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On the optimal choice of the monetary policy instrument

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RESUMEN

En esta tesis se analiza la elección de instrumento de política monetaria en una economía dolarizada como la uruguaya. Se estiman dos modelos neo keynesianos simples cuya diferencia reside en el instrumento de política utilizado, tasa de interés o cantidad de dinero. Se evalúa el desempeño relativo de los modelos en cuanto a su capacidad de absorber shocks y de minimizar una función de pérdidas que penaliza la volatilidad de la inflación y de la brecha de producto. Se concluye que la elección de instrumento de política monetaria depende de la valoración relativa entre estabilidad de precios o de producto que la sociedad tenga. Si se valora más la estabilidad de precios el instrumento adecuado es la cantidad de dinero, en caso contrario, la tasa de interés.

Palabras claves:
Macroeconomía, Política monetaria, Instrumento óptimo, Dinámica de corto plazo, Modelos Neokeynesianos.

ABSTRACT

This work analyses the choice of a monetary policy instrument in a dollarised economy such as the Uruguayan. I estimate two simple neo-Keynesian models whose difference lies in the monetary policy instrument used, interest rate or quantity of money. The relative performance of the models is evaluated in terms of their capacity to absorb shocks and to minimise a loss function that penalises the volatility of inflation and of output gap. It is concluded that the choice of monetary policy instrument depends on the society's relative preference between price or output stability. If price stability is valued more, the adequate instrument is the amount of money, otherwise, it is the interest rate.

Keywords:
Macroeconomics, Monetary policy, Optimal instrument, Short run dynamics, New-keynesian models.

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Chapter 1

Introduction

This paper deals with the election of monetary policy instrument for a small, open and dollarised economy like Uruguay. In this sense, we seek to find which is the most appropriate instrument to meet the objectives of the Central Bank, namely, price and growth stability.

A small and open economy faces the so-called unholy trinity. This consists of three desirable objectives that are attainable only by pairs: complete financial integration, monetary independence and stability of the exchange rate. Once the use of capital controls has been ruled out, the dilemma lies on the flexibility − credibility axis (Aboal and Lorenzo (2005)). Thus, we must choose between different exchange rate regimes, which have in their extremes the peg of the relative price of the domestic currency with respect to a foreign currency on the one hand and pure floating on the other. In the middle there is a continuum of regimes where the degree of intervention of the central bank in the exchange rate market is variable.

On the other hand, a small open economy with free capital mobility, faces another restriction from the operational point of view of monetary policy. Monetary policy can be implemented through the control of one of the following variables: exchange rate, interest rate and amount of money. Once one of these variables is determined the values of the other two are endogenously set. By way of example, if the money supply is fixed, the interest rate in domestic currency will be determined from the equilibrium in the money market. Then, together with the interest rate in foreign currency, through the interest rate parity (Fisher), the depreciation of the domestic currency is determined and therefore the exchange rate. In other words, we have three variables that are defined from three equations: Fisher's parity, money demand, and the monetary policy rule.

After 2002's crisis, Uruguay abandoned the exchange rate band scheme. In substitution, the country adopted a regime of inflation targets under floating exchange rates[1]. In this way, Uruguay faces a dilemma between using the interest rate or money aggrerates as the monetary policy instrument. All the economies of the world that have adopted an inflation targeting scheme have had to deal with this same choice. Although in recent years advanced economies have been forced to use instruments more typical of a monetary aggregate regime (through plans such as Quantitative Easing), most have opted to use the interest rate as the operational instrument of monetary policy. (See IMF (2017)).

This dilemma of the Uruguayan monetary authority is evident in the management of monetary policy in the 15 years after the crisis, where although an inflation targeting scheme has been established, the monetary policy instrument has varied over time. Thus, in the years following the crisis, the policy was carried out using the monetary base as an instrument, then towards 2007 the policy instrument became the interest rate of overnight interbank loans. Finally, since June of 2013 the policy is instrumented through the management of the expanded M1 monetary aggregate[2], also referred to as means of payment.

In order to approach this problem I estimate two variants of a new-keynesian model with two different monetary policy rules, one with monetary aggregates management (McCallum) an the other with interest rate management (Taylor). The models are validated by studying their impulse response functions, the historical decomposition and the moments of the variables. Afterwards, the way the models deal with the different shocks of the model is analysed. A widely used loss function is evaluated in order to compare the performance of the models globally.

The next section presents the theoretical framework on the optimal monetary policy instrument. In section 3 the main features of the model and its core equations are presented together with the specification of the two policy

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[1] The optimum exchange rate regime has been broadly addressed in the literature. The general conclusion is neither one of the extremes but a mix, where the exchange rate floats but the central bank intervenes the market in order to reduce its volatility.

[2] The expanded M1 or M1' is defined as the sum of the circulating currency held by the public plus demand deposits and savings accounts in national currency.

rules. The forth section presents the data used. In the fifth section the estimation results are analysed, the models are validated and compared and the loss function analysis is presented. Lastly, in section 6 we conclude.

Chapter 2

Theoretical framework

This work deals with short run dynamics and the convergence to the equilibrium through the actions carried out by the monetary authority. The monetary policy is neutral in the long run, so its objectives focus on the economic performance in the short and medium run. The central objective of monetary policy is to achieve price stability. However, while achieving its objective, it must take into account the effects it could generate in the real sector of the economy, minding not to provoke costly effects on the output level. So, its objective could be summarised as minimising the variance of the nominal gross domestic output (GDP) around its desired long-term value. Other desirable objectives for most policymakers are to limit strong financial and exchange rate fluctuations, given the drop in welfare they generate (White (1979)). In this framework, evaluating the optimal monetary policy instrument implies considering the one that achieves these objectives more efficiently.

At the theoretical level there is no clear answer about which instrument is the most suitable. As Poole (1970) explains, the problem is not such when considering a deterministic world. If we consider the basic static neo-Keynesian model (IS-LM), with no shocks to any of the curves, it is indistinct which variable the central bank decides to manage, given that it will always meet its objective. However, by introducing uncertainty the choice of instrument ceases to be innocuous and the relative magnitude of the effects of the shocks becomes central.

Poole (1970) presents the following graphs that show his argument in a simple and concise way. In the first figure we have three curves, one IS and two LM, the horizontal LM curve represents the rule that sets the interest rate

(LM(r*)) and the one with a positive slope the rule that sets the money supply (LM(m*)). In a deterministic environment such as the one with the following graph, the same result can be obtained using any of the instruments

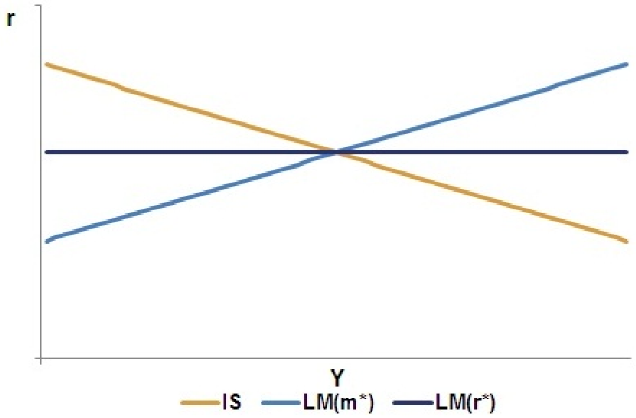

Figure 2.1: Stochastic static IS-LM

In the following graph we see how an economy that only faces real shocks would behave. In this case, the IS curve is shifted to the right or left according to the sign of the shock. As can be seen, the variability of the output is greater when the interest rate is fixed than when the money supply is fixed. This results from the fact that, when fixing the money supply, the interest rate has movements that buffer those of the real demand. Thus, the interest rate experiences a fall in the face of negative shocks, contributing to a smaller drop and vice versa in cases of positive shocks.

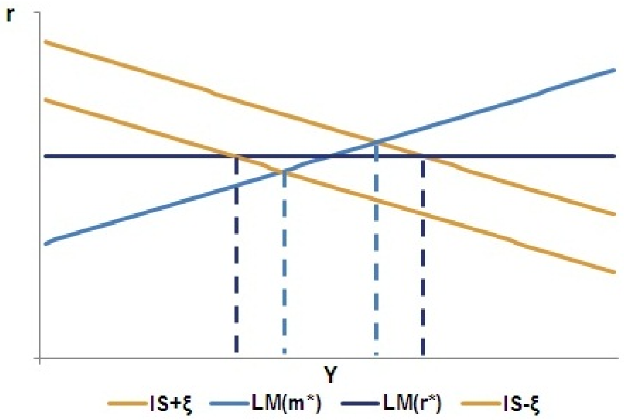

Figure 2.2: Stochastic static IS-LM: real demand shock

However, when shocks affect the demand for money, the previous result is reversed. The following graph shows how the affected curve is the LM(m*). Thus, the variability of the product when the money supply is fixed is greater than zero, while it remains nil when the interest rate is fixed.

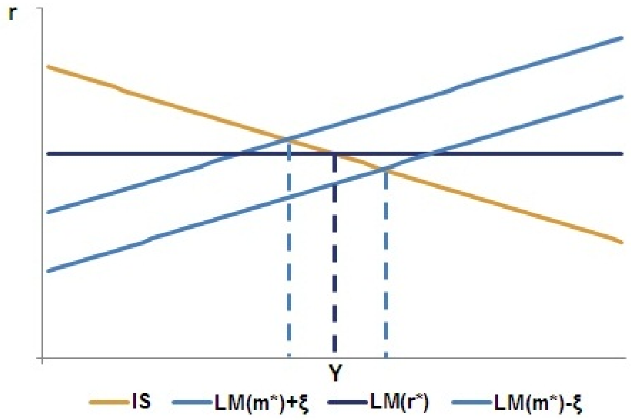

Figure 2.3: Stochastic static IS-LM: money demand shock

The analysis of Poole (1970) is useful to present the problem in an extremely simple framework, which led him to receive a series of criticisms. The main ones focus on the fact that it is a static model, of a closed economy, and that it assumes that central banks can perfectly control the amount of money, when in a strict sense only the monetary base can be controlled. There are successive extensions of the model proposed by the author that incorporate these aspects, but do not change their contributions.[1]

By incorporating the temporal dimension into the analysis, new considerations arise. Kydland and Prescott (1977) analyse the monetary policy taking into account time. Thus, they arrive to the so-called dynamic inconsistency of monetary policy, which consists of the phenomena that arises when an action announced for the future may not be optimal once it has to be applied. In this way, they analyse different equilibria where the announcements made are credible or not, where the Central Bank has the capacity to commit to a goal or not. They conclude that equilibrium under commitment brings greater benefits than the equilibrium under discretion.

If uncertainty is also taken into account, given that the central bank can

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[1] See Friedman (1975), LeRoy and Lindsey (1978), Sparks (1979) and Pierce and Thomson (1972). For a detailed review of the work carried out by the literature on this subject refer to Froyen and Guender (2007)

not foresee future events, it commits to a policy rule, a reaction function. The rule makes the monetary authority react to various shocks that push a set of variables out of the desired target level. In this sense, Taylor (1993) affirms that "policy rules have greater advantages over discretion by improving economic performance". The problem pointed out by this author is that the complexity of the rules developed at the academic level does not allow them to be useful when designing the policy, which is why he proposes a simple rule. Another argument in favour of simple rules is the information needed to feed them, if such is not available in due time or with a high grade of certainty it becomes useless.

