How Do Central Banks React To Wealth Composition And Asset Prices?

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Abstract

We assess the response of monetary policy to developments in asset markets in the Euro Area, the US and the UK. We estimate the reaction of monetary policy to wealth composition and asset prices using: (*i*) a linear framework based on a fully simultaneous system approach in a Bayesian environment; and (*ii*) a nonlinear specification that relies on a smooth transition regression model.

The linear framework suggests that wealth composition is indeed important in the formulation of monetary policy. However, the attempts of central banks to mitigate undesirable fluctuations in say, financial wealth, may disrupt housing wealth. A similar result can be found when we assess the reaction of monetary authority to asset prices, although concerns about "price" effects are smaller.

The nonlinear model confirms these findings. However, the concerns over wealth and its components are stronger once inflation is under control, i.e. below a certain target. Some disruptions between financial and housing wealth effects are still present. They can also be found in the reaction to asset prices, despite being less intense.

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"We mustn't allow the financial system to collapse as it did in the 1930s... The financial system has gone overboard and the financial engineering has grown to big, it takes up too big a share in the world's resources... Now it is shrinking. When it becomes regulated it will be less profitable than the last 25 years."

- George Soros, BBC Newsnight, 17 September 2008

1 Introduction

The severity of the 2008-2009 financial turmoil has revealed the strength of the linkages between the financial markets and the banking system, the housing sector, the credit market, and the monetary framework. Moreover, its dramatic economic damages and potentially long-lasting effects emerged as key elements for evaluating the impact that external imbalances, oil prices, private investment, stock and credit markets or even duration dependence has on the likelihood of "boom-bust" episodes and expansion and contraction ending (Castro, 2010a). Not surprisingly, a quick response and targeted conduction of monetary policy became crucial for the attempt of promoting economic recovery.

Similarly, the relationship between policy instruments, macroeconomic variables, and wealth has received a renewed interest in terms of research agenda (Sousa, 2010a). In fact, those unconventional interventions may negatively affect the nexus between monetary stability and financial stability (Castro, 2010b; Granville and Mallick, 2009; Martin and Milas, 2010; Sousa, 2010b) and lead to business cycle de-synchronization (Rafiq and Mallick, 2008; Mallick and Mohsin, 2007, 2010). In addition, they represent a major test to the long-term (un)sustainability of public accounts as the evidence on current developments in government bond markets shows (Hallett, 2008; Hallett and Lewis, 2008).

The dynamics of wealth composition and asset prices is undeniably of great importance for financial institutions and homeowners. Monetary authorities and policy makers also pay a close attention those developments. However, our knowledge about the reaction of monetary authorities to asset markets is still incomplete. In this context, the monetary policy rule reaction function is fundamental. First, it provides the basis for forecasting changes in the conduct of monetary policy and the effects of economic shocks in the context of macroeconomic modelling. Second, it allows one to understand what the major considerations underlying a central bank's behavior are in the outcome of a wide set of economic developments.

More importantly, despite the analysis of the macroeconomic effects of monetary policy and the importance of asset markets over the business cycle, there is still an important gap in the literature, in particular, regarding the empirical relationship between monetary policy actions and wealth developments. How does the monetary authority adjust to the dynamics of wealth? How does the central bank react to asset prices? Does monetary policy respond to wealth composition and to asset price composition in the same manner? These are important questions that we try to address in the current paper.

Using quarterly data for the Euro Area, the US and the UK, we compare the formulation of monetary policy in the context of "quantity" effects (that is, the response of the monetary authority to financial and housing wealth) and "price" effects (i.e., the reaction of the central bank to stock and housing prices). Specifically, we estimate the monetary policy reaction function using a fully simultaneous system approach in a Bayesian framework, therefore, allowing for simultaneity between the monetary aggregate and the interest rate. We pay close attention to the monetary policy rule and focus on the empirical evidence linking monetary policy and asset markets.

Next, we assess the existence of nonlinearity in the monetary policy rule using a smooth transition regression (STR) model. The traditional models derive monetary policy rules from the minimization of a symmetric quadratic central bank's loss function and assume that the aggregate supply function is linear. However, in reality, this may not be the case and central banks can have asymmetric preferences - i.e. they might assign different weights to negative and positive gaps in inflation, output or even in monetary variables included in their loss function. This gives rise to the existence of a nonlinear monetary policy reaction function (Petersen, 2007; Surico, 2007a, 2007b).

Thus, we extend the analysis in this field by applying a nonlinear smooth transition regression to the study of the European Central Bank (ECB), the Federal Reserve Board (Fed), and the Bank of England (BoE) policy reaction to wealth and asset prices, therefore, directly accounting for the presence of asymmetries in the structure of the model. This procedure allows us to clarify the importance of nonlinearity and whether the monetary policy is conducted differently towards wealth composition and asset prices when inflation is above or below (inside or outside) a certain target (range).

The results from the linear framework suggest that all central banks keep a vigilant posture regarding developments in aggregate wealth. In particular, an increase in aggregate wealth leads to a rise in the interest rate and the coefficient associated to aggregate wealth in the policy rule is, generally, large.

The empirical findings also show that wealth composition is relevant for the formulation of monetary policy. Specifically, while the ECB and the Fed seem to pay a special attention to the dynamics of financial wealth, the BoE tends to be more focused on the developments of housing wealth. Interestingly, the estimated reaction functions for the Euro Area and the US suggest that the interest rate is raised when financial wealth increases, while it is reduced in the outcome of an expansion in housing wealth. In contrast, in the UK, the monetary authority counteracts the changes in housing wealth, while potentially allowing an amplification of the dynamics of financial wealth. This duality is extraordinary and it highlights that the attempts of the central bank to mitigate unfavorable shocks in one component of wealth may have a disruptive effect in the other wealth component. As a result, tackling the developments in wealth composition may be a complicated task for monetary policy, that is, providing a unique answer to both financial and housing wealth may be hard to achieve from a monetary perspective.

When assessing how central banks react to asset prices, the empirical findings provide a similar picture regarding the importance of the asset composition. Nevertheless, our results suggest that "price" effects are not particularly relevant. In fact, the estimated policy rules show that the coefficients associated with asset prices are substantially smaller than the ones linked with wealth components.

The empirical findings give support to the idea that both the ECB and the Fed strongly respond to the dynamics in money markets. In fact, an increase in the relevant monetary aggregate leads to a strong rise in the interest rate, reflecting the concerns of monetary authorities regarding medium to long-term price stability. As for the BoE, there seems to be an "hybrid" approach that places an important weight in both the monetary aggregate and the interest rate dynamics in the policy conduction.

The results of the estimation of the nonlinear smooth transition regression model show that the ECB seems to put more attention to inflation than to wealth (or to developments in its components), especially, when inflation is high. This may indicate a higher concern with inflation than with wealth per se. In fact, only when inflation is under control, we find a positive reaction of the interest rate to financial wealth. Similar evidence is found for the BoE: as soon as the BoE is able to keep inflation at a "low" level, the reaction to wealth becomes stronger. In that case, the inflationary pressures that may arise from increases in the aggregate wealth (or its financial component) are fought with a rise in the interest rate. On the contrary, the Fed is always tracking the dynamics of financial and housing wealth - especially, since the eighties - no matter what the inflation state is.

In what concerns the reaction of central banks to asset prices, the empirical findings confirm the role played by asset composition. The monetary authorities seem to adjust their behavior in response to stock prices (in particular, in the case of the Fed and the BoE), but their reaction to housing prices is, somewhat, relaxed when inflation is "low". On the other hand, the ECB seems to actively reacts to housing prices, but only when inflation is "high". However, a greater allocation of attention is given towards inflation, in particular, when it surpasses its target. Therefore, asset prices seem to have a secondary relevance in the policy rule. Summing up, these findings confirm the conclusions provided by the linear framework that central banks' concerns over asset prices are, generally, limited and it is difficult to simultaneously stabilize stock and housing prices.

The rest of the paper is organized as follows. Section 2 reviews the existing literature on the monetary policy rule. Section 3 presents the estimation methodologies. Section 4 discusses the evidence on the reaction of monetary policy to wealth composition, while Section 5 analyzes the results on the adjustment of policy conduction to asset price' developments. Finally, Section 6 concludes with the main findings and policy implications.

2 Review of the Literature

Since the seminal work by Taylor (1993), that assumes that central banks take into account inflation and output gap to set up the interest rate, several studies have developed different versions of the reaction function. Some include a lagged interest rate term and justify the decision on optimal monetary policy inertia or interest rate smoothing behavior (Woodford, 1999) or simply a misspecification that fails to take into account the existence of correlation among different shocks (Rudebusch, 2002). Other works incorporated features of forward-looking behavior in the policy rule and emphasized the importance of inflation targeting (Clarida et al., 1998) or real-time data in the information set of the monetary authority (Orphanides, 2001).

Over the last years, some extensions have been made to this simple linear rule. In particular, Clarida et al. (1998) suggest the use of a forward-looking version of the this rule where central banks target expected inflation and output gap instead of past or current values of these variables. Other authors extend this linear rule by considering the effect of other variables in the conduction of monetary policy, a point that we intend to explore further in this paper. Chadha et al. (2004) presents some evidence of central banks' reaction to the exchange rate deviations from its average. Considering the role of money supply in the ECB reaction function, Surico (2007b) argues that it does not affect the ECB's behaviour directly but it is a good instrument to predict future inflation. The role of asset prices is also an important issue considered in other studies. However, no consensus was reached about whether the central bank should or should not target this kind of variables. Cecchetti et al. (2000) and Chadha et al. (2004) consider it important that central banks target asset prices and provide strong support and evidence in that direction. On the contrary, Bernanke and Gertler (2001) and Bullard and Schaling (2002) do not agree with an ex-ante control over asset prices. They consider that once the predictive content of asset prices for inflation has been accounted for, monetary authorities should not respond to movements in assets prices. Instead, central banks should act only if it is expected that they affect inflation forecast or after the burst of a financial bubble in order to avoid damages to the real economy. Similarly, for housing markets, Aoki et al. (2004) argue that there is a collateral transmission mechanism to consumption but do not condition on monetary policy. Chirinko et al. (2008) stress the role that housing shocks have in the formulation of monetary policy vis-a-vis equity shocks. Iacoviello and Neri (2010) show that residential investment and housing prices are very sensitive to monetary policy and the wealth effects from housing on consumption are positive and significant.

