma_2(y_{t-1})\right)\right]^{-1},\ \gamma_2 \geq 0$$

If $\gamma_1 > 0$ and $\gamma_2 \to \infty$, there is a large deviation of the state variable y_{t-1} and an ESTAR transition occurs between the central regime $\Delta y_t = \varepsilon_t$ and the outer-regime model that depends on the direction of the deviation. The speed of transition is determined by γ_1. The deviations can be either positive or negative. If the deviations are positive, the outer regime is $\Delta y_t = \rho_1 y_{t-1} + \varepsilon_t$. On the other hand, if the deviations are negative the outer regime is $\Delta y_t = \rho_2 y_{t-1} + \varepsilon_t$ (see Emirmahmutoglu & Omay, 2014; Sollis, 2009).

Global stationarity requires ρ_1<0 and ρ_2 <0, and γ_1>0 (Sollis, 2009). One can observe that ESTAR is nested in AESTAR and the asymmetric adjustment occurs when $\rho_1 \neq \rho_2$.

In Chapter 2 of this thesis, the PPP hypothesis is re-examined by testing the null hypothesis of a unit root against the alternative of stationary linear, ESTAR or asymmetric ESTAR real effective exchange rates (REERs) in a panel of Sub-Saharan African countries.

1.3.The exchange rate as a shock absorber

> "If internal prices were as *flexible* as *exchange rates*, it would make little economic difference whether adjustments were brought about by changes in exchange rates or equivalent changes in internal prices," Friedman (1953, p.165).

The alleged link between global current account imbalances and the 2007-08 global financial crisis (see Obstfeld & Rogoff, 2009) has reinvigorated the debate on the role of a flexible exchange rate in external adjustment. This debate can be traced back to Friedman (1953) who argued that the inflexibility of internal prices causes distortions in adjustments in response to changes in external conditions, and flexible exchange rates act as an external shock absorber. That is, in a world where internal prices (goods' prices and wages) are highly inflexible and when the economy is hit by real shocks, the effect on the rest of the economy will differ depending on the flexibility of the foreign exchange regime in place in each country; more flexible exchange rates are therefore expected to deliver a faster adjustment of current account imbalances.

The adjustment of current account imbalances takes place through the following channels. First, the trade channel which acts via the expenditure-switching mechanism whereby the nominal exchange rate serves as a tool for relative price adjustment and spurs corrective substitution by consumers both locally and abroad. This pushes the trade balance towards zero. Second, deciding between a fixed and a floating exchange rate regime could have an impact on the financing of deficit balances; this is the credit channel (Martin, 2016). Moreover, the choice of an exchange rate regime may be influenced by the level of debt of each country. It is presumed that there might be more current account persistence in countries with high debt servicing and this may reduce the effect of exchange rate flexibility on current account adjustment. This is because at some point countries make a trade-off between the benefits of currency flexibility and the extra debt servicing due to an expensive foreign currency in which their debt is denominated. This channel is linked to the "fear of floating" whereby monetary authorities exert influence on the volatility of the price of the domestic currency through official interventions in the foreign exchange market (Calvo & Reinhart, 2002).

As Calvo and Reinhart (2002) point out this practice has led to a surge in *de facto* managed floats, especially in emerging economies. Canales-Kriljenko (2003) claims that nominal exchange rates in emerging economies are insufficiently volatile, and because of large external liabilities denominated in a foreign currency, emerging markets continue to hold unusually large reserves to limit exchange rate volatility (Hausmann et al., 2001). Third, the valuation channel which operates through the expected exchange rate changes whereby the dynamics of the exchange rate affect the differential in the rates of return between assets and liabilities denominated in different currencies and the value of future net exports (Gourinchas & Rey, 2007).[9]

Empirically, the hypothesis that flexible exchange rate arrangements deliver a faster mean reversion of current account imbalances has been taken for granted for a long time. Chinn and Wei (2013) refer to it as a "faith-based initiative". To further investigate Friedman's hypothesis, we follow a different approach. Unlike previous studies (Chinn & Wei, 2013 ; Edwards & Yeyati, 2005 among others) that mainly use the exchange rate regime classification as a proxy for exchange rate flexibility, we estimate a measure of exchange rate volatility. This measure is then used as a proxy for exchange rate flexibility to test whether more flexible exchange rates

[9] It is worth mentioning that in addition to these discussed channels, in countries with fixed exchange rate regimes the adjustment of external imbalances may occur through an exchange rate crisis. As Gervais et al. (2016) point out, this type of adjustment through a crisis is costlier in terms of forgone output and employment.

are associated with less persistent current account imbalances. This is done in a panel of emerging and developing economies. Most emerging market and developing countries tend to intervene much more heavily in the foreign exchange market (Hausmann et al., 2001), so it becomes difficult and unrealistic to formally classify their exchange rate regimes across time. Using actual exchange rate volatility instead of the exchange rate classification is one way of overcoming this limitation.