The Taylor rule specifies a target for the short run interest rate which reacts to deviations from inflation and the product of its goal and its potential equilibrium value respectively. The specification he proposes is the following:

$$i = \pi + 0.5y + 0.5(\pi - \bar{\pi}) + \bar{r}$$

Where i is the interest rate of monetary policy, π is inflation, whose goal is $\bar{\pi}$, y is the output gap and the natural real interest rate is $\bar{r}$. In later developments, inflation is replaced by expected inflation, indicating that monetary policy should react to deviations in the expected value of inflation and not to its current level. On the other hand, in this specification of the rule the Taylor principle is reflected, which implies that the interest rate must react more than one to one over changes in expected inflation, in order to affect the real interest rate, thus ensuring that the system equilibrium is determined.

Switching to monetary aggregates rules, there are two central approaches that share their origin in the quantitative theory of money. As Salter (2014) explains, this theory starts from the fact that the nominal transactions carried out in an economy are equal to the amount of money times its velocity. Assuming that the velocity of money (which depends on technology) and the transactions made in an economy (related to GDP) are constant in time, then prices are directly proportional to the amount of money. As a consequence, Friedman proposed making the money grow at a constant rate expecting inflation to converge to that rate.

The second approach is the one developed by McCallum (1984, 1990a,b, 1993), who proposes a rule in which the growth rate of money presents movements, in contrast to the rule of constant growth postulated by Friedman.

The difference is that McCallum understands that monetary policy, although neutral in the long run, is not so in the short run, and may affect the evolution of output, while Friedman considers the money demand to be stable and does not take into account short-term frictions such as price stickiness. Thus, McCallum proposes a rule in which the central bank fixes the monetary base following the evolution of the potential nominal output of the economy, taking into consideration changes in the money velocity and deviations of the nominal output of the previous period from its steady state level. In its most general version, the specification would be as follows:

$$\Delta b_t = \Delta y_t^* - \Delta v_t^a + \alpha(\Delta y_t^* - \Delta y_{t-1})$$

Where Δb_t is the quarterly variation of the logarithm of the monetary base, Δy_t^* is the quarterly variation of the logarithm of the potential nominal output, Δv_t^a is the change in the velocity of the monetary base, α a coefficient greater than zero (McCallum proposed a value of 0.5) and Δy_{t-1} the nominal output growth in the previous period.

The literature on monetary policy rules is quite prolific. However, the optimal monetary policy instrument has not been properly addressed from this perspective. Most of the work done after Poole (1970) concentrated on fixing instruments that did not react after shocks. On one extreme, if the policy maker could identify every shock in a perfect way, the problem would not be such, as the central bank could set the most appropriate value of the instrument in every moment of time. But, as information failures exist, this can't be done and the best way to cope with the problem is through simple rules. Allowing the instruments to move following a rule at least ameliorates the consequences of using one or the other and could even make the choice trivial if both rules react the same way after different shocks. However, the literature hasn't approached the problem with this outlook.

There are several papers that compare monetary policy rules and their relative performance to conclude on which is the optimal instrument for the economy analysed. On the other hand, at the theoretical level, there are papers that highlight relative advantages of one instrument with respect to the other.

Sargent and Wallace (1975) analyse the equilibrium characteristics achieved using both instruments. They find some disadvantages on the use of the interest rate compared to money, specially due to the indeterminacy of the equilibrium under interest rate management. This result is disputed in Woodford (2003) where the authors indicate that the types of rules evaluated by these authors do not contemplate reactions of the interest rate to changes in endogenous variables (such as prices and product). In rules of the type proposed by Taylor, this result does not apply in a general way, since compliance with the Taylor principle ensures the determination of equilibrium.

Gichuki et al. (2012) highlight some strengths of the interest rate such as the fact that it is observable with accurate data, controllable and is a key variable in savings and investment decisions, which puts it at the centre of the monetary policy's transmission mechanisms. It is effective in neutralising shocks to the demand for money since the amount of money is fixed endogenously. Among the strengths of managing money, they mention that it is controllable and measurable without lags and with high frequency data. Also, using it as an instrument allows shocks to the real sector of the economy to be buffered by the endogenous movements of the interest rate. These authors find that the interest rate is the most appropriate instrument for Kenya.

Atkeson et al. (2007) analyse the problem from another perspective. They compare the three policy instruments (the present paper focuses on the two that are relevant for Uruguay), exchange rate, interest rate and amount of money according to two characteristics, their transparency and their "level of proximity to the target variable" or tightness. Thus, the authors establish that in terms of transparency, the exchange rate and interest rate have some advantage given that they are prices. Regarding the second characteristic, they establish the following order of preference: interest rate, exchange rate and amount of money[1]. The results show that when the monetary authority is able to commit it does not matter which instrument is used. But when there is no such capacity, the more transparent instruments provide greater welfare.

Niemann et al. (2013) analyse the interactions of monetary and fiscal policy and how they affect the decision of an optimal instrument. They state that there is no option that surpasses the other in all cases, it depends on the economic environment considered.

Regarding the empirical literature, Fair (1988) formulates a macroeconomic model and then simulates shocks to different variables under two regimes, depending on which is the monetary policy instrument. Then calculates the

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[1] It could be posed that in a small open and dollarised economy the exchange rate should come first with regard to the tightness of the instrument.

resulting variances of output and other variables. Thus, it finds that the variance resulting from the output is similar in both cases, but when the amount of money is used as an instrument, the variance of the components of the output and share prices are greater.

Sparks (1979) studies the case of Canada. The author takes into consideration an open economy model, in particular the role of capital flows, and argues that the money demand shocks have comparatively large effects. As a consequence he argues that the interest rate is the most appropriate instrument for Canada.

Galindo and Alatorre (2004) analyses the choice of the best monetary policy instrument in the case of Mexico. They estimate in isolation two rules, one with interest rate management (Taylor) and another with management of money aggregates (McCallum). This work is interesting as it uses monetary policy rules in order to conclude on the choice of instrument. However, their approach is different to the one proposed in this paper, by means of an encompassing test they seek to determine if any rule contains information that contributes to predict the movements of the other variable. Thus they conclude that the Taylor rule has "relevant information (...) to predict the movements of the monetary base" recommending the use of the interest rate as the instrument.

For the Uruguayan case, there are no specific papers on the optimal monetary policy instrument. Discussions have focused on the optimal policy rule and on the analysis of optimal exchange rate flexibility. Thus, Aboal and Lorenzo (2005) use a calibrated model for a small, open and dollarised economy and analyses the performance of different monetary policy rules. The rules include one with a fixed exchange rate, and different variants of the Taylor rule, monetary aggregates are not included as an alternative. The most efficient version is a forward looking Taylor rule according to the authors.

On the other hand Rossi (2006) asks whether the Central Bank of Uruguay should construct a scheme of inflation targeting and what would be an optimal rule to adopt from a set of thirteen rules. These rules vary in terms of the flexibility that the Central Bank allows in determining the evolution of the policy instrument and the exchange rate, and in the relative weight that it placed on output stabilisation. It only evaluates the use of the monetary base as a policy instrument since it was what the central bank used at the time. The main conclusion reached is that adopting an inflation targeting scheme would be beneficial for Uruguay.

Finally, Carballo et al. (2015) and Güenaga (2017) develop the benchmark model for this work, which has been modified with further improvements during the course of this investigation. The innovations were introduced with the aim of best fitting the data in the estimation process. The model is presented next.

Chapter 3

The Model

The model stems from the New Keynesian tradition, and is known in the literature as small open neokeynesian model[1]. These models appear from a mixture between the neo-Keynesian emphasis on nominal and real frictions and the role that aggregate demand plays in the determination of output and, on the other hand, the traditional methods of the real business cycle, general dynamic and stochastic (DSGE) models with rational expectations. The basic structure of this model is composed of 4 equations, an IS curve, which represents the aggregate demand, a Phillips Curve, interpreted as the supply, the parity of international interest rates and a monetary policy rule.

It is a general equilibrium model, in the sense that their main variables are endogenous and so depend on the evolution of the rest of the variables. It is stochastic because it incorporates random shocks that affect the endogenous variables of the model and incorporate rational expectations given that expectations are formed in a manner consistent with the model (although adaptive expectations are also incorporated). The structure of the model is not derived from microeconomic foundations, however, it can be interpreted as the reduced form of a model that is derived from microeconomic foundations.

Berg et al. (2006b) point out that the basic version they present of the model has certain limitations that are interesting to point out. It does not explore the determinants of the current account, the equilibrium level of output, the real exchange rate or the interest rate. It also abstracts from related issues such as aggregate supply and fiscal solvency. However, they emphasise that such limitations can be addressed in an appropriate way by incorporating

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[1] Berg et al. (2006b,a) provide a finished description of a basic version of the these models, focusing on their forecast performance.

extensions to the basic model.

This model, together with DSGE models and their approach on macroeconomics modelling in general, has received some critics that are worth reviewing[1]. First of all, agents in the model present rational expectations, which implies that they know the structure of the model and even the value of the parameters we are trying to estimate. Also, it is assumed that the agents operate in an information-rich environment or that there is a central planner that processes all the information for them. It is argued that these assumptions are oversimplifying and unrealistic, instead it is proposed that the agents should not know more than what the modeller knows. The consistency between agent and modeller arises other issues such as model selection, learning or agents' interactions.

Another feature criticised is their characterisation of the long run equilibrium. New-Keynesian models treat the equilibrium as a unique steady state where the economy converges in the long run once short run nominal frictions are no longer operative.

Despite its limitations, the model is constructed in order to properly reflect the monetary policy transmission mechanism, which justifies the use of the model to analyse the choice of the monetary policy instrument. Carballo et al. (2015) and Güenaga (2017) develop the Macroeconomic Projections Model (MPM), which is the model we are going to work with. In the former, the authors construct a small neo-Keynesian model for the Uruguayan economy, calibrating two possible monetary policy rules, a Taylor rule that uses the interest rate as an instrument, and a McCallum rule, which uses monetary aggregates. On the other hand, the second work, based on the previous model, estimates a New Keynesian model for a small and partially dollarised economy with a monetary policy rule *á la* McCallum.

The Güenaga (2017) model serves as the starting point for this work[2]. The main equations of the model are presented below[3].

Demand Curve (IS)

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[1] The following comments are based on Colander (2006)

[2] Some of the model's equations are modified in in order to best fit the data. These modifications are presented in Annex 8.