The interaction between monetary policy and the futures market is also analyzed by Driffill et al. (2006) in the context of a linear reaction function. They find evidence supporting the inclusion of futures prices, which are considered as a proxy for financial stability. This issue is also investigated by Castro (2010b), who builds a financial indicator that includes the exchange rate, share and house prices, and credit spread and futures interest rate spread in the estimation of a Taylor rule for some central banks.

In most of the studies mentioned so far, the monetary policy reaction function is not modelled in the context of parsimoniously restricted multivariate time-series models, an issue that the works of Leeper and Zha (2003) and Sims and Zha (2006) have nicely overcome. Moreover, the analysis has typically focused on asset prices, therefore, not targeting the impact of central bank's actions on household's wealth composition. The first attempts to tackle this issue are Sousa (2010b, 2010c) who, using data for the US and the Euro Area, shows that a monetary contraction generates an important (negative) wealth effect, and leads to a quick adjustment in financial wealth and a gradual and persistent response by housing wealth. Note, however, that the author's analysis is aimed at looking at the impact of monetary policy on asset markets and not on how it reacts to developments in such markets. In this context, Christiano et al. (1996) show that a contraction in monetary policy leads to an increase of the net funds raised by non-financial corporations, while leaving net funds raised by households unchanged.

The extraordinary events associated with the current financial turmoil have brought the strength of the relationship between wealth, the financial and the housing sectors and monetary conduction to the first place. In fact, portfolio diversification effects are important and financial market interdependence is crucial. Additionally, the above mentioned econometric models assume the existence of a linear reaction of monetary policy to economic developments. Therefore, they neglect the existence of important nonlinear linkages. For instance, if the central bank is assigns different weights to negative and positive dynamics (say, in inflation) in its loss function, then a nonlinear monetary rule will be able to capture such behaviour of monetary policy.

As a result, the literature has recently started to consider nonlinearity or asymmetry in the analysis of monetary policy. In general, these features underlie nonlinear macroeconomic models (Dolado et al., 2005), or asymmetric central bank preferences (Nobay and Peel, 2003; Surico, 2007a), or both (Surico, 2007b). In particular, Surico (2007b) studies the presence of nonlinearity in the ECB monetary policy. The author estimates a linear GMM model drawn from the derivation of a loss function with asymmetric preferences and the existence of a convex aggregate supply curve. He shows that output contractions imply larger monetary policy responses than output expansions of the same size. Castro (2010b) also finds evidence of an asymmetric response of the ECB with regards to developments in inflation. Contrary to Surico (2007b), the author relies on a nonlinear STR model for monetary policy, which confirms that the ECB follows a point inflation target close to 2%. In addition, there is evidence of nonlinearity for the BoE - which defines a target range for inflation -, but not for the Fed. In contrast, Petersen (2007) finds support for the existence of nonlinearity in the monetary policy of the Fed using a simple logistic STR model. Martin and Milas (2004) apply a nonlinear quadratic logistic STR model to the BoE's monetary policy. They show that the UK monetary authority tries to keep inflation within a range rather than pursuing a point target, and show that nonlinearity is important. Taylor and Davradakis (2006) confirm this evidence using a simple threshold autoregressive model, i.e. without allowing a smooth transition between high and low inflation regimes.

While assessing the linkages between monetary policy and asset markets, we improve and extend the existing literature in several directions. First, we distinguish between the linear response of monetary policy to wealth composition (that is, the reaction to financial and housing wealth, which captures the "quantity" effects) and asset prices (that is, the adjustment to stock and housing prices, which tracks the "price" effects). Second, we explore the presence of nonlinearity in monetary policy, while controlling for the possibility that central banks react differently to wealth composition and asset prices and conditioning the effect on the "state" of the inflation rate. Finally, we compare the empirical evidence for the Euro Area, the US, and the UK.

3 Empirical Methodology

3.1 A Linear Approach: The Fully Simultaneous System

We estimate the following Structural VAR (SVAR)

$$\underbrace{\Gamma(L)}_{n\times n}\underbrace{X_t}_{n\times 1} = \Gamma_0 X_t + \Gamma_1 X_{t-1} + ... = c + \varepsilon_t \text{ where } \varepsilon_t | X_s, s < t \sim N(\underline{0}, \Lambda) \tag{1}$$

where $\Gamma(L)$ is a matrix valued polynomial in positive powers of the lag operator L, n is the number of variables in the system, and ε_t is a vector of fundamental economic shocks that span the space of innovations to X_t. The "reduced form" form of (1) can be expressed as

$$\Gamma_0^{-1}\Gamma(L) X_t = B(L) X_t = a + v_t \sim N(\underline{0}, \Sigma) \tag{2}$$

where $\Sigma = \Gamma_0^{-1} \Lambda \left(\Gamma_0^{-1}\right)'$, the vector $v_t = \Gamma_0^{-1} \varepsilon_t$ contains the innovations of X_t, and Γ_0 pins down the contemporaneous relations among the variables in the system. In what follows we use the normalization $\Lambda = I$.

We follow Leeper and Zha (2003) and Sims and Zha (2006) in that we: (*i*) do not assume that the central bank reacts only to variables that are predetermined relative to policy shocks; and (*ii*) assume that there are no predetermined variables with respect to the policy shock. The economy is divided into three sectors: a financial, a monetary and a production sector. The financial sector reacts contemporaneously to all new information and is summarized by the commodity price index (cp). The monetary sector allows for simultaneous effects, and comprises: (*i*) "money demand" that links money reserves (m) with the short-term interest rate (i), the real GDP (y), and the GDP deflator (p); and (*ii*) "money supply", where monetary authority reacts to commodity prices (cp), money reserves (m) and the interest rate (i). Finally, the production sector consists of log real GDP (y), unemployment rate (u), and the GDP deflator (p). This sector reacts contemporaneously to the financial sector but not directly to the monetary sector.

While estimating the monetary policy rule, we consider several specifications, namely, by linking the interest rate (i) with: 1) money reserves (m) (Leeper and Zha, 2003); 2) money reserves (m) and aggregate wealth (w) (Sousa, 2010c); 3) money reserves (m) and financial wealth (fw) (Sousa, 2010b); 4) money reserves (m), financial wealth (fw) and housing wealth (hw); 5) money reserves (m) and commodity prices (Sims and Zha, 2006); 6) money reserves (m), aggregate wealth (w), and commodity prices (cp); 7) money reserves (m) and exchange rate (er) (Lubik and Schorfheide, 2007), and 8) money reserves (m), aggregate wealth (w), and commodity prices (cp). These different policy reactions allow us to understand how the monetary authority reacts to wealth composition. Then, we assess the adjustment of monetary policy in the outcome of changes in asset prices. More specifically, we estimate a number of policy rules that link the interest rate (i) with: 1) money reserves (m) and stock prices (sp); and 2) money reserves (m), stock prices (sp) and housing prices (hp). In this way, we are able to detect whether the central bank reacts differently to changes in the wealth composition vis-a-vis changes in asset prices. This analysis is crucial as it makes possible to infer about the weights that the monetary authority puts into asset markets' quantity and price effects.

Finally, the fully simultaneous identification scheme as defined above implies that the estimates of Γ_0 are obtained via numerical maximization of the integrated likelihood. The confidence bands for the impulse-response functions should be constructed by drawing jointly from the posterior distribution of $B(L)$ and Γ_0. Given that the integrated likelihood is not in the form of any standard probability density function, one cannot draw Γ_0 from it directly to make inference.

We solve this problem by: (i) taking draws for Γ_0 using an importance sampling approach that combines the posterior distribution with the asymptotic distribution of Γ_0; and (ii) drawing $B(L)$ from its posterior distribution conditional on Γ_0. Confidence bands are then constructed from the weighted percentiles of the impulse-response functions. This approach is explained in detail in the Appendix A.

3.2 A Nonlinear Approach: The Smooth Transition Regression Model

The traditional monetary rules, like the Taylor rule, are simple linear functions that represent central banks' policy rules under the condition that they are minimizing a symmetric quadratic loss function and that the aggregate supply function is linear. However, in reality, this may not be the case and central banks can be responding differently to deviations of aggregates from their targets. Inflation and the output gap tend to show an asymmetric adjustment to the business cycle: output exhibits short and sharp recessions over the business cycle, but long and smooth recoveries; inflation increases more rapidly than it decreases. If the central bank indeed assigns different weights to negative and positive inflation, output gaps, wealth composition or asset prices (relative to the respective targets) in its loss function, then a nonlinear monetary rule may reflect that behaviour.

Therefore, we employ a smooth transition regression (STR) model. While allowing for smooth endogenous regime switches, it is able to explain when a central bank changes its policy rule. Although a few versions of this model have been applied to study the behaviour of some relevant central banks, we provide the first attempt to control for the presence of a nonlinear reaction of central banks to wealth composition and asset prices.

A standard STR model for a nonlinear monetary rule can be defined as follows:[1]

$$i_t = \psi' z_t + \omega' z_t G(\eta, c, s_t) + \varepsilon_t, \quad t = 1, ..., T \tag{3}$$

where $z_t = (1, z_{1t}, ... z_{kt})$ is a vector of k explanatory variables. The vectors $\psi = (\psi_0, \psi_1, ..., \psi_k)$ and $\omega = (\omega_0, \omega_1, ..., \omega_k)$ represent the parameter vectors in the linear and nonlinear parts of the model, respectively. In total, we have $k+1$ parameters to estimate, and some of these may be zero a priori. The disturbance term is assumed to be independent and identically distributed with zero mean and constant variance, $\varepsilon_t \sim iid(0, \sigma^2)$. The transition function $G(\eta, c, s_t)$ is continuous and bounded between zero and one in the transition variable s_t, that is, as $s_t \to -\infty$, $G(\eta, c, s_t) \to 0$ and as $s_t \to +\infty$, $G(\eta, c, s_t) \to 1$. s_t, can be an element of z_t or even a linear combination of elements of z_t (or a simple deterministic trend).

[1] For further details, see Granger and Teräsvirta (1993), Teräsvirta (1998) and van Dijk et al. (2002).

We start by considering $G(\eta, c, s_t)$ as a logistic function of order one:

$$G(\eta, c, s_t) = [1 + \exp\{-\eta (s_t - c)\}]^{-1}, \quad \eta > 0. \tag{4}$$

This kind of STR model is called logistic STR model or LSTR1 model. In this case, the transition function is a monotonically increasing function of s_t, where the slope parameter, η, indicates the smoothness of the transition from one regime to another, i.e. it shows how rapid the transition from zero to unity is, as a function of s_t. Finally, the location parameter, c, determines where the transition occurs. Considering this framework, the LSTR1 model can describe relationships that change according to the level of the threshold variable and, consequently, an asymmetric reaction of the central bank to, for example, a high and a low inflation regime.