1.4. Wavelet analysis and timescale effects of monetary policy

"One of the most cogent rationalizations for the use of wavelets and timescale analysis is that different agents operate at different *time scales,*" Ramsey (2014, p.18).

Policymakers, individuals, households and firms make decisions simultaneously at different time horizons. As a result, the data that we encounter in economic analysis consists of a mixture of variations at short, medium and long horizons. As Ramsey (2014) points out, an example of the relevance of time scales or "planning horizons" in economic analysis is that of traders operating in the market for securities. The fundamentalists may have a very long view and trade looking at market fundamentals and may concentrate their attention on "long-run variables" and average-over short run fluctuations, while the chartists operate with a time horizon of only weeks, days, or even hours. However, in mainstream economics it is standard practice to divide the time horizon into only two horizons —the short and the long run. This division, as Ramsey and Lampart (1998) point out, has primarily been a matter of convenience and pedagogical advantage because of lack of tools to decompose economic time series into more detailed scales.

To examine the role of timescales in the relationships among economic variables it is necessary to have an appropriate tool to decompose economic data. Economists have always shown a need of understanding economic relationships not only in the time domain (variation in time) but also in the frequency domain (variation in a frequency range). The classical tool for this type of an analysis is the Fourier Transform (FT) which represents a finite energy function f(t) as the sum of sine and cosine functions at various wavelengths. Each of these sines and cosines is a function of frequencies, and therefore FT is a decomposition on a frequency-by-frequency basis (Gençay et al., 2002, p.2). However, despite its popularity, FT is only suitable for processes that are periodic and globally stationary. FT assumes that the frequency content of the function is covariance stationary along the time axis and therefore only keeps information on frequencies while the time information is lost. Since it is a well-known stylized fact that the frequency structure of real world economic and financial time series evolves over time, a transform that can simultaneously capture time and frequency localizations is desirable. This makes wavelets versatile tools in econometric analysis.

The wavelet transform is a refinement of FT. While the latter uses constant length windows, the former uses basis functions that are local in time and frequencies. The wavelet basis functions are flexible and can be stretched (dilated) and translated (shifted in time) to represent a variety of functions. Wavelet analysis can be compared to camera lenses; the zooming option allows the researcher to observe hidden structures and relationships (Schleicher, 2002). Unlike FT, the wavelet transform is local in time and scale and is therefore able to handle and represent non-stationary or transient components of the series (Gençay et al., 2002, p.3)

Wavelets can be defined as small waves that grow and decay essentially in a limited time period (Percival & Walden, 2006, p.2). The wavelet transform uses two types of wavelets -- the father wavelet $\phi(t)$ and the mother wavelet $\psi(t)$. The father wavelet integrates to one whereas the mother wavelet integrates to zero as (Crowley, 2007):

$$\int_{-\infty}^{\infty} \phi(t)\,dt = 1 \text{ and} \int_{-\infty}^{\infty} \psi(t)\,dt = 0. \qquad (5)$$

The father and mother wavelets serve as filters in a multiresolution analysis (MRA). MRA consists of decomposing the time series into different scales of variations. The father wavelet acts as a low-pass filter that reconstructs the low-frequency (long-scale) smooth component or trend of the series. On the other hand, the mother wavelet captures the deviations from the smooth component or trend (Ramsey & Lampart, 1998).

Important historical developments of a wavelet analysis can be dated back to Haar's (1910) development of a discrete orthonormal wavelet basis that took his name. In the 1980s, Grossman and Morlet developed the continuous wavelet transform. The multiresolution analysis (MRA) was an important development by Stephane Mallat who also developed the pyramid algorithm (Mallat, 1989) that uses an iterative process to decompose a function f(t) into wavelet coefficients using the low-pass (scaling) filter and the high-pass (wavelet) filter and reconstructing f(t) from its wavelet coefficients. Further developments occurred with the development of wavelets bases with compact support by Daubechies (1988, 1992). Daubechies's wavelets have compact support, that is, they are nonzero on a given interval determined by the length of the wavelet.