[3] As a general guide Δ means the quarterly difference, the variables followed by a subindex *"gap"* represent its gap with respect to the equilibrium level, the subscripts *"ss"* refers to the steady state value of the variable, *"t"* is the contemporary period, *"t+i"* and *"t-i"* are expected values and lags of the variables respectively. Finally ϵ_i represents a shock on the variable "i".

$$y_{gap,t} = a_1 y_{gap,t-1} - a_r((1-c_r) r_{gap,t-1} + c_r r^{me}_{gap,t-1}) + a_q q_{gap,t} + a_y y^*_{gap,t} + a_t tot_{gap,t} + \epsilon_{y_{gap,t}} \tag{3.1}$$

The aggregate demand curve is similar to the Euler equation with persistence of habits, it comprises an inertial component of the output gap, reflecting that consumers seek to smooth their consumption intertemporally (Clarida et al. (1999)). It also has a negative effect of the real interest rate gap lagged a period (which is constructed as an average between the interest rate gaps in domestic currency and in foreign currency, $(r_{gap,t-1}, r^{me}_{gap,t-1})$) reflecting the intertemporal substitution of consumption (Clarida et al. (1999)). On the other hand, the real exchange rate gap (REER; $q_{gap,t}$) reflects two opposing effects, that of net exports (where demand is driven by a REER greater than its fundamentals) and balance sheet (the demand is depressed when the REER is over its equilibrium) [1]. An external output indicator is incorporated to account for the effect of external demand on net exports $(y^*_{gap,t})$. Finally, the terms of trade gap is included in order to take into consideration phenomena such as the expansionary commodity price cycle present in most of the estimation sample.

Prices equations

Prices are modelled separately following the decomposition of the CPI proposed by Brum et al. (2013). Non tradables are modelled with a Phillips Curve, tradable prices follow international prices and the exchange rate, lastly the administrated and volatile prices are modelled as an exogenous process.

Phillips Curve

$$\pi^{ntx}_t = a_6 \pi^{ntx}_{t+1} + a_{10} \pi^{ntx}_{t-1} + a_7 y_{gap,t} + a_8 q_{gap,t} + \epsilon_{\pi^{ntx}_t} \tag{3.2}$$

Tradable Prices

$$\pi^{tx}_t = a_{14} \pi^{tx}_{t-1} + a_{15}(\delta_t - (\pi^{target} - \pi^*_{ss})) + a_{16}(\pi^*_t - \pi^*_{ss}) + \epsilon_{\pi^{tx}_t} \tag{3.3}$$

Volatile and administrated Prices

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[1] For a deeper discussion of the effect of this variable in the model see Güenaga (2017).

$$\pi_t^{fva} = c_{15}\pi_{t-1}^{fva} + (1 - c_{15})(\pi^{target}) + \epsilon_{\pi_t^{fva}} \tag{3.4}$$

The main features of the Phillips curve are based on a tiered pricing mechanism. In any period of time a company has a probability θ of having to keep its price fixed and 1 - θ to adjust it [1]. Thus, prices evolve according to the expected value of them in the future [2], with some inertia. In addition, there is a positive relationship between the output gap and non-tradable prices (π_t^{ntx}), reflecting demand pressures on prices. On the other hand, the REER gap is also included, with a positive effect on the prices of non-tradable goods and services, capturing the effect of imported inputs and nominating the prices in dollars of some non-tradable services (for example, housing and consumer insurance and others).

The tradable prices (π_t^{tx}) show inertia but tend to comply with the parity of purchasing powers in the long term (in the growth rate version).

Exchange rate

Interest rate parity

$$s_t = s_{t+1}^e + (i_t^* + \rho_t - i_t^{sr}) + \epsilon_{s,t} \tag{3.5}$$

$$s_{t+1}^e = (1 - a_s)(s_{t-1} + 2(\pi^{target} - \pi_{ss}^*)) + a_s s_{t+1} \tag{3.6}$$

$$\delta_t^e = (i_t^{sr} - i_t^* - \rho_t) + \epsilon_{s,t} \tag{3.7}$$

$$s_t = (1 - a_s)(s_{t-1} + 2(\pi^{target} - \pi_{ss}^*)) + a_s s_{t+1} + (i_t^* + \rho_t - i_t^{sr}) + \epsilon_{s,t} \tag{3.8}$$

Equation 3.8 states that the exchange rate should be adjusted taking into account the expected depreciation (δ_t^e) and the expected value of the exchange rate for the following period (s_{t+1}^e). The expected depreciation is given by Fisher's interest rate parity. This parity stipulates that the return of an asset in national currency must be equal to that of an asset in foreign currency plus

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[1] This pricing mechanism was proposed by Calvo (1983).

[2] Given that companies take into account that in the future there is a probability that they can not adjust their prices, they incorporate their expectations of future prices when they set prices in *"t"*.

a risk premium and the expected depreciation, so that there are no arbitrage opportunities.

The expected value of the exchange rate (s^e_{t+1}) is given by a "real exchange rate parity". That is, as presented by Beneš et al. (2008), the expected evolution of the exchange rate is consistent with the inflation target and the REER in the long term.

Money market

The money market has two variants as a consequence of the monetary policy instrument used in each case. As a general definition, in this market the supply and demand of money interact and as a result the amount of money and the interest rate in domestic currency are obtained. If the policy is implemented controlling the amount of money, then it is necessary to model the demand for money to determine the interest rate. If the instrument is the interest rate, the role of the money demand is secondary in the model, being necessary only to determine the amount of money.

The policy rules are the following:

Taylor rule (interest rate):

$$(i^{sr}_t - i_{ss}) = \alpha_1(i^{sr}_{t-1} - i_{ss}) + \alpha_2(\pi_{t+1} - \pi^{target}) + \alpha_3 y_{gap,t} + \alpha_4(\delta_t - (\pi^{target} - \pi^*_{ss})) + \epsilon_{tay} \tag{3.9}$$

McCallum rule (amount of money):

$$\mathit{\Delta} m1'_t = \mathit{\Delta} x_{eq,t} - \beta_1 \mathit{\Delta} v_t + \beta_2(\pi_t - \pi^{target}) + \beta_3(\mathit{\Delta} y_t - \mathit{\Delta} y_{eq}) + \beta_4(\delta_t - (\pi^{target} - \pi^*_{ss})) + \epsilon_{mc} \tag{3.10}$$

The rules include some modifications to the original rules discussed previously, in particular both incorporate a correction term on the deviations of the rate of depreciation from its steady state value (equal to the difference in the steady state of the domestic and foreign inflation rates). This component is included in order to reflect more precisely the behaviour of the central bank which publicly seeks to reduce the exchange rate volatility. In the case of the McCallum rule, the main difference is that the monetary authority reacts with different coefficients to contemporaneous deviations of output and inflation from their steady state values.

Money demand

$$\mathit{\Delta} m1r_t - \mathit{\Delta} y_{ss} = c_y(\mathit{\Delta} y_t - \mathit{\Delta} y_{ss}) + c_i \mathit{\Delta} i_t^{sr} - ... \tag{3.11}$$

$$... - c_{lr}((m1r_{t-1} - y_{t-1}) + c_{ilr}(i_{t-1}^{sr} - (\pi^{target} + r_{ss} + remonet_t))) + \epsilon_{m1r_t}$$

$$\mathit{\Delta} m1'_t = \mathit{\Delta} m1r_t + \pi_t \tag{3.12}$$

The money demand closely follows the specification proposed by Brum et al. (2011), presenting a short-term evolution that follows the deviations of the output with respect to its steady-state value, the short-term interest rate, the expected depreciation and a correction mechanism to its long run equilibrium. This equilibrium is given by the output and the deviations of the nominal interest rate from its long run level[1][2].

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[1] Money is affected in the long run by a persistent shock called *remonet* that captures remonetization processes that are typical of dollarised economies.

[2] Money demand included a short term shock, with no persistence in the original specificaction of the model. During the estimation process it had to be ruled out due to pile-up problem.

Chapter 4

Data

The sample period goes from the second quarter of 2005 to the fourth of 2017. Following Basal et al. (2016), the sample selected is determined in order to avoid the crisis that the Uruguayan economy suffered in 2002 and its aftermath.

The sample presents some disadvantages. Its relative shortness does not allow to embrace a full cycle of the economy. In this period the economy has experienced a steady growth of above 4% in average. The last three years of the sample show a slowdown in the economic growth associated with a less dynamic phase of the cycle.

From the monetary policy point of view, the sample has some features that are interesting. First of all, the central bank installed and pursued its policy under an inflation targeting scheme, with differences in the grade of development, during the whole period. Another interesting fact is that, as aforementioned, the monetary policy has been carried out with both of the instruments evaluated. When estimating each model it is implicitly assumed that each instrument was employed during the hole period, which may introduce bias in the estimation of some parameters. The alternative to sort this problem would be to estimate the model for the data corresponding to each instrument, but this option is discarded for the low number of observations available.

The variables included as observable and their source are shown in Table 4.1. Given that the variables in the model are expressed as differences with respect to their steady state value and are de-trended, there are some adjustments to be made in order to achieve the highest level of coherence between the variables in the model and in the data. Most of the variables are seasonally adjusted and demeaned, as well as transformed in order to obtain their stationary version.

Table 4.1: Variables included as observable

Variable	Source
Uruguay's gross domestic product	BCU
Uruguay's relevant foreign output gap (HP filter)	BCU
Non tradable price index	BCU based on INE
Tradable price index	BCU based on INE
Administered and volatile price index	BCU based on INE
Uruguay's trade partners' inflation	BCU
Nominal exchange rate	BCU
Three months LIBOR	BLOOMBERG
Average of central bank's medium term bills rates	BCU
Risk premium (EMBI index)	BLOOMBERG
Interbank interest rate	BCU
Monetary aggregates (M1')	BCU
Active interest rate in USD	BCU
Terms of trade gap (HP filter)	BCU
Real exchange rate	BCU[1]

As pointed out in Table 4.1 foreign output and terms of trade gaps where obtained using the Hodrick-Prescott filter. The rest of the gaps in the model (output gap, interest rate gap and exchange rate gap) are calculated within the model using the multivariate Kalman filter. The resulting gaps where validated by comparison with previous estimations[2].

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[2] Gianelli et al. (2011), Brum et al. (2012), España (2008), Güenaga et al. (2012).

Chapter 5

Results

In this section the results are presented together with some details of the estimation and some measures of the models' performances.

5.1. Estimation

The estimation was carried out employing bayesian techniques in the platform dynare on MATLAB. Following the common practice in the estimation of stochastic general equilibrium models, part of the parameters are calibrated. These are the steady state values, taken from Güenaga (2017), the share of the price on the CPI basket and the parameters associated with exogenous processes, such as their persistence and standard deviation, that are estimated from the data.

Table 5.1: Steady State values

Steady State (*)	
π^{target}	1.25%
r	0.75%
ρ	0.50%
i*	1%
π^*	0.75%
Δy	0.75%
spread	0%
(*) Quarterly rate	

Bayesian estimation consists, in first place, on constructing the likelihood function which is done by obtaining the joint density of all the variables in the model for the sample, conditional on the structure and parameters imposed by the model. Some measurement errors are considered in the process of linking the data and the model in order to take into account the differences between the observable data and the values adjusted by the model. These measurement errors are specified as gaussian white noises. The state-space representation is obtained with this specification, and the maximum likelihood function is computed in a recursive way using the Kalman filter.