The STR model is equivalent to a linear model with stochastic time-varying coefficients and, as so, it can be rewritten as:

$$i_t = \left[\psi' + \omega' G(\eta, c, s_t)\right] z_t + \varepsilon_t \Leftrightarrow i_t = \zeta' z_t + \varepsilon_t, \quad t = 1, ..., T. \tag{5}$$

The combined parameters, ζ, will fluctuate between ψ and $\psi + \omega$ and change monotonically as a function of s_t. The more the transition variable moves beyond the threshold, the closer $G(\eta, c, s_t)$ will be to one, and the closer ζ will be to $\psi + \omega$. Similarly, the further s_t approaches the threshold, c, the closer the transition function will be to zero and the closer ζ will be to ψ.

Given that a monotonic transition may not be a satisfactory alternative, we will also consider (and test for) the presence of a non-monotonic transition function. This can be the case where central banks consider not a simple point target for the transition variable, but a band or an inner regime where the transition variable - for instance, inflation - is considered to be under control. Consequently, the reaction of the monetary authority will be different from the situation where inflation is outside that regime.

We consider the following logistic function of order two:

$$G(\eta, c, s_t) = [1 + \exp\{-\eta (s_t - c_1)(s_t - c_2)\}]^{-1}, \quad \eta > 0, \tag{6}$$

where $c = \{c_1, c_2\}$ and $c_1 \leq c_2$. This transition function is symmetric around $(c_1 + c_2)/2$ and asymmetric, otherwise, and the model becomes linear when $\eta \rightarrow 0$. If $\eta \rightarrow \infty$ and $c_1 \neq c_2$, $G(\eta, c, s_t)$ becomes equal to zero for $c_1 \leq s_t \leq c_2$ and equal to one for other values; when $s_t \rightarrow \pm\infty$, $G(\eta, c, s_t) \rightarrow 1$. This model is called the quadratic logistic STR or LSTR2. If, for example, inflation is the transition variable, this model allows us to estimate separate lower and upper bands for the inflation instead of a simple target value.

In the estimation of the nonlinear model, it is important to test whether the behaviour of monetary policy in a given country can be really described by a nonlinear rule. This implies testing linearity against the STR model. The null hypothesis of linearity is $H_0 : \eta = 0$ and the alternative hypothesis is $H_1 : \eta > 0$. Neither the LSTR1 model nor the LSTR2 model are defined under the null hypothesis; they are only defined under the alternative. Teräsvirta (1998) and van Dijk et al. (2002) show that this identification problem can be solved by approximating the transition function with a third-order Taylor-series expansion around the null hypothesis. This approximation yields, after some simplifications and re-parameterisations, the following auxiliary regression:

$$i_t = \beta_0' z_t + \beta_1' \widetilde{z}_t s_t + \beta_2' \widetilde{z}_t s_t^2 + \beta_3' \widetilde{z}_t s_t^3 + \varepsilon_t^*, \quad t = 1, ..., T, \tag{7}$$

where $\varepsilon_t^* = \varepsilon_t + \omega' z_t R(\eta, c, s_t)$, with the remainder $R(\eta, c, s_t)$, $z_t = (1, \widetilde{z}_t')'$, and $\widetilde{z}_t$ is a $(k \times 1)$ vector of explanatory variables. Moreover, $\beta_j = \gamma \widetilde{\beta}_j$, where $\widetilde{\beta}_j$ is a function of ω and c. The null hypothesis of linearity becomes $H_{01} : \beta_1 = \beta_2 = \beta_3 = 0$, against the alternative of $H_{11} : \exists \beta_j \neq 0$, $j = 1, 2, 3$. An LM-test can be used to investigate this hypothesis because $\varepsilon_t^* = \varepsilon_t$ under the null. The resulting asymptotic distribution is χ^2 with $3k$ degrees of freedom under the null (Teräsvirta, 1998). If linearity is rejected, we can proceed with the estimation of the nonlinear model. However, in this process it is important to select the adequate transition variable. Sometimes, it is clear from the economic theory which one to choose. However, Teräsvirta (1998) argues that if there is no theoretical reason to choose one variable over another to be the threshold variable, and if nonlinearity is rejected for more than one transition variable, the variable presenting the lowest p-value for the rejection of linearity should be chosen to be the transition variable.[2]

There is a final question to answer before proceeding with the estimation of the nonlinear model: Which transition function should be employed? The decision between an LSTR1 and an LSTR2 model can be made from the following sequence of null hypotheses based on the auxiliary regression: $H_{02} : \beta_3 = 0$; $H_{03} : \beta_2 = 0 | \beta_3 = 0$; and $H_{04} : \beta_1 = 0 | \beta_3 = \beta_2 = 0$. Granger and Teräsvirta (1993) show that the decision rule works as follows: if the p-value from the rejection of H_{03} is the lowest one, we should choose an LSTR2 model; otherwise, the LSTR1 model should be selected.

[2] Theoretically, we would choose inflation to be the threshold variable because of the important weight central banks have been putting on this variable. However, despite this expectation, we will take into account Teräsvirta's (1998) suggestion and choose for transition variable the one that presents the lowest p-value for the rejection of the linear model.

4 Does the Monetary Authority React to Wealth Composition?

4.1 Data

This Section provides a summary description of the data employed in the empirical analysis. All variables are in natural logarithms and measured at constant prices unless stated otherwise.

The set of variables considered in the econometric methodologies is as follows. First, we use the short-term interest rate (i) as the monetary policy instrument. Second, regarding macroeconomic aggregates, we consider the choice of variables of the works of Leeper and Zha (2003) and Sims and Zha (2006). Therefore, we include: the real GDP (y), the GDP deflator (p), the producer price index of raw materials (cp), and the unemployment rate (u). The monetary aggregate (m) corresponds to M_3, in the case of the Euro Area, M_2, for the US, and M_4, in the UK, as these are the relevant ones for assessing the behavior of money markets and long-term price stability. Finally, the variables of interest in the monetary policy rule are: (1) the aggregate wealth (w); (2) the measure of the financial market (that is, either financial wealth (fw) or the stock price index(sp)); (3) the measure of the housing market (that is, either housing wealth (hw) or the housing price index(hp)); and (4) the real effective exchange rate (er). The data are available: for the period 1980:1-2007:4, in the case of the Euro Area; 1967:2-2008:4, for the US; and 1975:1-2007:4, in the UK.

4.2 Linear Evidence

We start by presenting and discussing the evidence from the estimation of the linear monetary rules using the fully simultaneous system approach described in Section 3.1. Tables 1, 2 and 3 summarize the results for the Euro Area, the US and the UK, respectively. In particular, they provide information about the median estimates and the 68% probability intervals computed using a Monte Carlo Importance Sampling algorithm (and based on 50000 draws) of the coefficients associated with the variables included in the different monetary policy rules (Rows 1 to 8).

Table 1 shows that the ECB strongly responds to the money stock: disturbances that raise the M_3 aggregate induce an increase in the interest rate. In fact, Column 2 shows that the coefficient associated with the monetary aggregate is large in magnitude, therefore, revealing the importance of this policy instrument in the conduction of ECB's monetary policy. Similarly, our results suggest that the monetary authority keeps a vigilant posture regarding developments in aggregate wealth. In particular, specifications (2), (6) and (7) show that the coefficient associated with aggregate wealth is large in magnitude and has the expected sign: an increase in aggregate wealth leads to a rise in the interest rate. These findings are in accordance with the work of Sousa (2010b). When we focus on wealth composition (rows 3 and 4), we find that the monetary authority pays a special attention to the dynamics of financial wealth: as in the case of aggregate wealth, monetary policy is tightened when financial wealth rises. In contrast, monetary policy seems to be relaxed in the outcome of an expansion in housing wealth. This duality is important as it suggests that, in the attempt of stabilizing financial wealth, the central bank may allow for an amplification of the dynamics of housing wealth. In addition, it is linked with the concerns about a possible business cycle de-synchronization, as suggested by Rafiq and Mallick(2008) and Mallick and Mohsin (2010). Rows 5 and 6 assess whether the monetary authority systematically reacts to changes in commodity prices. The results show that the developments in commodity markets do not seem to play a major role for the conduction of ECB's monetary policy. The coefficient associated with the commodity price is typically small in magnitude and somewhat imprecisely estimated. Rows 7 and 8 provide weak evidence of a systematic reaction of the ECB to changes in real effective exchange rate.

[INSERT TABLE 1 AROUND HERE]

Similarly to the case of the Euro Area, Table 2 shows that the monetary authority in the US vigilates very closely the dynamics of money markets: a rise in M_2 leads to a strong increase in the interest rate, as can be seen in specifications (1) to (4). Nevertheless, rows 5 to 8 suggest that the interest rate dynamics is also relevant. As a result, this piece of evidence shows that Fed adopts a more flexible conduction of monetary policy, namely, by considering both the monetary aggregate and the interest rate behaviours. Column 3 reports that the monetary authority vigilates the developments in aggregate wealth, despite not placing a great weight to them in the policy rule. Nevertheless, this hides an important wealth composition effect, that is: (*i*) equations (3) and (4) clearly show that developments in financial wealth substantially impact on the conduct of monetary policy and, in particular, a rise in financial wealth is strongly counteracted by a rise in the interest rate; and (*ii*) equation (4) reveals that developments in housing wealth do not seem to deserve a crucial role in the policy rule, as the coefficient associated with this component of wealth is typically small. That is, similarly to the case of the Euro Area, our results suggest that Fed's attempts to mitigate movements in financial wealth may disrupt the behaviour of housing wealth. In line with this evidence and although in a different context, Granville and Mallick (2009) also emphasize the importance of the linkages between monetary and financial stability. Specifications (5) and (6) highlight the "active" response of the US monetary authority regarding the behaviour of commodity prices: a rise in the commodity price index leads to an increase in the interest rate. In this way, the Fed tries to counterbalance the inflationary pressure from the rise in the price of raw materials, a feature that clearly distinguishes it from the ECB. Rows 7 and 8 provide additional evidence of the "activism" of monetary policy in the US. In fact, the real effective exchange rate enters significantly in the formulation of monetary policy rule: a fall in the exchange rate (that is, a real depreciation of domestic currency) is typically followed by a monetary policy contraction.