Throughout their evolution, wavelets were not widely used in economics. However, they have been extensively applied in areas such as image compression, signal denoising, forensics, astronomy, meteorology and medical sciences. Even though wavelets possess many desirable properties that make them a suitable tool for econometric analyses, the application of wavelets in economics and finance is rather recent. Perhaps the most attractive quality of wavelets in economic analyses is that they are localized both in time and frequency which makes them suitable for an analysis of economic and financial time series which very often are not stationary.

Several propositions in economics have been re-tested using wavelets. Ramsey and Lampart (1998) suggest that the timescale decomposition is very important for analysing the relationship between income and consumption which was originally formulated by Friedman (1957, 1963) as the permanent-income hypothesis. In the New Keynesian tradition, Gallegati et al. (2011) re-examine the "wage Phillips curve" in US data and find a frequency-dependent long run relationship between wage inflation and unemployment at business cycle scales. Aguiar-Conraria et al. (2008) argue that the relation between monetary policy variables and macroeconomic variables has changed and evolved with time and these changes are not homogeneous across the different frequencies. Moreover, monetary authorities may react to inflation news in the short run, while in the long run the price level is essentially determined by money supply.

There is still no consensus on the nature of the correlation between monetary aggregates and real economic activity (Aguiar-Conraria et al., 2008). Ramsey and Lampart (1998) argue that this lack of consensus may well be due to the fact that there are several timescales involved in the relationship between monetary aggregates and the rest of the macroeconomic variables. Understanding the timescale dynamics between monetary aggregates and the rest of the macroeconomy is very important, not least because it helps to ascertain the time horizon of monetary policy effects.

Economic theory suggests that in the short run an increase in money supply induces a decrease in the nominal interest rate, which is defined as the price that equilibrates the desire to hold wealth in the form of cash with the available quantity of cash (Keynes, 1936). This is known as the “liquidity effect” (Friedman, 1968), and it is considered the primary channel through which monetary policy affects the real economy (Crowder, 2012).

Empirically, earlier studies could not find support for an increase in the money stock being associated with a decline in short-term interest rates (Christiano, 1991; Leeper & Gordon, 1992; Melvin 1983; Mishkin, 1982). This lack of empirical support for the liquidity effect has since been coined the “liquidity puzzle”. As Kelly et al. (2011, p. 768) point out, “this puzzle has been a persistent thorn in empirical monetary economics research.”

Another key classical macroeconomic proposition is the long-run neutrality of money. This proposition postulates that a change in money stock changes nominal prices (and wages) and does not affect real variables such as output, employment, real interest rates and real wages in the long run. Empirical evidence (Fisher & Seater, 1993; King & Watson, 1997; Serletis & Koustas, 2017; Westerlund & Costantini, 2009) on this rather important proposition has been very mixed. As Westerlund and Costantini (2009, p.1) point out, “there are few propositions in classical economics that are less controversial than the long-run neutrality of money.”

In his Nobel Prize lecture, Lucas (1996) talked of money neutrality in particular and the quantity theory of money (QTM) in general. QTM’s central prediction is that in the long run money is neutral. However, Lucas highlighted the ambiguous nature of the terminology “long run”. Since economic agents make decisions at different time horizons, this terminology is relative.

Economic theory suggests that the liquidity effect is a short-run phenomenon while the neutrality of money is a long-run phenomenon. However, building on Lucas’s (1996) argument, both short-run and long-run are relative terminologies. It is possible to shed more light on the empirical validity of these two rather important propositions at detailed time horizons by decomposing money, output and interest rates into detailed scales of variations using wavelets.

1.5. Outline and Summary of the articles

1.5.1. Article 1: Asymmetric nonlinear mean reversion in real effective exchange rates: A Fisher-type panel unit root test applied to Sub-Saharan Africa

This paper investigates the long-run relationship between nominal exchange rates and relative prices, known as relative purchasing power parity (PPP). The analysis builds on recent developments of nonlinear econometric models by Kapetanios et al., (2003), Sollis et al. (2002) and Sollis (2009). Nonlinearities in real exchange rate adjustment potentially arise from nonlinearities in international goods arbitrage, due to transport costs, trade barriers (tariffs and nontariff) which drive a wedge between the prices of similar goods traded in spatially separated markets (Taylor, 2003). Moreover, interventions by central banks which are common and relatively successful in developing and transition economies (Canales-Kriljenko, 2003) are more likely during depreciation than they are during appreciation leading to an asymmetric adjustment of RER. The analysis is performed in a panel of 29 Sub-Saharan African countries for the period January 1995 to January 2015.