Secondly, the estimation procedure requests a set of prior distributions of the parameters to be estimated. These incorporate the previous knowledge on the values that each parameter can take. Most are taken from Güenaga (2017) and Carballo et al. (2015). Then, given the likelihood function and the priors, a distribution *a posteriori* is obtained, which represents the update of the priors using the information provided by the data. Finally, the posterior distributions are optimised through Monte Carlo Markov Chain sampling methods (MCMC). The main advantage of the bayesian method is its validity in short samples such as the one we use.

The results of the estimation are presented in Table 5.2 and in Appendix 2. The estimated values of most of the parameters are similar in both models, and are in accordance with previous estimations. The largest difference between the estimation of the models is found on the coefficients of expected inflation and inertia in the Phillips Curve, where the model with the monetary aggregates rule allocates more weight in the forward looking component. The rest of the differences, though reduced, present the same pattern. The model tries to explain the whole economy through a little number of equations and it is not microfunded, we are not estimating structural parameters of the economy, and so these differences may appear.

One possible explanation to these differences is that the Taylor rule defines the interest rate incorporating the deviation of future inflation from its target whereas the McCallum rule is backward looking. Moreover, as explained by Atkeson et al. (2007), the interest rate is a more transparent instrument compared to the amount of money. So, the actions carried out by the central bank under the Taylor rule are more informative to the agents of the economy on which is the stance of the monetary policy and on how it will evolve in the following periods. In this way, the agents find the present and previous values of the variables in the model to be more informative of how the economy will behave in the future. On the other hand, the quantity of money is less informative and the agents need to rely more on their own expectation of the future values of the variables to make their decisions.

The value of the parameter of the q_{gap} in the IS Curve, which resumes two effects that have different sign, although close to zero, has a positive mode which would indicate that in this estimation the predominant effect is that of net exports (over the balance sheet effect). In comparison with Güenaga (2017) the inclusion of the terms of trade gap allowed a larger effect of the external demand on Uruguayan goods and services (y^{gap}).

The policy rule in the interest rate model follows the Taylor principle and presents comparatively small parameters in the correction of the output gap and the evolution of the exchange rate. The persistence is smaller than the values obtained in previous estimations (Basal et al. (2016)).

With regard to policy rules both models show a greater coefficient in the price component than in the other components. Compared to the theoretical version, the McCallum rule is more active when stabilising prices and similar to the proposed correction with output[1].

Finally, the money demand presents some differences that were expected as in one of the models it doesn't play any role (Taylor) and in the other is central in the monetary policy mechanism. The model with the monetary aggregates rule shows a less stable money demand with more weight of the interest rate in the short term and less in the long run relationship.

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[1] The policy rule proposed by McCallum assigned a parameter equal to 0.5 for both prices and product as it stabilised nominal output around its potential growth

Table 5.2: Estimated parameters

Equation	Variable involved	Parameter	Taylor	McCallum
IS Curve	$y_{gap,t-1}$	a_1	0.26	0.31
	financial channel	a_r	0.15	0.12
	r^{me}_{gap}	c_r	0.26	0.31
	q_{gap}	a_q	0.01	0.03
	y^*_{gap}	a_y	0.25	0.24
	tot_{gap}	a_t	0.16	0.15
Phillips Curve	π^{ntx}_{t+1}	a_6	0.39	0.65
	π^{ntx}_{t-1}	a_{10}	0.44	0.20
	y_{gap}	a_7	0.03	0.04
	$q_{gap,t-1}$	a_8	0.00	0.01
Fisher parity	Forward	a_s	0.81	0.88
Tradable prices	π^{tx}_{t-1}	a_{14}	0.36	0.28
	δ	a_{15}	0.14	0.22
	π^*	a_{17}	0.07	0.15
Taylor Rule	Persistence	α_1	0.50	-
	δ	α_s	0.04	-
	π	α_p	1.35	-
	y_{gap}	α_y	0.07	-
McCallum Rule	Δv	β_1	-	0.22
	δ	β_s	-	-0.31
	π	β_p	-	-2.09
	Δy	β_y	-	-0.50
Money demand	Δy	c_y	0.15	0.14
	Δi^{cp}_t	c_i	-1.06	-1.21
	Long run level	c_{mce}	0.44	0.36
	i^{cp}_t (LR)	c_{imce}	1.02	0.16

Both models reproduce reasonably well the standard deviations of the data. The McCallum model presents larger standard deviations for the interest rate, as expected, and for the prices, in the rest of the variables both models have a similar performance. The variable that shows the worst performance is the interest rate in foreign currency which has a parity with the international interest rate that should hold in the long run but in the sample period doesn't seem to do so (see equation 1.20 in Appendix 1).

Table 5.3: Standard deviation of the model and the data

Variable	Taylor	McCallum	Data
y_{gap}	1.21	1.24	1.21
i^{cp}	0.72	1.25	0.86
i^{lp}	0.63	1.10	0.82
π^{sub}	0.30	0.42	0.50
π^{ntx}	0.33	0.64	0.32
π^{tx}	0.83	1.02	0.85
π^{fva}	1.21	1.21	1.18
$\varDelta y$	1.33	1.37	1.36
i^{me}	2.03	2.03	0.26
$\varDelta m1$	1.96	1.74	2.41
δ	4.97	4.61	4.86
ρ	0.24	0.24	0.26
π^*	3.56	3.58	3.13
y^*_{gap}	1.47	1.47	1.55
i^*	0.24	0.24	0.46
tot_{gap}	3.02	3.02	2.57

5.2. Impulse response analysis

Monetary policy shock

The monetary policy shock raises interest rates, in the Taylor model this comes from the definition of the shock itself whereas in the McCallum model the shock causes a fall in monetary aggregates which makes interest rates rise in order to maintain the money market equilibrium. The sign of the effects and the underlying channels are the same in both models, but the size of the effects is larger in McCallum. The difference in magnitude stems from the persistence of the effect on the interest rates, in the McCallum model the rise in the interest rates takes longer to fade away. As a consequence, the effect on the exchange rate is larger, which produces a more persistent gap in the real exchange rate. Larger interest rates and real exchange rate gaps produces a deeper fall in output and prices. The persistence of the effect is larger in the McCallum model because the monetary policy channel goes through the money demand in order to obtain the interest rate. The money demand incorporates a long run relationship with the level of output and the interest rate and the return to the long run equilibrium is slow, which makes the effect on the interest rate more persistent.

Non tradable cost shock

A shock in non tradables starts by rising inflation which provokes a contraction of monetary policy in both models. The answer in the Taylor model is stronger but concentrated in the first periods whereas in McCallum the reaction is less active but more persistent and shades away slower. The contraction produces a fall in the exchange rate and a negative REER gap, that makes tradable prices drop. At the same time the rise in the interest rate makes the output gap negative which (together with the REER gap) controls the inflation pressures in the non tradable inflation. In both cases inflation converges to the target with the difference that McCallum returns to the price level previous the shock and Taylor allows some inflation in the process. The reaction of McCallum produces larger falls in the exchange rate and a slower convergence of the output gap.

Aggregate demand shock

The aggregate demand shock raises output which pushes non tradable inflation up in the first periods. The monetary policy reaction is harsher on the McCallum model and causes a deeper fall of the exchange rate. The initial push on non tradable inflation is reverted in McCallum, while in the Taylor model it is stabilised in a price level higher than previous to the shock. As a result of the contraction of the monetary policy, tradable prices fall in both models, and later returns to the level previous to the shock. This fall in tradables is larger than the rise in non tradables in the McCallum model, which makes inflation drop in this model, and as the components end up stabilising in the level previous to the shock, so does the general price level. In the Taylor model the shock causes prices to go up because of the larger rise of non tradable relative to the drop of tradable prices.