[INSERT TABLE 2 AROUND HERE]

Finally, Table 3 shows that, in contrast with the Euro Area and the US, the UK monetary authority does not seem to emphasize the developments of money markets in the policy conduction. Column 3 shows that indeed the coefficient associated to the monetary aggregate is small in magnitude, a feature that can not be disentangled from the fact that the BoE uses a broad monetary aggregate measure (i.e. M_4) as an indicator of the medium to long-term price (in)stability. The empirical evidence does point to a very important role for wealth in the formulation of monetary policy: specification (2) suggests that when aggregate wealth increases, the BoE responds by rising the interest rate. Moreover, wealth composition is key, as equations (3) and (4) highlight. In particular, a rise in housing wealth is mitigated by an increase in the interest rate, while a fall in financial wealth leads to the same policy reaction. That is: (*i*) in contrast with the Euro Area and the US, housing markets' developments seem to be the key in the conduction of monetary policy in the UK; and (*ii*) similarly to the ECB and the Fed, our results emphasize the difficulty of stabilizing both wealth components. This may be a source of concern given the important economic costs associated with periods of extreme variation in asset prices. In accordance with the findings for the US, specifications (5) and (6) reveal that the monetary authority in the UK is also very "active" towards the developments in commodity prices. In fact, the potentially inflationary effects of a rise in commodity prices are strongly balanced by a strong rise in the interest rate. Similarly, equations (7) and (8) add further evidence of a very "active" monetary authority with regards to the dynamics of foreign exchange markets. This is reflected in the large and significant coefficient associated with the real effective exchange rate in the monetary policy rule. It suggests that monetary policy in tightened (that is, interest rate is raised) when there is a real depreciation of the domestic currency.

[INSERT TABLE 3 AROUND HERE]

4.3 Nonlinear Evidence

The evidence from the estimation of the nonlinear monetary rules is presented in this section. The results are first reported for the Euro Area (Table 4), then for the US (Table 5) and, finally, for the UK (Table 6). We also provide some robustness checks considering the larger time period that is common to the three economic blocks: 1981-2007 (Table 7).

In general, results are robust in supporting the idea that the monetary policy followed by the ECB, Fed and BoE exhibit some nonlinearities. In fact, the tests provided at the bottom of Tables 4 to 6 (see line H_{01}) corroborate that evidence at a level of significance of 1%. Inflation was chosen to be the threshold variable ($s_t = p_t$), because it was associated with the lowest p-value for the rejection of the linear model. This helps explaining the important weight that central banks put on this variable. The tests for the choice of the transition function are presented at the bottom of Tables 4 to 7 (see lines H_{02}, H_{03} and H_{04}) and indicate that an LSTR1 fits better the analysis carried on this study. This means that, over the time period, the respective central banks seem to be more concerned in pursuing a point target than a target range for inflation.

In general, we expect that central banks have a specific reaction to economic developments when inflation is below the abovementioned targets and a different (stronger or weaker) reaction when inflation increases beyond them. Results provide such evidence for some variables. In the next step, we analyze those results in detail, giving particular attention to the reaction of the monetary authority to wealth composition. For each economic block, we start by estimating what we call a basic nonlinear Taylor rule, where we assume that the central bank reacts to inflation and output gap by changing the interest rate. In addition, we assume that the response should be different when inflation is below or above the target (c).

Results are quite interesting, in particular, for the Euro Area, as can be seen in Table 4. They show that the ECB reacts to inflation (p_t) only when it increases significantly above an estimated target of 2.6%;[3] as inflation decreases below that target, the reaction to inflation also smoothly weakens. When inflation is below 2.6%, the only significant reaction is related with the output gap (y_t). In the next two regressions (Columns 3 and 4), we add money (m_t) and aggregate wealth (w_t) to the model. This provides a better fitting according to the Schwarz Bayesian Information Criteria (SBIC).[4] Column 4 shows that the inflation and output gap effects significantly behave in accordance with the "Taylor Principle", but the stabilizing effect over inflation is felt only when it rises above 2.7%; the output gap is always a concern for the ECB. Contrary to Surico (2007b), we find evidence that the monetary authority has reacted to money supply over the period 1981-2007. In particular, when inflation is above 2.7%, increases in money supply are followed by rises in the interest rate. In fact, the overall effect ($\psi + \omega$) is significantly positive, which provides evidence that the ECB actively targets money supply when inflation is "high" or surpasses a certain level ($\approx 2.7\%$).[5]

The inclusion of wealth (w_t) in the monetary reaction function shows that the effect is clearly

[3] When inflation is above 2.6%, for each percentage point increase in inflation, the ECB reacts by raising the nominal interest rate by about 0.9 to 1.4 percentage points. As the coefficient on inflation is, in most of the regressions, higher than 1, that implies that the real interest rate will increase as well. As a result, the monetary behaviour of the ECB will exert the required and desired stabilizing effect over inflation. In fact, according to the "Taylor Principle", for the monetary policy to be stabilizing, the coefficient on inflation should exceed the unity and the coefficient on the output gap should be positive.

[4] Here, we should stress that we start by presenting the estimation results with all variables in the linear and non-linear parts Then, we present (and analyse) the results from the best fitting models. Those are found by sequentially eliminating regressors that are not statistically significant, namely, by using the SBIC measure of fit. Therefore, we report the combination of effects ($\psi + \omega$) - when present - only for the best fitting models (see columns 3, 6, 7 and 8).

[5] Table 4 confirms this result in all regressions that include m_t.

linear despite being negative: for each percentage point increase in the growth rate of wealth, the interest rate is cut by 0.15 percentage points. This piece of evidence can be the result of the conflicting duality between the components of aggregate wealth detected in the linear model. To evaluate that possibility, we include financial wealth (fw_t) and housing wealth (hw_t) in the nonlinear model instead of an aggregate measure of wealth (Columns 6, 7 and 8). The results suggest that the reaction to financial wealth is positive when inflation is low (that is, below 2.8%). However, as inflation increases, there is an erosion in this effect, and it even becomes negative for "high" levels of inflation. As for housing wealth, the response of the central bank is slightly different: when inflation is below 2.8%, the effect is highly negative; as inflation increases, its negative effect is reduced in magnitude, and becomes not statistically significant when we do not control for fw_t (Column 8). So, there is a somewhat timid reaction of the ECB to developments in housing wealth, which are eclipsed by the focus on inflation and may lead to an amplification of the dynamics in the housing markets. Controlling for the existence of nonlinearity in the conduction of monetary policy reveals the difficulties of the monetary authority in finding the equilibrium trade-off between the effects of different wealth components.

[INSERT TABLE 4 AROUND HERE]

Table 5 reports the results for the US. Column 1 reports the results from a nonlinear version of the basic Taylor rule. Output gap was chosen to be the threshold variable ($s_t = y_t$), because it has provided the lowest p-value for the rejection of the linear model. The empirical findings still respect the "Taylor Principle", in particular, when growth in output gap is higher than -1.04%. When money growth is included in the equation, the evidence no longer supports the output gap as the threshold variable: this role is now played (again) by the inflation rate. Moreover, in all the remaining regressions, inflation and output gap obey to the "Taylor Principle" and there is some evidence that the Fed targets money growth, especially when inflation is "high". Columns 3 and 4 provide evidence against the idea that the Fed vigilates the growth in aggregate wealth, which is somehow in line with the results obtained in the linear framework. However, when wealth is disaggregated into financial and housing wealth, results provide a remarkable finding: controlling for nonlinearity, one can see that the central bank does not target financial wealth but it is concerned with the growth in housing wealth, especially, when inflation is "high". This result supports our previous conjecture that monetary authorities tend to put a higher concern on the growth of housing wealth than on the growth of financial wealth, in particular, when inflation surpasses a specific target. In sum, the evidence for the US support the idea that the Fed is worried much more with the dynamics of wealth composition than with aggregate wealth developments per se.

[INSERT TABLE 5 AROUND HERE]

The findings for the UK are presented in Table 6. Contrary to the Euro Area and the US, the "Taylor Principle" does not seem to be respected: the estimated coefficient on inflation is always lower than one, which indicates an accommodative behaviour of interest rates to inflation; on the other hand, the BoE only reacts to output gap when inflation is well above 4.8%, as Columns 1 and 2 suggest. The inclusion of money growth and wealth effects in the model (Columns 3 to 8) does not significantly change this scenario. However, some results should be stressed. First, there is some evidence showing that the BoE vigilates monetary developments as in the case of the Euro Area and the US. Second, there is evidence of a significantly positive reaction of the BoE to increases in wealth when inflation is well below 4.1%. However, when it reaches "high" levels, the BoE does not seem to react to those effects anymore. Hence, the nonlinear framework confirms the results obtained in the linear model that aggregate wealth effects matter for the BoE, but now results are more precise in indicating that they matter only when inflation is "low".

The results from the disaggregation of wealth effects into financial and housing effects (Columns 5 to 8) show a reaction of the BoE that is similar to the ECB. When inflation is below 4.1%, the BoE reacts to increases in financial wealth by rising the interest rate. However, such response does not emerge when inflation is above 4.1%. This can be explained by the illusion that higher inflation erodes the effect of financial wealth. Similarly, in such scenario, the BoE will also be much more concerned with inflation than with financial wealth effects. In the case of housing wealth, the evidence seems to point that the central bank does not counteract the inflationary pressures that may arise from developments in that wealth component. This result may help explaining the boom in house prices that one observed in the UK in the last decade.

[INSERT TABLE 6 AROUND HERE]

So far, we made use of all available data for each economic block, which means that the time periods considered in the analysis are different. To check the robustness of the results and make the analysis more comparable, we estimate the most relevant policy reaction functions over the same sample period (1981:1-2007:4). The results are presented in Table 7.

In the case of the Euro Area, the evidence is similar to the one reported in Table 4. The results for the US are presented in Columns 3 and 4. The most striking finding is that the threshold parameter for the US is more reasonable now (around 3% which compares with 7.8%, previously). While there is not strong evidence of a reaction of the Fed to aggregate wealth, the monetary authority has indeed vigilated its composition. In particular, the Fed has reacted to growth in financial wealth by increasing the interest rate. On the other hand, the growth of housing wealth seems to be a source of concern when inflation is far above the 3%.