Using Monte Carlo techniques we simulate the empirical distribution of the linear, the exponential smooth transition autoregressive (ESTAR) and the asymmetric ESTAR data generating processes and uses these distributions to test the null hypothesis of a unit root against the alternative of stationary linear, ESTAR or asymmetric ESTAR real effective exchange rates (REERs). In general, accounting for nonlinear and asymmetric adjustment in REER leads to more empirical evidence in favour of the relative PPP hypothesis in Sub-Saharan Africa.

The findings in this paper add to literature on the empirical validity of the PPP theory, not least because, as Cuestas and Regis (2013) also point out, PPP is the cornerstone of models of exchange-rate determination, a basis for international comparisons of national account statistics and can in practice help to assess the degree of currency misalignment and economic integration.

1.5.2. Article 2: Do flexible exchange rates facilitate external adjustment? A dynamic approach with time-varying and asymmetric volatility

Following Chinn and Wei (2013) and Ghosh et al. (2013), this paper investigates Friedman's (1953) hypothesis that in the face of inflexible internal prices that cause distortions of adjustments in response to changes in external conditions, flexible exchange rates act as an external shock absorber. Specifically, we examine whether more flexible exchange rates are associated with faster current account adjustment in a panel of emerging and developing countries.

Two main aspects distinguish this paper from previous studies. First, while previous studies have used the exchange rate regime as a proxy for exchange rate flexibility, we argue that countries may in practice switch from one regime to another to support *ad hoc* interventions in the economy and thus there might be a difference between a country's declared exchange rate regime and what is actually done in the foreign exchange market. Accordingly, we follow a different approach and estimate real effective exchange rate volatility using both GARCH and exponential GARCH (EGARCH) models; the latter takes into account the possibility that positive shocks have a smaller effect on the conditional variance than negative shocks of the same magnitude. Second, this study follows a dynamic panel data approach to estimate the model in Chinn and Wei (2013) primarily using three estimators — the Arellano-Bond, the Blundell-Bond and the bias-corrected least square dummy variable.

The analysis uses data for 28 emerging market and developing economies during 1995-2014. The choice of emerging market and developing countries is motivated by the fact that such countries tend to intervene much more heavily in the foreign exchange market (Hausmann et al., 2001), and so it becomes unrealistic to formally classify their exchange rate regimes across time.

Our findings suggest that greater exchange rate volatility is associated with less persistent current account imbalances. The estimated speed of adjustment is even higher when the possibility of the exchange rate's asymmetric responses to shocks is taken into account. These results provide empirical support for Friedman's hypothesis and are an addition to the strand of literature that makes a case for more flexible exchange rates.

1.5.3. Article 3: Wavelet multiresolution analysis of the liquidity effect and monetary neutrality

In this paper we employ wavelets to empirically examine the validity of two propositions in monetary economics—the liquidity effect and the long-run neutrality of money—using quarterly data for the US and Sweden for the period 1985-2017. The liquidity effect implies that an increase in money supply induces a decrease in the nominal interest rate in the short run. The neutrality of money suggests that the change in money stock changes nominal prices (and wages) and does not affect real variables such as output, employment, real interest rates and real wages.

This study differs from previous ones in the following ways. First, while some studies assume that money supply is exogenous, and that causality runs from money to interest rate and output, we do not follow this restriction; instead we allow for causality in both directions. Second, it has been standard practice to divide the time horizon into only two horizons, the short and the long run. We argue that there might be more scales of variations than just these two. Moreover, the time horizons for policy interventions differ in countries and hence the dynamics of the relationship among macroeconomic variables may be country- and scale-dependent.

The analysis in this paper proceeds as follows. First, we decompose the series into orthogonal components using the discrete wavelet transform (DWT) together with the Daubechies least asymmetric wavelet filter (LA8), and then causality analysis —in the Granger (1969) sense — is performed at each scale of variations. The dynamics at the finest scale of one-year movements indicate that interest rate and real output respond to movements in the quantity of money. At long time scales of four years and above, there is a feedback mechanism. This pattern is very similar in both countries at the mentioned scales and suggests that monetary disturbances have significant real effects and these effects last longer than assumed in real business cycle models. Further, a nonparametric analysis based on locally weighted regressions suggests that not only is the direction and strength of the relationship among these variables scale-dependent but also the shape of the relationship may change from one scale to another.

Our findings indicate that in both economies (i) there is a negative relationship between money and the short-term interest rate as predicted by the liquidity preference theory at intermediate cycles corresponding to the frequency band of one to four-year periods, (ii) monetary disturbances have significant real effects and these effects last longer than is assumed in RBC models. Taken together, these results highlight the relevance of timescale decomposition in macroeconomic analysis.

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