Foreign interest rate shock

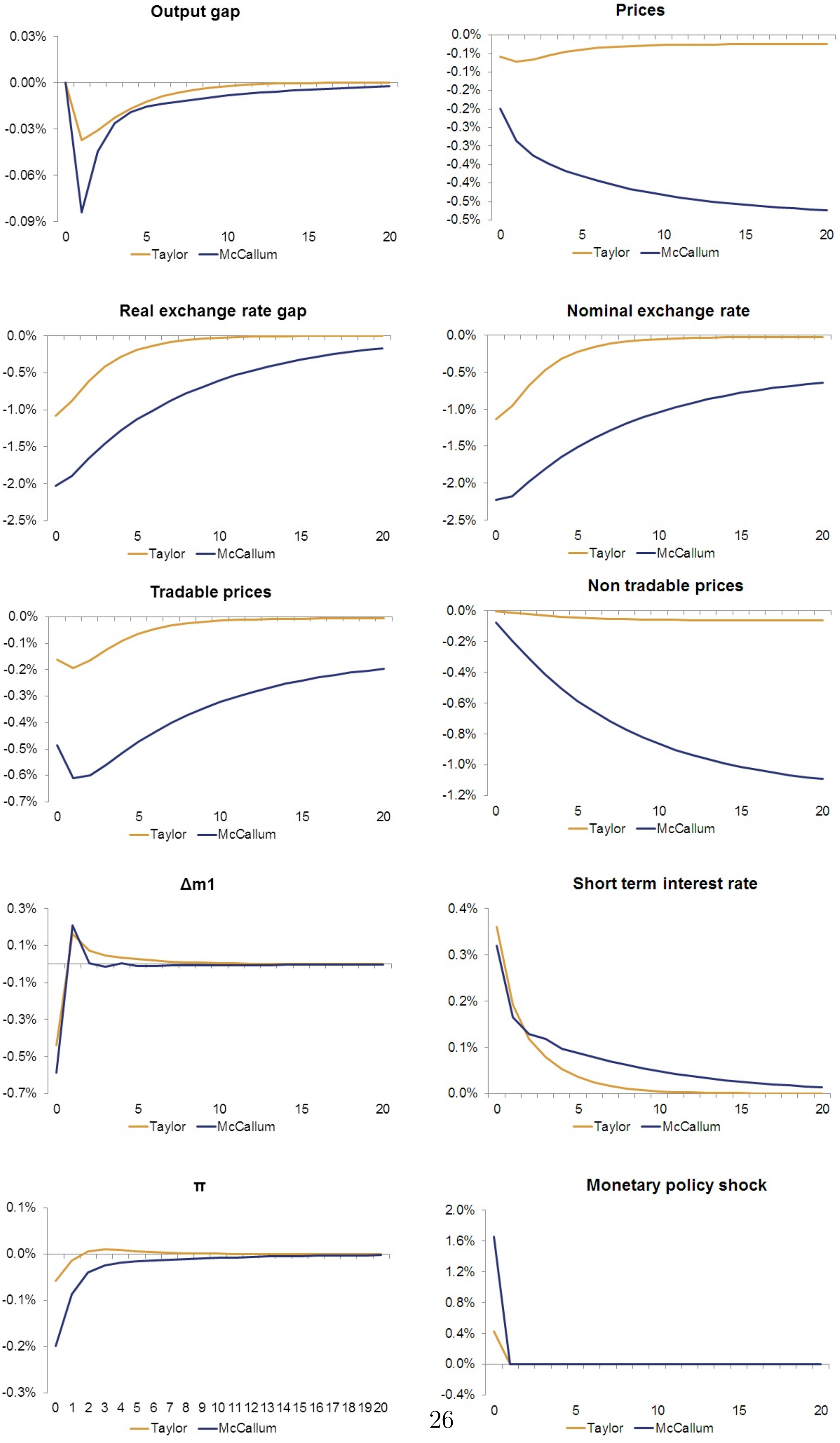

Figure 5.1: Monetary policy shock

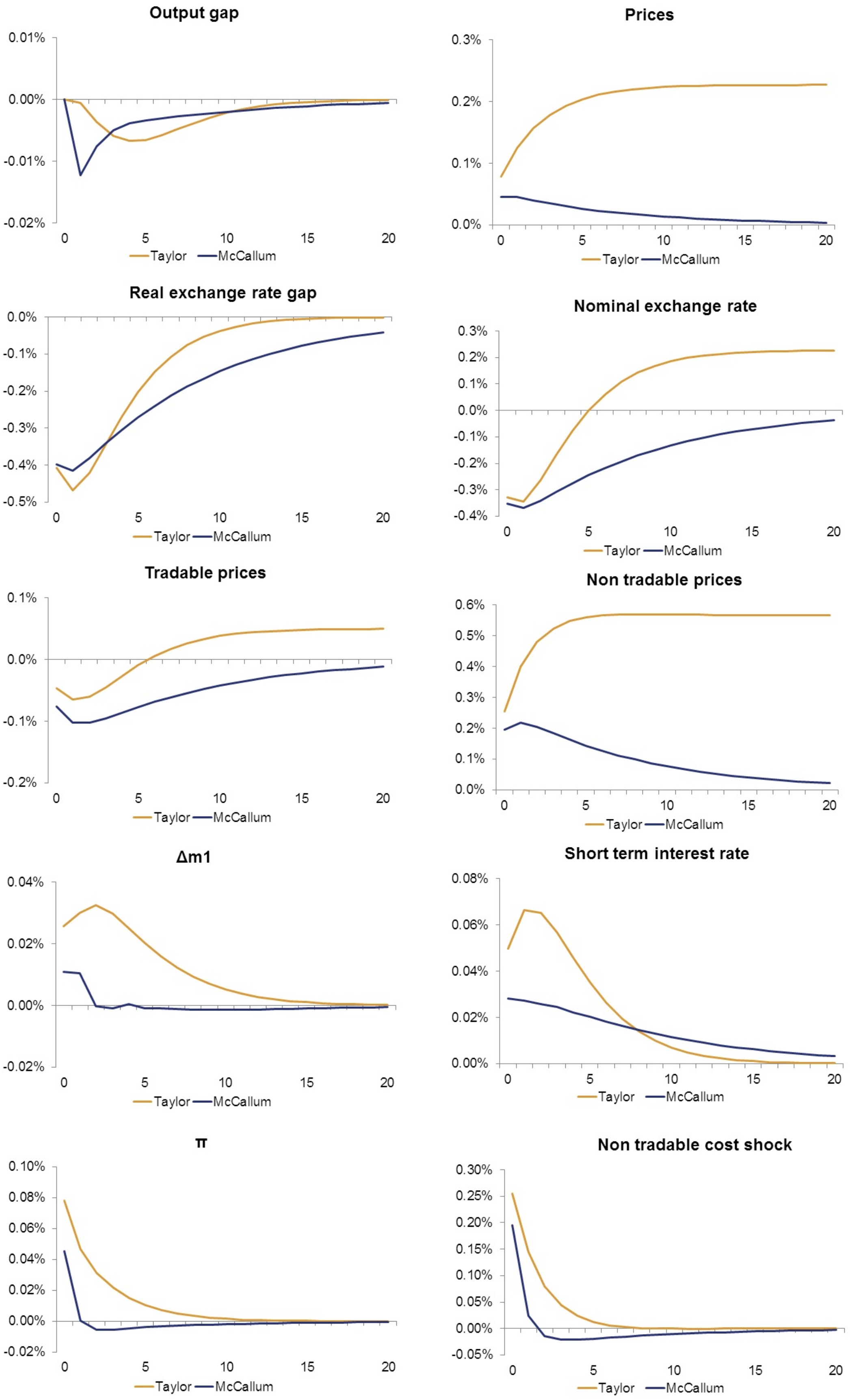

Figure 5.2: Non-tradable cost shock

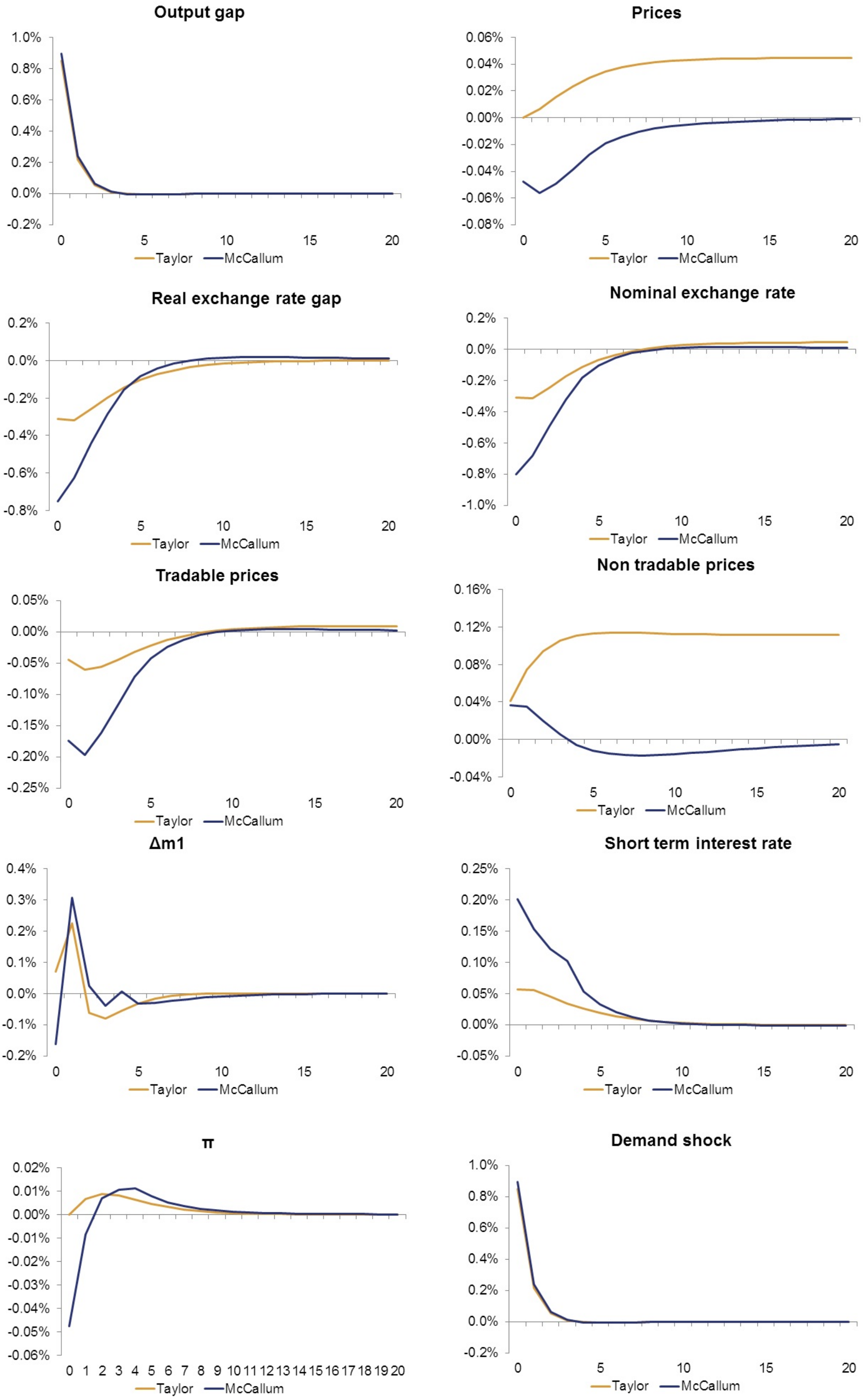

Figure 5.3: Aggregate demand shock

The shock in the foreign interest rate has a high level of persistence, it fades away after 40 periods, which makes the system converge slowly to the steady state. The shock makes the domestic currency to depreciate generating inflationary pressures on the tradable side of the economy. At the same time, the higher foreign interest rate pushes the output downwards. The reaction of the monetary policy is contractionary in the first periods in both models. The model with Taylor rule after some periods performs an expansionary policy in order to stabilise the output gap. In the case of McCallum, the interest rate slowly returns to its steady state level. This policy reactions causes a higher impact on the exchange rate in the Taylor model and a deeper fall in output in the McCallum model. Prices in McCallum are barely affected and the inflationary pressures caused by the higher foreign interest rate are controlled. In the case of the Taylor model, the price level rises as a consequence of the depreciation of the domestic currency. Once again prices in the McCallum model return to the level previous to the shock whereas in the Taylor model they converge to a higher level.