Finally, the evidence for the UK does not change much and has some similarities with the Euro

Area, especially, regarding wealth composition. When inflation is below 4%, there is some evidence suggesting that the BoE positively reacts to increases in aggregate wealth and, in particular, in financial wealth (but not to housing wealth changes). Therefore, as long as the BoE is able to keep a "low" level for inflation, it also reacts to the potentially inflationary wealth effects. When inflation suffers a positive boost, the monetary policy seems to loose track of wealth developments, in the sense that inflation becomes the major "threat".

[INSERT TABLE 7 AROUND HERE]

5 Does the Monetary Policy React to Asset Prices?

5.1 Linear Evidence

We now look at the reaction of the central bank to asset prices using a linear framework. We aim at understanding whether there are substantial differences vis-a-vis the monetary policy rules that include wealth measures. In this way, we can assess the "quantity" and "price" impact of asset markets' developments in the formulation of the monetary policy rule.

Table 8 summarizes the results for the Euro Area (rows 1 and 2), the US (rows 3 and 4) and the UK (rows 5 and 6), respectively. In particular, it reports the median estimates and the 68% probability intervals computed using a Monte Carlo Importance Sampling algorithm and based on 50000 draws.

The empirical evidence suggests that both the ECB and the Fed place a major role to developments in money markets. In particular, disturbances that raise the relevant monetary aggregate lead to a strong increase in the interest rate. Only the BoE seems to a little bit of more emphasis on the interest rate as the policy instrument.

Our results also highlight the importance of the composition of asset prices in designing the policy rule. In the case of the Euro Area, there is mixed evidence regarding the inclusion of stock prices in the monetary policy reaction. In what concerns housing prices, monetary policy seems to be relaxed when there is an increase in this set of asset prices. For the US and the UK, the results also reveal that the composition of asset prices matter. However and, in contrast with the evidence for the Euro Area, the findings suggest that monetary policy tends to counteract the developments of housing prices while accommodating the dynamics of stock prices, that is: (*i*) a rise in housing prices leads to an increase of the interest rate; and (*ii*) the policy instrument decreases in the outcome of a rise in stock prices.

Taken together, these findings confirm that central banks may find it quite difficult to simultaneously stabilize stock and housing prices. In fact, the attempts to circumvent the developments in housing prices may lead to an unstabilizing effect on stock prices. In addition, given that the coefficients associated with asset prices are substantially smaller than the ones linked with wealth components in the different monetary policy rule specifications, our work suggests that central banks do not seem to be particularly concerned with "price" effects. However, they do focus enormously on the developments of wealth, which strongly indicates that monetary authorities fear the impact of those dynamics in real economic activity and, in particular, in the achievement of medium to long-term price stability.

[INSERT TABLE 8 AROUND HERE]

5.2 Nonlinear Evidence

After analyzing the reaction of monetary policy to asset prices using a linear framework, we are tempted to ask whether there are nonlinearities in the central bank's reaction function to this set of prices. To answer that question, we use the STR model where we control for the effects of housing and stock prices.

The results from the estimation of the nonlinear monetary rules for the Euro Area, the US and the UK are presented in Table 9. They support the presence of nonlinearities in the policy reaction function of the ECB, the Fed and the BoE. In particular, the linearity tests reported at the bottom of Table 9 (see line H_{01}) show that the linearity hypothesis can be rejected at a level of significance of 1% in all estimations. Inflation is chosen as the threshold variable ($s_t = p_t$), in line with the lowest p-value for the rejection of the linear model. Lines H_{02}, H_{03} and H_{04} report the tests for the choice of the transition function. As in the case of the analysis regarding the inclusion of wealth variables in the monetary policy reaction function, they indicate that the LSTR1 model has the best fit. Hence, when the nonlinear monetary rule is augmented with asset prices, the results corroborate the evidence that suggests that the three monetary authorities are more concerned in pursuing a point target than a target range for inflation.

[INSERT TABLE 9 AROUND HERE]

Columns 1 and 2 of Table 9 summarize the results for the Euro Area over the period 1981:1-2007:4. In the first Column, we include all variables in the linear and nonlinear parts of the model; in Column 2, we report only the results from the best fitting model. This model is found by sequentially eliminating the regressors that are not statistically significant, namely, with the use of the SBIC measure of fit.[6] The evidence confirms that the ECB reacts to output and inflation according to the "Taylor Principle", but the response to inflation is only statistically significant

[6] We report the combination of effects ($\psi + \omega$) - when present - only for the best fitting model.

when inflation surpasses 2.6%. Similarly, the ECB seems to avoid inflationary pressures that may result from increases in money growth, but only when inflation is "high". Regarding the reaction to asset prices, the results show a significantly positive reaction to increases in the commodity prices, but no significant reaction to the stock prices is found. The response to housing prices is, as in the case of the linear framework, negative, especially, when inflation is "low". This can be reflecting an easing of monetary policy in terms of credit access for new housing purchases. However, when general inflation goes above the 2.6% threshold, the monetary authority starts reacting differently to an increase in housing prices.

Similar regressions for the US are presented in Columns 3 to 5. Columns 3 and 4 are estimated over the entire period for which data are available, that is, 1968:1-2008:4; Column 5 reports the results for the period 1981:1-2007:4, which allows a direct comparison with the evidence for the Euro Area. The reaction of monetary policy to inflation and output gap respects the "Taylor Principle" in all regressions. Moreover, there is evidence that the Fed reacts to developments in the money markets. Regarding the response to asset prices, there is a clearly positive reaction to an increases in stock prices. Hence, as expected, the Fed targets rises the interest rate in order to mitigate the potentially unstabilizing effects of stock prices' fluctuations. This reaction is independent of the level of general inflation, i.e. of whether general inflation is "low" or "high". A different pattern is observed for the response to an increase in housing prices: when inflation is "low", the Fed reduces the interest rate, possibly in order to accommodate the increase in demand for mortgages. When we focus on the time period 1981-2007, the evidence is quite similar to the one found for the ECB, i.e. as inflation surpasses the threshold of 2.8%, the Fed starts reacting to an increase in housing prices in a different manner, but the overall effect is not statistically significant. In this period, the empirical findings also suggest some concerns over commodity prices, but only when inflation is "high". These results support the argument that the US monetary policy authority keeps vigilant regarding asset prices (Cecchetti et al., 2000).

Finally, Columns 6 to 7 provide a summary of the results for monetary policy reaction functions augmented with asset prices in the case of the UK and over the period 1975:1-2007:1. In Column 8, the sample period is 1981:1-2007:4 In the analysis of the reaction of the Bank of England to wealth composition, the evidence did not support the "Taylor Principle". However, this is no longer the case when we include asset prices in the policy specifications. First, the BoE reacts to increases in stock prices by increasing the interest rate when inflation is below 4.4%. However, in the period 1981:1-2007:4, the monetary authority seems to be always concerned about the behavior of stock prices, no matter what the "state" of the inflation is. This may reflect the process of financial deregulation that started in the eighties and which has increased the exposure of the economy as a whole to the developments in financial markets. As a result, a stronger track of such dynamics is observed in this period. Second, contrary to the ECB and the Fed that react to an increase in housing prices by reducing the interest rate only when inflation is "low", the BoE seems to promote such behaviour for every inflation level. This may reveal a stronger accommodation of housing (and mortgage) demand shocks and contribute to explain the boom in the UK housing market.

Summing up, our results suggest that: 1) monetary authorities target stock prices and try to mitigate unstabilizing developments in financial markets, especially, when inflation is "low"; and 2) central banks allow interest rates to fall in response to an increase in housing prices, in particular, when inflation does not represent a major threat to price stability. In accordance with the evidence provided by the linear framework, this confirms the idea that it may be quite difficult to simultaneously mitigate the adverse dynamics in stock and housing prices without triggering an unstable amplification of the developments in one market.

6 Conclusion

In this paper, we assess the relationship between monetary policy and asset markets. Using quarterly data for the Euro Area, the US and the UK, we estimate monetary policy reaction functions that allow us to understand how a central bank reacts to wealth composition and asset prices. That is, we compare the adjustment of the conduction of monetary policy in the outcome of "quantity" effects vis-a-vis "price" effects enhanced by asset market developments.

We pay close attention to the design of the monetary policy rule. Specifically, we estimate a linear policy reaction function based on a fully simultaneous system approach in a Bayesian framework. Then, we investigate the existence of nonlinearity using a smooth transition regression model.

The linear framework suggests that all central banks vigilate the developments in aggregate wealth, and wealth composition is indeed important in the formulation of monetary policy. In particular, while the ECB and the Fed pay a special attention to the dynamics of financial wealth, the BoE tends to focus on housing wealth developments. Consequently, the attempts of central banks to mitigate undesirable fluctuations in say, financial wealth, may disrupt housing wealth. This result reflects the importance of the linkages between monetary stability and financial stability (Castro, 2010b; Granville and Mallick, 2009; Sousa, 2010b).

A similar policy implication can be drawn when we assess the reaction of the monetary authority to asset prices. However, the estimated policy rules show that the coefficients associated with asset prices are substantially smaller than the ones linked with wealth components, which reflects the smaller concern about asset "price" effects.

Additionally, we show that: (*i*) both the ECB and the Fed strongly respond to the dynamics in money markets, while the BoE conducts monetary policy by looking at both the monetary aggregate and the interest rate dynamics; (*ii*) the Fed and the BoE are particularly "active" in mitigating the potentially inflationary effects that are driven by a rise in commodity prices or a depreciation of domestic currency.

The results of the estimation of the nonlinear smooth transition regression model show that central banks react to aggregate wealth developments, especially, when inflation is "low". The concerns over wealth composition seem to be particularly strong in the case of the Fed.

In what concerns the reaction to asset prices, the monetary authorities target asset prices even when we control for the existence of nonlinearity. Specifically, the Fed and the BoE seem to be particularly responsive to stock and commodity prices when inflation is under control. In contrast, there is evidence of an accommodative behavior relative to developments in housing prices. While this may be linked to the goal of stabilizing the demand of housing and mortgages in the market, it can lead to a disruption in financial markets. A de-synchronization of the business cycle may be an important consequence of the difficulties found by the monetary authority in mitigating unpleasant developments that hit simultaneously the housing and the financial markets (Rafiq and Mallick, 2008; Mallick and Mohsin, 2010).

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Appendix

A A Mixed Monte Carlo Importance Sampling Algorithm

To be able to identify the structural monetary shocks, one needs at least $(n-1)\,n/2$ linearly independent restrictions. With enough restrictions in the Γ_0 matrix and no restrictions in the matrix of coefficients on the lagged variables, the estimation of the model is numerically simple since the log-likelihood will be

$$\begin{aligned} l\left(B,a,\Gamma_0\right) &= -\frac{T}{2}+\log\left|\Gamma_0\right|-\frac{1}{2}trace\left[S\left(B,a\right)\Gamma_0'\Gamma_0\right] \qquad (A.1)\\ \text{where } S\left(B,a\right) &= \sum_{t=1}^{T}\left(B\left(L\right)X_t-a\right)\left(B\left(L\right)X_t-a\right)' \end{aligned}$$

and the maximum-likelihood estimator of B and a can be found simply doing OLS equation-by-equation regardless of the value of Γ_0. Integrating $l\left(B,a,\Gamma_0\right)$ (or the posterior with conjugate priors) with respect to (B,a) the marginal log probability density function of Γ_0 is proportional to

$$-\frac{T-k}{2}\log\left(2\pi\right)+\left(T-k\right)\log\left|\Gamma_0\right|-\frac{1}{2}trace\left[S\left(\hat{B}_{OLS},\hat{a}_{OLS}\right)\Gamma_0'\Gamma_0\right]. \qquad (A.2)$$

In the S-VAR setting considered, the impulse-response functions are given by

$$B\left(L\right)^{-1}\Gamma_0^{-1}. \qquad (A.3)$$

This implies that to assess posterior uncertainty regarding the impulse-response function one needs joint draws for both $B\left(L\right)$ and Γ_0.

Since equation (A.2) is not in the form of any standard probability density function one cannot draw directly from Γ_0 to make inference. Nevertheless, if one takes a second order expansion of equation (A.2) around its peak one gets the usual Gaussian approximation to the asymptotic distribution of the elements in Γ_0. Since this is not the true form of the posterior probability density function, one cannot use it directly to produce a Monte Carlo sample. A possible approach is importance sampling, in which one draws from the Gaussian approximation, but weigh the draws by the ratio of (A.2) to the probability density function from which one draws. The weighted sample cumulative density function then approximates the cumulative density function corresponding to (A.2).

Note also that the distribution of $B(L)$, given Γ_0, is the usual normal distribution

$$vec(B(L))|\Gamma_0 \sim N\left(vec\left(\hat{B}_{OLS}\right), \Gamma_0^{-1}\left(\Gamma_0^{-1}\right)' \otimes \left(X'X\right)^{-1}\right). \tag{A.4}$$

So one can take joint draws using the following simple algorithm: (i) draw Γ_0 using (A.2); and (ii) draw $vec(B(L))$ using equation (A.4). Confidence bands for the impulse-response function are then constructed from the weighted percentiles of the Monte Carlo sample where the weights are computed by importance sampling.

Denote with $\hat{H}$ the numerical Hessian from the *minimization* routine at the point estimate and $\hat{\Gamma}_0$ the maximum-likelihood estimator. The algorithm used to draw the confidence bands from the posterior distribution is the following:

1. Check that all the coefficients on the main diagonal of $\hat{\Gamma}_0$ are positive. If they are not, flip the sign of the rows that have a negative coefficient on the main diagonal [that is, our point estimates are normalized to have positive elements on the main diagonal).

2. Set $i = 0$.

3. Drawn $vech\left(\tilde{\Gamma}_0\right)$ from a normal $N\left(vech\left(\hat{\Gamma}_0\right), \hat{V}\right)$, where $\hat{V} = \hat{H}^{-1}$ and $vech(.)$ vectorizes the unconstrained elements of a matrix. That is, this step draws from the asymptotic distribution of Γ_0. In order to handle draws in which some of the diagonal elements of $\tilde{\Gamma}_0$ are not positive, we follow the procedure where the draw is rejected (and one goes back to 2 and takes another draw) if some of the diagonal entries of $\tilde{\Gamma}_0$ are not positive.

4. Compute and store the importance sampling weight

$$m_i = \exp\left[\begin{array}{c} T\log\left|\det\left(\tilde{\Gamma}_0\right)\right| - \frac{1}{2}trace\left(S\left(\hat{B}_{OLS}, \hat{a}_{OLS}\right)\tilde{\Gamma}_0'\tilde{\Gamma}_0\right) \\ -\log\left|\hat{V}\right|^{-\frac{1}{2}} + .5\left(vech\left(\tilde{\Gamma}_0\right) - vech\left(\hat{\Gamma}_0\right)\right)'\hat{V}^{-1}\left(vech\left(\tilde{\Gamma}_0\right) - vech\left(\hat{\Gamma}_0\right)\right) \\ -SCFT \end{array}\right] \tag{A.5}$$

   where $SCFT$ is a scale factor that prevents overflow/underflow [a good choice for it is normally the value of the likelihood at its peak).

5. Draw $vec\left(\tilde{B}(L)\right)$ from a normal $N\left(vec\left(\hat{B}_{OLS}\right), \tilde{\Gamma}_0^{-1}\left(\tilde{\Gamma}_0^{-1}\right)' \otimes (X'X)^{-1}\right)$ to get a draw for $\tilde{B}(L)$.

6. Compute the impulse-response function and store it in a multidimensional array.

7. If $i < \#draws$, set $i = i + 1$ and go back to 3.

The stored draws of the impulse-response function, jointly with the importance sampling weights, are used to construct confidence bands from their percentiles. Moreover, the draws of $\tilde{\Gamma}_0$ are stored to construct posterior confidence interval for these parameters from the posterior (weighted) quantiles.

Normalized weights that sum up to 1 are simply constructed as:

$$w_i = \frac{m_i}{\sum_i^{\#draws} m_i}. \tag{A.6}$$

When the number of draws is sufficiently large for the procedure outlined above to deliver accurate inference, the plot of the normalized weights should ideally show that none of them is too far from zero – that is, one single draw should not receive 90% of the weight.

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Table 1 - Linear monetary rule: Reaction to wealth composition - Euro Area (1980:1-2007:4).

Equation	i_t	m_t	w_t	fw_t	hw_t	er_t	cp_t
(1)	10.738 i_t [−33.970; 53.471]	− 318.733 m_t [−331.953, −306.828]					
(2)	0.115 i_t [−0.149; 0.411]	− 383.644 m_t [−395.972, −369.635]	− 128.804 w_t [−139.656; −117.589]				
(3)	78.103 i_t [3.137; 129.900]	− 278.858 m_t [−300.401, −226.544]		− 31.856 fw_t [−51.378, −17.442]			
(4)	41.535 i_t [6.205; 81,433]	− 300.974 m_t [−322.398, −275.492]		− 36.920 fw_t [−48.446, −22.140]	+ 166.296 hw_t [141.152; 188.211]		
(5)	50.706 i_t [32.000; 87.393]	− 277.174 m_t [−301.907, −243.538]					+ 5.718 cp_t [2.590, 7.920]
(6)	0.317 i_t [−0.115; 0.513]	− 350.365 m_t [−358.684, −334.243]	− 100.441 w_t [−111.431; −89.945]				− 1.329 cp_t [−3.042, 1.315]
(7)	22.855 i_t [14.453; 82.712]	− 191.618 m_t [−250.728, −154.582]				+ 21.241 er_t [17.428, 22.913]	
(8)	0.035 i_t [0.032; 0.038]	− 376.022 m_t [−376.469, −375.575]	− 105.580 w_t [−106.211; −104.948]			− 3.454 er_t [−3.584, −3.324]	

Note: Median estimates and 68% probability intervals computed using a Monte Carlo Importance Sampling algorithm.

Table 2 - Linear monetary rule: Reaction to wealth composition - US (1967:2-2008:4).

Equation	i_t	m_t	w_t	fw_t	hw_t	er_t	cp_t
(1)	1.708 i_t [−19.313; 25.588]	− 194.372 m_t [−204.178, −178.783]					
(2)	0.720 i_t [−5.282; 5.588]	− 203.968 m_t [−209.255, −198.323]	− 17.610 w_t [−19.557; −15.796]				
(3)	5.633 i_t [−6.699; 15.431]	− 188.473 m_t [−197.340, −177.173]		− 183.690 fw_t [−192.669, −172.637]			
(4)	0.754 i_t [−7.019; 8.946]	− 189.719 m_t [−196.579, −182.799]		− 186.726 fw_t [−195.165, −175.452]	+ 5.344 hw_t [3.814; 7.361]		
(5)	111.319 i_t [104.530; 117.824]	− 1.409 m_t [−17.392, 11.430]					− 50.061 cp_t [−53.205, −46.736]
(6)	113.521 i_t [103.607; 120.443]	− 1.164 m_t [−19.640, 15.793]	− 1.599 w_t [−3.777; 0.679]				− 49.273 cp_t [−52.457, −45.385]
(7)	33.041 i_t [27.325; 39.912]	− 3.547 m_t [−5.066, −1.122]				− 40.171 er_t [−41.097, −39.499]	
(8)	30.728 i_t [19.323; 32.508]	− 27.467 m_t [−46.033, −14.699]	− 28.001 w_t [−45.891; −16.406]			− 37.691 er_t [−39.643, −35.961]	

Note: Median estimates and 68% probability intervals computed using a Monte Carlo Importance Sampling algorithm.

Table 3 - Linear monetary rule: Reaction to wealth composition - UK (1975:1-2007:4).

Equation	i_t	m_t	w_t	fw_t	hw_t	er_t	cp_t
(1)	$\underset{[0.209;\,0.653]}{0.456}\ i_t$	$-\underset{[-0.873,\,-0.740]}{0.819}\ m_t$					
(2)	$\underset{[0.013;\,0.112]}{0.073}\ i_t$	$-\underset{[-44.011,\,-41.841]}{42.703}\ m_t$	$-\underset{[-44.011;\,-41.841]}{42.703}\ w_t$				
(3)	$\underset{[0.018;\,0.141]}{0.077}\ i_t$	$-\underset{[-0.211,\,-0.092]}{0.152}\ m_t$		$+\underset{[21.462,\,22.831]}{22.208}\ fw_t$			
(4)	$\underset{[0.025;\,0.147]}{0.087}\ i_t$	$-\underset{[-0.177,\,-0.055]}{0.114}\ m_t$		$+\underset{[21.876,\,23.251]}{22.592}\ fw_t$	$-\underset{[-19.446;\,-12.197]}{16.203}\ hw_t$		
(5)	$-\underset{[-0.347;\,-0.215]}{0.278}\ i_t$	$+\underset{[0.045,\,0.178]}{0.111}\ m_t$					$+\underset{[66.435,\,70.127]}{68.288}\ cp_t$
(6)	$-\underset{[-0.349,\,-0.221]}{0.286}\ i_t$	$+\underset{[0.069,\,0.177]}{0.122}\ m_t$	$-\underset{[-3.907;\,-0.301]}{2.115}\ w_t$				$+\underset{[66.562,\,70.780]}{68.849}\ cp_t$
(7)	$\underset{[-0.025;\,0.117]}{0.048}\ i_t$	$-\underset{[-0.068,\,0.051]}{0.005}\ m_t$				$-\underset{[-39.658,\,-37.434]}{38.533}\ er_t$	
(8)	$\underset{[-0.007;\,0.123]}{0.055}\ i_t$	$-\underset{[-0.070,\,0.048]}{0.017}\ m_t$	$+\underset{[0.298;\,3.678]}{2.011}\ w_t$			$-\underset{[-39.763,\,-37.560]}{38.715}\ er_t$	

Note: Median estimates and 68% probability intervals computed using a Monte Carlo Importance Sampling algorithm.