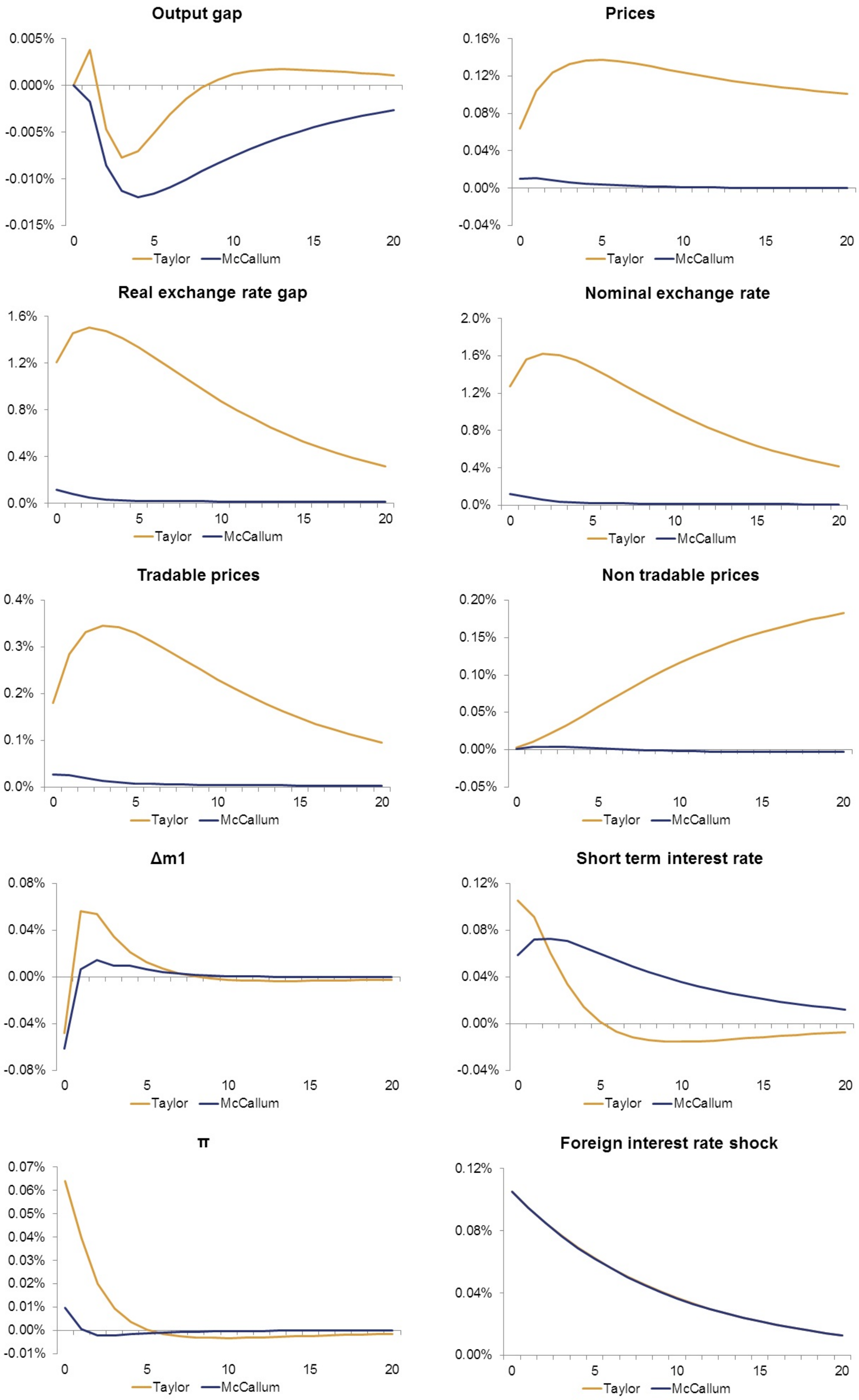

Figure 5.4: Foreign interest rate shock

5.3. Historical decomposition

The historical decomposition of the variables is a widely used tool in these kind of models. The results show how the shocks of the model explain the evolution of different variables and so make sense on how the model reads the data. This analysis is presented for two variables, the output gap and core inflation in the case of the McCallum model for simplicity. As can be seen, the results are in accordance with the stylised facts and common knowledge of the evolution of the economy, with respect to the variables analysed, in the sample considered.

The output gap starts being negative due primarily to demand shocks. In 2009 it shows a negative value that is explained by the international variables, specially the external output gap. This is strongly linked to the poor economic performance of the world during the global crisis and its aftermath. From that year up to 2014 the output gap was positive. In that period the recovery of the world and the increase in the weight of China in the Uruguayan commerce, together with positive demand shocks and shocks to the equilibrium real interest rate, were the main drivers. In the last three years the growth of the economy slowed and the output gap has been closed. In particular in 2016 the region presented a weak growth, with the Brazilian economy in recession, and the terms of trade deteriorated as the expansionary commodity price cycle began to revert.

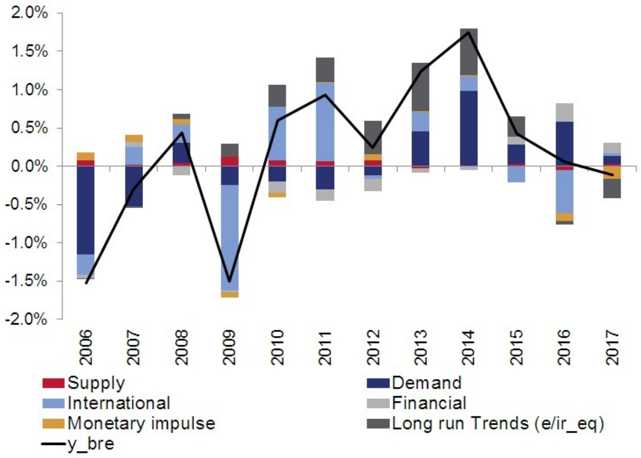

Figure 5.5: Historical decomposition - Output gap

In the first years of the period the core inflation began rising associated with supply shocks and monetary impulses. The central bank dealt with the global crisis by following a contractionary monetary policy that made the inflation go down. Afterwards, and up to 2015, the core inflation was above its mean. This is explained by the model by supply shocks in the non tradable prices and, from 2013, financial shocks associated with the slow normalisation of the monetary policy in the developed countries that impacted the economy through changes in the agents' portfolio management, a fall on money demand and depreciation pressures. The last two years of the sample show a drop in the core inflation driven by monetary policy shocks.

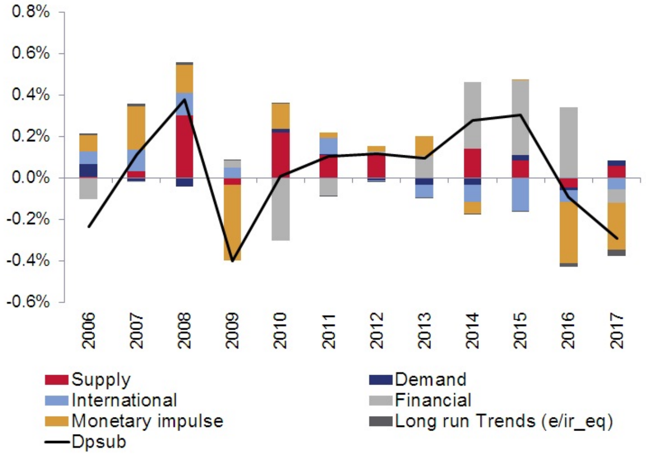

Figure 5.6: Historical decomposition - Core inflation

5.4. Variance decomposition of forecast errors

The variance decomposition of the forecast errors is another way of evaluating the quality of the answers that the models can pose to policy-relevant questions. It shows the contribution of every shock in the model to the variance of the variables of the model. In this case, we consider the output gap and inflation because the analysis of these variables' variance decomposition will be an input for the next section.

The variance of the forecast errors of the output gap has similar explanations in both models. The most relevant shocks are the demand shock, shock to the equilibrium interest rate, the foreign output gap shocks and the terms of trade shock. The monetary policy, foreign inflation and demand for money shocks are more relevant in the case of McCallum.

Table 5.4: Asymptotic variance decomposition of the forecast error - Output Gap

	Output Gap	
Shocks	Taylor	McCallum
Demand	53.0%	56.6%
Equilibrium real interest rate	17.3%	12.5%
Foreign output gap	14.8%	14.5%
Terms of trade	13.7%	12.4%
Dollarised domestic interest rate	0.4%	0.4%
Exchange rate	0.3%	0.4%
Monetary policy	0.2%	0.7%
Domestic interest rate spread	0.1%	0.2%
Foreign inflation	0.1%	0.8%
Equilibrium real exchange rate	0.1%	0.0%
Non tradable costs	0.0%	0.0%
Tradable costs	0.0%	0.1%
Foreign interest rate	0.0%	0.1%
Long term interest rate	0.0%	0.0%
Volatile and administered prices	0.0%	0.4%
Risk premium	0.0%	0.1%
Potential output growth	0.0%	0.0%
Money demand	0.0%	0.8%

In the case of the inflation the difference between the models is larger. In the Taylor model the most relevant shocks are those of the volatile and administered prices [1], tradable and non tradable costs, equilibrium real exchange rate and the exchange rate itself. In the McCallum model, the variance of the forecasts errors is mainly explained by the shocks of the monetary policy, the demand for money, volatile and administered prices, the exchange rate and foreign inflation. The cost shocks are more important in the case of the Taylor model whereas the shocks to the money market have a larger contribution in the McCallum model.

Table 5.5: Asymptotic variance decomposition of the forecast error - Inflation

	Inflation	
Shocks	Taylor	McCallum
Volatile and administered prices	55.5%	22.1%
Tradable costs	15.2%	5.8%
Equilibrium real exchange rate	7.1%	0.4%
Exchange rate	5.0%	8.2%
Non tradable costs	4.9%	1.1%
Foreign inflation	4.0%	9.6%
Foreign interest rate	3.0%	0.1%
Monetary policy	1.9%	25.6%
Equilibrium real interest rate	1.4%	0.1%
Risk premium	1.3%	0.1%
Foreign output gap	0.5%	0.3%
Demand	0.1%	1.4%
Domestic interest rate spread	0.0%	0.0%
Terms of trade	0.0%	0.2%
Potential output growth	0.0%	0.2%
Long term interest rate	0.0%	0.0%
Money demand	0.0%	24.9%
Dollarised domestic interest rate	0.0%	0.0%

5.5. Loss function

Traditionally, academia has assumed that monetary policy should minimise a quadratic loss function where deviations of inflation or output from their

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[1] The impulse response function of the volatile and administered prices is included in Appendix A

respective targets are penalised [1]. In this section we compare the performance of the models in their capacity to absorb the different shocks considered. In order to do so a policy maker's loss function is evaluated for both models and whichever minimises its value is considered to be the most appropriate. As the coefficient of inflation is taken to be unitary, the output gap variance parameter depends on each societies' relative preferences between output gap or inflation stabilisation.

$$L = (\pi - \pi^{target})^2 + b(y - y_{eq})^2$$

The variances of the inflation and the output gap are obtained for each shock from the impulse response functions. They are summed up taking into account the contribution of each shock in the variance decomposition of the forecast errors. Finally the variances of both variables are introduced in the loss function and we take different values of the coefficient associated to the output gap. The results are shown in table 5.6 for each shock separately and grouping them with the categories used in previous sections[2].

As can be seen in the table, the supply shocks are dealt differently by the models. The Taylor model focuses on stabilising the output gap and allows for a greater variance of inflation, whereas the McCallum model manages to reduce the inflation variance while coping with a more volatile output. The same happens with international shocks. Demand and financial shocks are better dealt with by the Taylor model, allowing for lesser variance of both variables. The result for financial shocks is the one expected, as the most relevant shock included in this group is the demand for money. As mentioned in the introduction (and analysed by Poole (1970)) the demand for money shocks are perfectly buffered by the interest rate rule whereas when controlling the money supply implies coping with some output and inflation volatility. Similarly, the monetary impulse produces less volatile inflation and output in the case of the Taylor model which could be related to the fact that interest rates are more transparent and easy to interpret. Finally, the shocks on the long run trends are better buffered by the McCallum model.

As shown in table 5.6, in both cases the losses associated with the output

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[1] The loss function used is similar to the one proposed by Galí (2008). The parameters are simplified and the one associated with inflation normalised to one.