Table 4 - Nonlinear monetary rule: Reaction to wealth composition - Euro Area (1980:1-2007:4).

Part	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Linear (ψ)								
p_t	-0.532		-0.674		1.709^{***}	1.281^{***}	1.236^{***}	1.175^{***}
	[0.749]		[0.556]		[0.310]	[0.066]	[0.087]	[0.067]
y_t	0.567^{**}	0.422^{**}	0.347	0.464^{***}	0.937^{***}	0.715^{***}	0.4102^{***}	0.605^{***}
	[0.285]	[0.168]	[0.234]	[0.147]	[0.193]	[0.132]	[0.147]	[0.142]
m_t			-0.237^{**}	-0.296^{***}	-0.064		-0.288^{***}	
			[0.095]	[0.088]	[0.075]		[0.079]	
w_t			-0.263^{***}	-0.153^{***}				
			[0.075]	[0.044]				
fw_t					0.056^{***}	0.040^{***}	0.060^{***}	
					[0.017]	[0.014]	[0.017]	
hw_t					-0.197^{***}	-0.212^{***}		-0.240^{***}
					[0.030]	[0.027]		[0.028]
Nonlinear (ω)								
p_t	1.442^{*}	0.908^{***}	1.914^{***}	1.258^{***}	-0.482			
	[0.749]	[0.134]	[0.562]	[0.150]	[0.333]			
y_t	-0.241		0.052		-0.415			
	[0.373]		[0.330]		[0.270]			
m_t			0.950^{***}	1.1495^{***}	0.818^{***}	0.845^{***}	0.883^{***}	0.626^{***}
			[0.245]	[0.221]	[0.195]	[0.086]	[0.076]	[0.077]
w_t			0.181^{*}					
			[0.115]					
fw_t					-0.125^{***}	-0.111^{***}	-0.096^{***}	
					[0.026]	[0.024]	[0.022]	
hw_t					0.112^{**}	0.105^{**}		0.228^{***}
					[0.048]	[0.043]		[0.037]
η	10.25	11.25	15.01	15.63	39.79	73.29	78.61	32.67
c	2.534^{***}	2.586^{***}	2.645^{***}	2.701^{***}	2.893^{***}	2.830^{***}	2.856^{***}	2.800^{***}
	[0.093]	[0.076]	[0.062]	[0.058]	[0.001]	[0.182]	[0.428]	[0.056]
($\psi + \omega$)								
m_t				0.854^{***}			0.595^{***}	
				[0.096]			[0.073]	
fw_t						-0.071^{***}	-0.036^{*}	
						[0.015]	[0.020]	
hw_t						-0.107^{***}		-0.011
						[0.029]		[0.028]
Obs.	105	105	105	105	105	105	105	105
Adj.R^2	0.867	0.866	0.906	0.902	0.941	0.938	0.905	0.925
SBIC	0.885	0.806	0.720	0.622	0.338	0.213	0.590	0.308
H_{01}	0.000	0.006	0.000	0.000	0.000	0.000	0.000	0.000
H_{02}	0.000	0.543	0.011	0.001	0.160	0.005	0.187	0.009
H_{03}	0.639	0.679	0.000	0.056	0.001	0.000	0.001	0.000
H_{04}	0.001	0.008	0.000	0.000	0.000	0.000	0.000	0.000
Model	LSTR1	LSTR1	LSTR1	LSTR1	LSTR1	LSTR1	LSTR1	LSTR1
$s_t =$	p_t	p_t	p_t	p_t	p_t	p_t	p_t	p_t

Notes: * statistically significant at 10% level; ** at 5% level; *** at 1% level. All variables are in log differences. Standard errors are in square brackets. Adj.R^2 is the adjusted R^2 and SBIC is the Schwarz Bayesian Information Criterion. H_{01} reports the *p-value* of the linearity test; H_{02} to H_{04} report the *p-value* of the tests used to choose the preferred model.

Table 5 - Nonlinear monetary rule: Reaction to wealth composition - US (1967:2-2008:4).

Part	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Linear (ψ)								
p_t	0.668^{***}	1.022^{***}	1.024^{***}	1.028^{***}	1.086^{***}	1.036^{***}	1.029^{***}	1.031^{***}
	[0.144]	[0.081]	[0.085]	[0.082]	[0.090]	[0.084]	[0.082]	[0.084]
y_t	-1.673^{***}	0.755^{***}	0.696^{***}	0.736^{***}	0.649^{***}	0.733^{***}	0.742^{***}	0.748^{***}
	[0.581]	[0.079]	[0.089]	[0.083]	[0.092]	[0.082]	[0.082]	[0.079]
m_t			0.002		0.023			0.013
			[0.050]		[0.050]			[0.048]
w_t			0.0193	0.021				
			[0.030]	[0.029]				
fw_t					0.027	0.019	0.021	
					[0.026]	[0.025]	[0.026]	
hw_t					-0.004			
					[0.019]			
Nonlinear (ω)								
p_t	0.710^{***}		-0.544		0.379			
	[0.177]		[1.231]		[0.994]			
y_t	1.996^{***}		0.532		0.618^{*}			
	[0.578]		[0.409]		[0.352]			
m_t		1.334^{***}	1.101^{*}	1.288^{***}	0.762		1.311^{***}	
		[0.235]	[0.671]	[0.247]	[0.195]		[0.244]	
w_t			-0.033					
			[0.245]					
fw_t					-0.365			
					[0.221]			
hw_t					0.638^{***}	0.362^{***}		0.370^{***}
					[0.104]	[0.062]		[0.061]
η	3.81	50.54	58.45	47.28	48.95	47.66	46.79	49.17
c	-1.042^{***}	7.602^{***}	7.802^{***}	7.518^{***}	6.875^{***}	7.800^{***}	7.796^{***}	7.800^{***}
	[0.253]	[0.100]	[0.350]	[2.595]	[1.165]	[0.302]	[0.768]	[0.344]
($\psi + \omega$)								
p_t	1.377^{***}							
	[0.066]							
y_t	0.323^{***}							
	[0.084]							
Obs.	164	164	164	164	164	164	164	164
Adj.R^2	0.763	0.753	0.759	0.754	0.776	0.762	0.754	0.761
SBIC	1.229	1.239	1.369	1.267	1.357	1.263	1.265	1.236
H_{01}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
H_{02}	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000
H_{03}	0.003	0.012	0.001	0.019	0.002	0.005	0.005	0.002
H_{04}	0.124	0.000	0.123	0.000	0.004	0.000	0.000	0.000
Model	LSTR1	LSTR1	LSTR1	LSTR1	LSTR1	LSTR1	LSTR1	LSTR1
$s_t =$	y_t	p_t	p_t	p_t	p_t	p_t	p_t	p_t

Notes: * statistically significant at 10% level; ** at 5% level; *** at 1% level. All variables are in log differences. Standard errors are in square brackets. Adj.R^2 is the adjusted R^2 and SBIC is the Schwarz Bayesian Information Criterion. H_{01} reports the *p-value* of the linearity test; H_{02} to H_{04} report the *p-value* of the tests used to choose the preferred model.

Table 6 - Nonlinear monetary rule: Reaction to wealth composition - UK (1975:1-2007:4).

Part	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Linear (ψ)								
p_t	0.688**	0.156***	0.068	0.283***	0.191	0.269***	0.130	0.303***
	[0.302]	[0.059]	[0.389]	[0.078]	[0.379]	[0.075]	[0.085]	[0.079]
y_t	−0.085***		−0.565		−0.283			
	[0.202]		[0.089]		[0.418]			
m_t			0.081	0.098*	0.078	0.126**	0.113**	0.119**
			[0.081]	[0.546]	[0.079]	[0.052]	[0.054]	[0.054]
w_t			0.109	0.086**				
			[0.045]	[0.042]				
fw_t					0.063***	0.059***	0.065***	
					[0.022]	[0.021]	[0.023]	
hw_t					0.008	−0.003**		−0.003**
					[0.042]	[0.001]		[0.001]
Nonlinear (ω)								
p_t	−0.536*		0.263		0.141			
	[0.302]		[0.402]		[0.390]			
y_t	0.583**	0.431***	0.717*	0.183*	0.381	0.142*	0.165	0.176*
	[0.256]	[0.138]	[0.425]	[0.106]	[0.443]	[0.085]	[0.144]	[0.099]
m_t			0.061		0.112			
			[0.112]		[0.110]			
w_t			−0.113**	−0.089**				
			[0.045]	[0.042]				
fw_t					−0.108***	−0.101***	−0.110***	
					[0.027]	[0.025]	[0.029]	
hw_t					−0.011			
					[0.042]			
η	11.48	7.78	19.39	25.33	29.86	31.40	9.87	26.22
c	5.484***	4.787***	4.084***	4.095***	4.090***	4.086**	4.440***	4.095***
	[0.497]	[0.297]	[0.941]	[0.866]	[1.394]	[1.901]	[0.306]	[0.914]
$(\psi + \omega)$								
w_t				−0.003				
				[0.046]				
fw_t						−0.042**	−0.045*	
						[0.021]	[0.024]	
Obs.	201	201	132	132	132	132	132	132
Adj.R^2	0.590	0.586	0.729	0.723	0.750	0.746	0.736	0.713
SBIC	1.725	1.683	1.651	1.562	1.642	1.509	1.514	1.559
H_{01}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
H_{02}	0.864	0.000	0.001	0.000	0.000	0.000	0.020	0.000
H_{03}	0.123	0.001	0.005	0.003	0.000	0.001	0.001	0.004
H_{04}	0.000	0.000	0.003	0.000	0.002	0.000	0.000	0.000
Model	LSTR1	LSTR1	LSTR1	LSTR1	LSTR1	LSTR1	LSTR1	LSTR1
$s_t =$	p_t	p_t	p_t	p_t	p_t	p_t	p_t	p_t

Notes: * statistically significant at 10% level; ** at 5% level; *** at 1% level. All variables are in log differences. Standard errors are in square brackets. Adj.R^2 is the adjusted R^2 and SBIC is the Schwarz Bayesian Information Criterion. H_{01} reports the *p-value* of the linearity test; H_{02} to H_{04} report the *p-value* of the tests used to choose the preferred model.

Table 7 - Nonlinear rule: Reaction to wealth composition - Euro Area, US and UK (1980:1-2007:4).

Part	(1-EA)	(2-EA)	(3-US)	(4-US)	(5-UK)	(6-UK)
Linear (ψ)						
p_t		1.281^{***}	2.240^{***}	2.286^{***}		
		[0.066]	[0.130]	[0.107]		
y_t	0.464^{***}	0.715^{***}	0.710^{***}	0.660^{***}	-0.609^{**}	-0.338
	[0.147]	[0.132]	[0.086]	[0.079]	[0.271]	[0.255]
m_t	-0.296^{***}		0.175^{*}	0.335^{***}	0.103^{**}	0.107^{**}
	[0.088]		[0.094]	[0.041]	[0.047]	[0.046]
w_t	-0.153^{***}		0.036		0.107^{***}	
	[0.044]		[0.027]		[0.032]	
fw_t		0.040^{***}		0.048^{***}		0.060^{***}
		[0.014]		[0.017]		[0.015]
hw_t		-0.212^{***}		-0.087^{***}		
		[0.027]		[0.019]		
Nonlinear (ω)						
p_t	1.258^{***}				0.967^{***}	0.931^{***}
	[0.151]				[0.236]	[0.235]
y_t					0.818^{***}	0.635^{*}
					[0.325]	[0.329]
m_t	1.150^{***}	0.845^{***}	0.268^{**}			
	[0.221]	[0.086]	[0.117]			
w_t					-0.193^{**}	
					[0.048]	
fw_t		-0.111^{***}				-0.084^{***}
		[0.024]				[0.029]
hw_t		0.105^{**}		0.162^{***}		-0.070^{**}
		[0.043]		[0.036]		[0.033]
η	15.63	73.29	15.18	12.38	24.12	27.86
c	2.701^{***}	2.830^{***}	3.024^{***}	3.116^{***}	3.940^{**}	3.945^{***}
	[0.058]	[0.182]	[0.126]	[0.235]	[1.625]	[0.605]
($\psi + \omega$)						
y_t					0.209	0.298
					[0.275]	[0.256]
m_t	0.854^{***}		0.442^{***}			
	[0.096]		[0.078]			
w_t					-0.086^{**}	
					[0.033]	
fw_t		-0.071^{***}				-0.024
		[0.015]				[0.154]
hw_t		-0.107^{***}		0.083^{***}		
		[0.029]		[0.019]		
Obs.	105	105	105	105	102	102
Adj.R^2	0.902	0.938	0.884	0.909	0.832	0.840
SBIC	0.622	0.213	0.346	0.143	0.990	0.986
H_{01}	0.000	0.000	0.000	0.000	0.001	0.000
H_{02}	0.001	0.005	0.664	0.224	0.139	0.085
H_{03}	0.056	0.000	0.000	0.000	0.008	0.003
H_{04}	0.000	0.000	0.000	0.000	0.006	0.000
Model	LSTR1	LSTR1	LSTR1	LSTR1	LSTR1	LSTR1
$s_t =$	p_t	p_t	p_t	p_t	p_t	p_t

Notes: * statistically significant at 10% level; ** at 5% level; *** at 1% level. All variables are in log differences. Standard errors are in square brackets. Adj.R^2 is the adjusted R^2 and SBIC is the Schwarz Bayesian Information Criterion. H_{01} reports the *p-value* of the linearity test; H_{02} to H_{04} report the *p-value* of the tests used to choose the preferred model.

Table 8 - Linear monetary rule: Reaction to asset prices - Euro Area, US and UK.

Equation	i_t	m_t	sp_t	hp_t
		Evidence from the Euro Area		
(1)	$\underset{[71.242;\ 155.420]}{113.239}\ i_t$	$-\ \underset{[-213.232,\ -146.629]}{186.901}\ m_t$	$-\ \underset{[-14.259,\ -9.613]}{11.862}\ sp_t$	
(2)	$\underset{[0.470;\ 1.361]}{0.903}\ i_t$	$-\ \underset{[-301.071,\ -234.726]}{267.520}\ m_t$	$+\ \underset{[8.495,\ 13.917]}{11.268}\ sp_t$	$+\ \underset{[41.172;\ 61.653]}{44.400}\ hp_t$
		Evidence from the US		
(3)	$\underset{[-2.795;\ 38.864]}{16.833}\ i_t$	$-\ \underset{[-175.209,\ -151.526]}{161.395}\ m_t$	$+\ \underset{[5.738,\ 8.414]}{7.267}\ sp_t$	
(4)	$\underset{[1.105;\ 72.695]}{47.477}\ i_t$	$-\ \underset{[-28.213,\ -0.991]}{13.732}\ m_t$	$+\ \underset{[12.450,\ 14.068]}{13.240}\ sp_t$	$-\ \underset{[-10.140;\ -4.740]}{5.333}\ hp_t$
		Evidence from the UK		
(5)	$-\ \underset{[-0.452,\ -0.337]}{0.391}\ i_t$	$+\ \underset{[0.029,\ 0.136]}{0.083}\ m_t$	$-\ \underset{[-12.675,\ -11.976]}{12.310}\ sp_t$	
(6)	$-\ \underset{[-0.414,\ -0.309]}{0.361}\ i_t$	$-\ \underset{[-0.067,\ 0.054]}{0.005}\ m_t$	$-\ \underset{[-12.604,\ -11.924]}{12.260}\ sp_t$	$+\ \underset{[8.249,\ 14.490]}{11.243}\ hp_t$

Note: Median estimates and 68% probability intervals computed using a Monte Carlo Importance Sampling algorithm.

Table 9 - Nonlinear rule: Reaction to asset prices - Euro Area, US and UK.

Part	(1-EA)	(2-EA)	(3-US)	(4-US)	(5-US)	(6-UK)	(7-UK)	(8-UK)
Linear (ψ)								
p_t	0.519		1.093***	1.159***	2.071***	1.245***	1.363***	
	[0.480]		[0.115]	[0.113]	[0.136]	[0.091]	[0.088]	
y_t	0.576***	0.405***	0.900***	0.863***	0.624***	0.261	0.459***	0.185
	[0.213]	[0.134]	[0.099]	[0.102]	[0.074]	[0.173]	[0.130]	[0.142]
m_t	−0.091		0.111**	0.095**		0.133**		0.121***
	[0.089]		[0.046]	[0.046]		[0.053]		[0.043]
sp_t	−0.009	−0.003	0.019**	0.013*	0.014**	0.020*	0.028***	0.017*
	[0.011]	[0.059]	[0.008]	[0.007]	0.006	[0.011]	[0.011]	[0.009]
hp_t	−0.593***	−0.643***	−0.123***	−0.110**	−0.285***	−0.092***	−0.081***	−0.088***
	[0.093]	[0.074]	[0.043]	[0.046]	[0.047]	[0.024]	[0.022]	[0.020]
cp_t	0.023**	0.026***	−0.053			−0.054**	−0.054**	−0.105***
	[0.009]	[0.006]	[0.038]			[0.021]	[0.022]	[0.022]
Nonlinear (ω)								
p_t	0.548	1.044***	0.520			0.034		1.024***
	[0.466]	[0.132]	[0.994]			[0.240]		[0.215]
y_t	−0.287		1.074***	1.032***		−0.119		
	[0.313]		[0.243]	[0.209]		[0.453]		
m_t	0.472*	0.348*	−1.012**		0.481***	0.953***	1.240***	
	[0.282]	[0.205]	[0.452]		[0.051]	[0.235]	[0.089]	
sp_t	−0.018		−0.019			−0.061**	−0.069***	
	[0.015]		[0.025]			[0.018]	[0.018]	
hp_t	0.583***	0.622***	−1.006***	−0.729***	0.254***	0.134		
	[0.115]	[0.096]	[0.222]	[0.121]	[0.082]	[0.117]		
cp_t	−0.001		−0.213	−0.208***	0.166**	0.404***	0.456***	0.093**
	[0.015]		[0.147]	[0.077]	[0.064]	[0.073]	[0.052]	[0.041]
η	10.26	11.18	4.96	9.74	7.50	8.10	5.63	28.33
c	2.626***	2.596***	6.512***	5.714***	2.840***	4.586***	4.380***	3.946***
	[0.067]	[0.057]	[0.313]	[0.301]	[0.0831]	[0.698]	[0.431]	[0.608]
($\psi + \omega$)								
y_t				1.894***				
				[0.215]				
sp_t							−0.041***	
							[0.015]	
hp_t		−0.021		−0.839**	−0.031			
		[0.073]		[0.400]	[0.047]			
cp_t							0.403***	−0.012
							[0.031]	[0.021]
Obs.	105	105	164	164	105	129	129	102
Adj.R^2	0.938	0.935	0.837	0.816	0.922	0.846	0.837	0.866
SBIC	0.484	0.299	1.103	1.102	0.343	1.231	1.141	0.813
H_{01}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
H_{02}	0.019	0.001	0.006	0.000	0.030	0.002	0.000	0.002
H_{03}	0.000	0.016	0.000	0.000	0.000	0.000	0.000	0.007
H_{04}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Model	LSTR1	LSTR1	LSTR1	LSTR1	LSTR1	LSTR1	LSTR1	LSTR1
$s_t =$	p_t	p_t	p_t	p_t	p_t	p_t	p_t	p_t

Notes: * statistically significant at 10% level; ** at 5% level; *** at 1% level. All variables are in log differences. Standard errors are in square brackets. Adj.R^2 is the adjusted R^2 and SBIC is the Schwarz Bayesian Information Criterion. H_{01} reports the *p-value* of the linearity test; H_{02} to H_{04} report the *p-value* of the tests used to choose the preferred model. The results presented in columns 5 and 8 were obtained from regressions for the same time period considered for the Euro Area: 1980:1-2007:4.