[2] A different way of evaluating these variances and their aggregation is presented in Appendix 5

Table 5.6: Variances of inflation and output after the shocks of the model

	Inflation		**Output Gap**	
Shocks	Taylor	McCallum	Taylor	McCallum
Exchange rate	1.6%	2.0%	0.9%	1.2%
Tradable costs	2.7%	1.7%	0.2%	0.5%
Non tradable costs	1.5%	0.7%	0.2%	0.2%
Demand	0.2%	0.8%	13.6%	14.4%
Domestic interest rate spread	0.1%	0.0%	0.6%	0.7%
Risk premium	0.8%	0.2%	0.1%	0.4%
Foreign inflation	1.4%	1.9%	0.5%	1.5%
Foreign output gap	0.5%	0.4%	6.4%	6.5%
Foreign interest rate	1.2%	0.2%	0.2%	0.4%
Potential output growth	0.0%	0.3%	0.0%	0.1%
Equilibrium real exchange rate	1.8%	0.3%	0.4%	0.3%
Equilibrium real interest rate	0.8%	0.2%	5.9%	5.0%
Long term interest rate	0.0%	0.0%	0.2%	0.2%
Money demand	0.0%	3.5%	0.0%	1.6%
Terms of trade	0.1%	0.3%	7.0%	6.8%
Volatile and administered prices	5.3%	3.3%	0.1%	1.0%
Dollarised domestic interest rate	0.0%	0.0%	1.2%	1.2%
Monetary policy	1.0%	3.3%	0.9%	1.5%
Supply	3.4%	0.8%	0.0%	0.0%
Demand	0.0%	0.0%	7.2%	8.2%
International	0.1%	0.1%	1.9%	1.8%
Financial	0.1%	1.0%	0.0%	0.0%
Monetary impulse	0.0%	0.9%	0.0%	0.0%
Long term trends	0.1%	0.0%	1.0%	0.6%
Weighted sum	3.7%	2.9%	10.1%	10.6%

gap are larger than those related to inflation. This is a consequence of the policy rule being more active with the stabilisation of inflation rather than of output in both models. Comparing between the models we can see that the model with the amount of money as instrument has a better performance than the one with interest rate with regard to minimising the variance of inflation. The opposite results when we compare their performance in output stabilisation. Ultimately, the answer on which instrument should the monetary authority choose depends on how much weight is put on either objective by the society.

As can be seen in table 5.7 if society cares for output stabilisation up to two times as much as it cares for price stabilisation, the model with monetary aggregates has a better performance. Otherwise, that is, if society values output stabilisation more than two times as much as price stabilisation, the model with interest rate management outperforms the model with monetary aggregates.

Table 5.7: Loss function

	Loss Function	
b	Taylor	McCallum
0	3.7%	2.9%
0.5	8.8%	8.2%
1	13.9%	13.5%
1.5	19.0%	18.8%
2	24.0%	24.1%
2.5	29.1%	29.5%
3	34.2%	34.8%
3.5	39.3%	40.1%
4	44.3%	45.4%

Chapter 6

Conclusions

In this work, I analyse the optimal choice of monetary policy instruments in a small, open and dollarised economy. The main feature studied to compare the instruments is their ability to absorb the shocks the economy faces in order to make it return to its steady state.

In order to do so, I estimate two variants of a new-keynesian model with two different monetary policy rules, one with monetary aggregates management (McCallum) an the other with interest rate management (Taylor). The models were analysed by studying their impulse response functions, the historical decomposition and the moments of the variables. It was found that both reproduce in a suitable way the data and some stylised facts of the Uruguayan economy and are fit to perform simulations.

A widely used welfare loss function, which penalises the volatility of inflation and output, was taken into account in order to compare the performance of the models. In particular, they were compared in terms of which minimised the loss function, which implies comparing which stabilised the most, both inflation and output.

As a result, it is found that some shocks are better dealt with by Taylor (Demand, Financial, Monetary impulse) others are better buffered by McCallum (Long term trends) and the rest are ambiguous as it depends on which variable's stability is most valued (Supply, International). Summing up the effects of all the shocks, the result is not clear. McCallum has a better performance with regard to the stabilisation of inflation, whereas Taylor presents a smaller variance of output. In conclusion, the decision on which instrument is most suitable depends on the preferences of society on the stability of the variables. If society cares for output stabilisation up to two times as much as it cares for price stabilisation, the model with monetary aggregates has a better performance. Otherwise, if society values output stabilisation more than two times as much as price stabilisation, the model with interest rate management outperforms the model with monetary aggregates. This result is conditional to the estimated values of the coefficients and the shocks the economy received during the sample period, which makes it relevant for the Uruguayan case. However, the paper further discusses several elements relevant for the choice of the monetary policy in general, such as the role that the demand for money plays in the monetary policy transmission and the convergence to the steady state or the agents' expectations formation under both regimes.

Further research on this topic for Uruguay could include the evaluation of a hybrid monetary policy rule, where an interest rate smoother component is added to the McCallum rule for example. Another characteristic of the uruguayan economy is the direct participation of the central bank in the exchange market with the purpose of limiting the exchange rate volatility. Although this phenomenon is partially incorporated in the policy rules used in both models, the effect considered is indirect and modelling the balance sheet of the central bank could contribute to the discussion on the optimal choice of monetary policy instrument.

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APPENDIX

Appendix 1

Equations of the model

$$y_{gap,t} = a_1 y_{gap,t-1} - a_r((1-c_r) r_{gap,t-1} + c_r r^{me}_{gap,t-1}) + a_q q_{gap,t} + a_y y^*_{gap,t} + a_t tot_{gap,t} + \epsilon_{y_{gap,t}} \tag{1.1}$$

$$\Delta y_t = \Delta y_{eq,t} + y_{gap,t} + y_{gap,t-1} \tag{1.2}$$

$$\Delta y_{eq,t} = c_{12} \Delta y_{eq,t-1} + (1 - c_{12}) \Delta y_{ss} + \epsilon_{y_{eq,t}} \tag{1.3}$$

$$\pi^{ntx}_t = a_6 \pi^{ntx}_{t+1} + a_{10} \pi^{ntx}_{t-1} + a_7 y_{gap,t} + a_8 q_{gap,t} + \epsilon_{\pi^{ntx}_t} \tag{1.4}$$

$$\pi^{tx}_t = a_{14} \pi^{tx}_{t-1} + a_{15}(\delta_t - (\pi^{target} - \pi^*_{ss})) + a_{16}(\pi^*_t - \pi^*_{ss}) + \epsilon_{\pi^{tx}_t} \tag{1.5}$$

$$\pi^{fva}_t = c_{15} \pi^{fva}_{t-1} + (1 - c_{15})(\pi^{target}) + \epsilon_{\pi^{fva}_t} \tag{1.6}$$

$$\pi_t = (v_1 \pi^{ntx}_t + v_2 \pi^{tx}_t + v_3 \pi^{fva}_t) \tag{1.7}$$

$$\pi^{core}_t = (v_1 \pi^{ntx}_t + v_2 \pi^{tx}_t)/(v_1 + v_2) \tag{1.8}$$

$$s_t = (1-a_s)(s_{t-1} + 2(\pi^{target} - \pi^*_{ss})) + a_s s_{t+1} + (i^*_t + \rho_t - i^{sr}_t) + \epsilon_{s,t} \tag{1.9}$$

$$r_{gap,t} = r_t + r_{eq,t} \tag{1.10}$$

$$r_t = i^{lr}_t + \pi_{t+1} \tag{1.11}$$

$$i^{lr}_t = c_{13} i^{lr}_{t+1} + (1-c_{13})0.5(i^{sr}_t + i^{sr}_{t+1}) + spread_t + \epsilon_{i^{lr},t} \tag{1.12}$$

$$r_{eq,t} = c_5 r_{eq,t-1} + (1-c_5) r_{ss} + \epsilon_{r_{eq,t}} \tag{1.13}$$

$$tot_{gap,t} = c_{100} tot_{gap,t-1} + \epsilon_{tot_{gap,t}} \tag{1.14}$$

$$spread_t = c_{30} spread_{t-1} + (1-c_{30}) spread_{ss} + \epsilon_{spread,t} \tag{1.15}$$

$$r^{me}_t = i^{me}_t + \delta^e_t - \pi_{t+1} \tag{1.16}$$

$$r^*_t = i^*_t - \pi^*_{t+1} \tag{1.17}$$

$$r^{me}_t = r^{me}_{eq,t} + r^{me}_{gap,t} \tag{1.18}$$

$$r^{me}_{eq,t} = r_{eq,t} \tag{1.19}$$

$$i^{me}_t = 0.5(i^*_t + i^*_{t-1}) + \rho_t + \epsilon_{i^{me},t} \tag{1.20}$$

$$\Delta q_t = \Delta q_{eq,t} + q_{gap,t} + q_{gap,t-1} \tag{1.21}$$

$$\Delta q_{eq,t} = c_{31} \Delta q_{eq,t-1} + \epsilon_{q_{eq,t}} \tag{1.22}$$

$$\rho_t = c_{10}\rho_{t-1} + (1 - c_{10})\rho_{ss} + \epsilon_{\rho,t} \tag{1.23}$$

$$y^*_{gap,t} = c_7 y^*_{gap,t-1} + \epsilon_{y^*_{gap,t}} \tag{1.24}$$

$$i^*_t = c_8 i^*_{t-1} + (1 - c_8) i^*_{ss} + \epsilon_{i^*,t} \tag{1.25}$$

$$\pi^*_t = c_9 \pi^*_{t-1} + (1 - c_9)\pi^*_{ss} + \epsilon_{\pi^*,t} \tag{1.26}$$

$$\Delta x_{eq,t} = \Delta y_{eq,t} + \pi^{target} \tag{1.27}$$

$$\Delta x_t = \Delta y_t + \pi_t \tag{1.28}$$

Alternative policy rules:

Taylor rule (interest rate):

$$(i^{sr}_t - i_{ss}) = \alpha_1(i^{sr}_{t-1} - i_{ss}) + \alpha_2(\pi_{t+1} - \pi^{target}) + \alpha_3 y_{gap,t} + \alpha_4(\delta_t - (\pi^{target} - \pi^*_{ss})) + \epsilon_{tay} \tag{1.29}$$

McCallum rule (amount of money):

$$\Delta m1'_t = \Delta x_{eq,t} - \beta_1 \Delta v_t + \beta_2(\pi_t - \pi^{target}) + \beta_3(\Delta y_t - \Delta y_{eq}) + \beta_4(\delta_t - (\pi^{target} - \pi^*_{ss})) + \epsilon_{mc} \tag{1.30}$$

$$\Delta m1r_t - \Delta y_{ss} = c_y(\Delta y_t - \Delta y_{ss}) + c_i \Delta i^{sr}_t - ... \tag{1.31}$$

$$... - c_{lr}((m1r_{t-1} - y_{t-1}) + c_{ilr}(i^{sr}_{t-1} - (\pi^{target} + r_{ss} + remonet_t))) + \epsilon_{m1r_t}$$

$$\Delta m1'_t = \Delta m1r_t + \pi_t \tag{1.32}$$

$$\Delta v_t = c_{32}\Delta v_{t-1} + (1 - c_{32})(1/4^*(\Delta y_t - (\Delta m1_t - \pi_t)) + 1/4^*(\Delta y_{t-1} - (\Delta m1_{t-1} - \pi_{t-1}))... \tag{1.33}$$

$$+ 1/4^*(\Delta y_{t-2} - (\Delta m1_{t-2} - \pi_{t-2})) + 1/4^*(\Delta y_{t-3} - (\Delta m1_{t-3} - \pi_{t-3})))$$

$$remonet_t = c_{97} remonet_{t-1} + (1 - c_{97})(remonet_{ss}) + \epsilon_{monet_t} \tag{1.34}$$

Appendix 2

Estimation Results

Table 2.1: Priors and estimation results - McCallum model

Parameter	Distrib. (Prior)	Prior mean	Posterior mean	90% HPD interval	
a_1	Normal	0.30	0.29	0.116	0.458
a_r	Beta	0.30	0.17	0.029	0.303
c_r	Beta	0.30	0.36	0.094	0.614
a_q	Normal	0.20	0.03	-0.045	0.106
a_y	Normal	0.30	0.26	0.107	0.398
a_t	Normal	0.20	0.15	0.065	0.241
a_6	Beta	0.50	0.45	0.201	0.700
a_{10}	Beta	0.50	0.19	0.033	0.331
a_7	Beta	0.20	0.05	0.006	0.085
a_8	Beta	0.20	0.02	0.002	0.036
a_s	Beta	0.70	0.87	0.800	0.947
a_{14}	Normal	0.30	0.29	0.152	0.433
a_{15}	Normal	0.40	0.23	0.175	0.292
a_{17}	Normal	0.40	0.16	0.087	0.240
β_1	Normal	0.40	0.26	0.095	0.433
β_s	Normal	-0.40	-0.31	-0.410	-0.211
β_p	Normal	-2.00	-2.09	-2.512	-1.689
β_y	Normal	-0.50	-0.50	-0.726	-0.273
c_y	Normal	0.20	0.16	-0.005	0.310
c_i	Normal	-1.00	-1.26	-1.455	-1.057
c_{mce}	Normal	0.10	0.38	0.313	0.440
c_{imce}	Normal	0.30	0.25	0.010	0.457

Table 2.2: Priors and estimation results - Taylor model

Parameter	Distrib. (Prior)	Prior mean	Posterior mean	90% HPD interval	
a_1	Normal	0.30	0.24	0.048	0.449
a_r	Beta	0.30	0.19	0.019	0.350
c_r	Beta	0.30	0.32	0.082	0.572
a_q	Normal	0.20	0.00	-0.071	0.080
a_y	Normal	0.30	0.26	0.086	0.419
a_t	Normal	0.20	0.15	0.069	0.239
a_6	Beta	0.50	0.26	0.051	0.438
a_{10}	Beta	0.50	0.48	0.313	0.630
a_7	Beta	0.20	0.05	0.007	0.088
a_8	Beta	0.20	0.00	0.000	0.008
a_s	Beta	0.70	0.83	0.757	0.907
a_{14}	Normal	0.30	0.36	0.236	0.490
a_{15}	Normal	0.40	0.14	0.095	0.193
a_{16}	Normal	0.40	0.07	0.003	0.134
α_1	Normal	0.60	0.51	0.393	0.629
α_s	Normal	0.20	0.05	0.018	0.077
α_p	Normal	1.50	1.37	0.929	1.832
α_y	Normal	0.20	0.06	-0.049	0.164
c_y	Normal	0.20	0.16	-0.013	0.334
c_i	Normal	-1.00	-1.06	-1.290	-0.845
c_{mce}	Normal	0.10	0.45	0.372	0.522
c_{imce}	Normal	0.30	1.01	0.675	1.331

The Monte Carlo Markov Chain (MCMC) algorithm was used in order to obtain the results, and the algorithm used for the diagnostics tests was Metropolis-Hastings (Smets and Wouters (2003)) with 100000 repetitions. In order to compare between different specifications of the model, and sets of priors it is recommended to resort to the graphical analysis as well as comparing the log likelihood obtained (Laplace approximation), choosing the model that presents its highest value.

For the MCMC estimation several chains are used. The acceptance ratio, which should be close to 27%, is presented next.

Table 2.3: Acceptance ratio per chain

	McCallum model	Taylor model
Chain 1	30.2%	29.0%
Chain 2	28.3%	28.8%

Appendix 3

Graphical analysis of the estimation

In the prior and posterior plots grey solid line corresponds to prior density, black solid line to posterior density, and green dotted line to the mode.

Dynare reports three measures to test the convergence of each parameter individually and from a multivariate perspective. “Interval” is the average to 80% confidence, “m2” and “m3” are the second and the third moments respectively. Red and blue lines are the measures intra and between chains.[1]

3.1. McCallum model

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[1] Brooks and Gelman (1998) convergence test compares the variances in each chain and between chains. The results ought to be consistent in the different iterations of the M-H algorithm. So the red and blue line should be close to each other and converge to a stable value.

Figure 3.1: Mode Check - McCallum

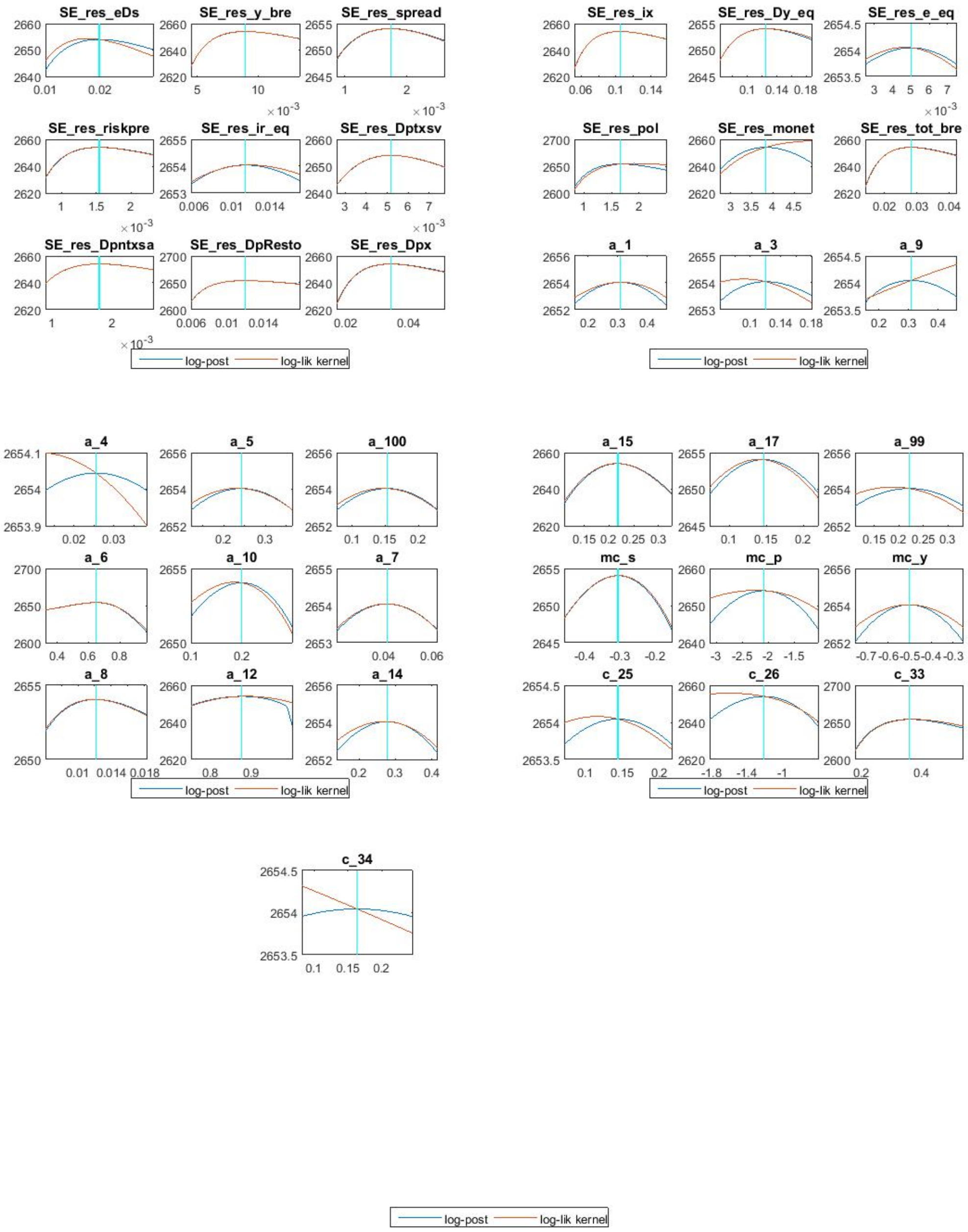


Figure 3.2: Priors and Posteriors - McCallum

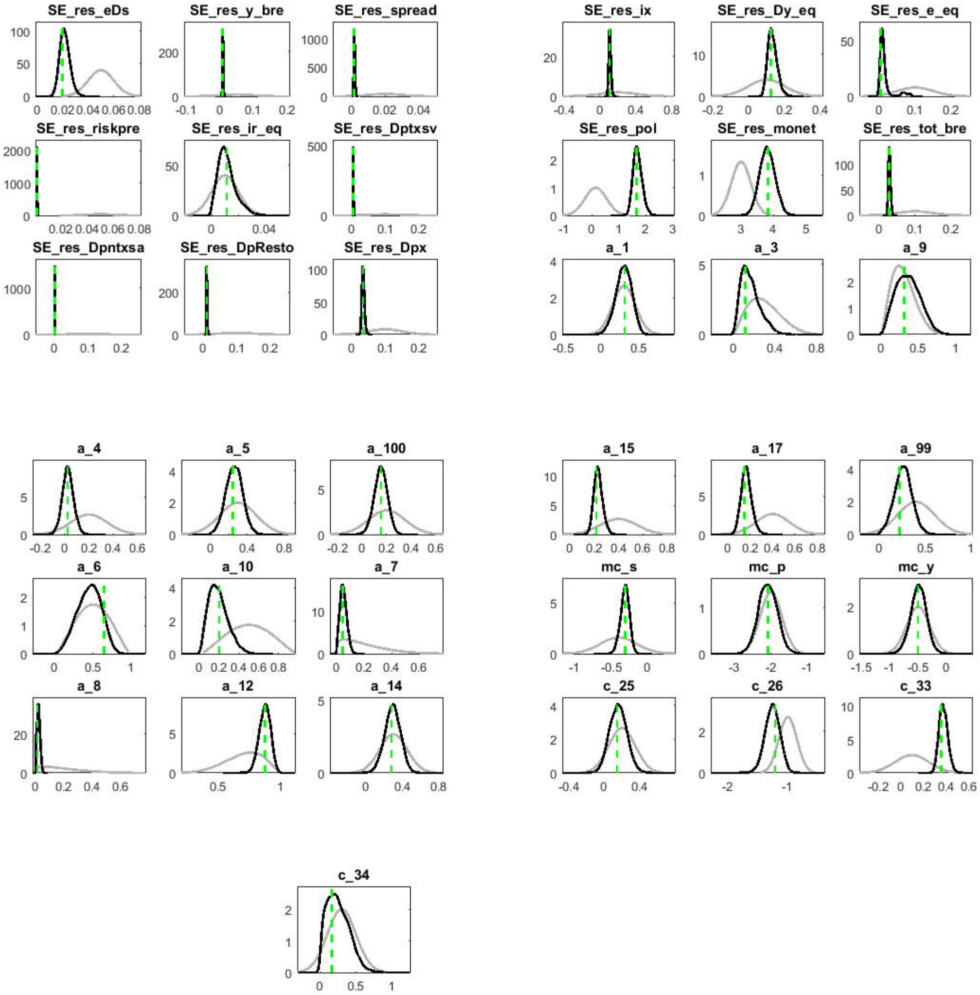


Figure 3.3: Estimated shocks - McCallum

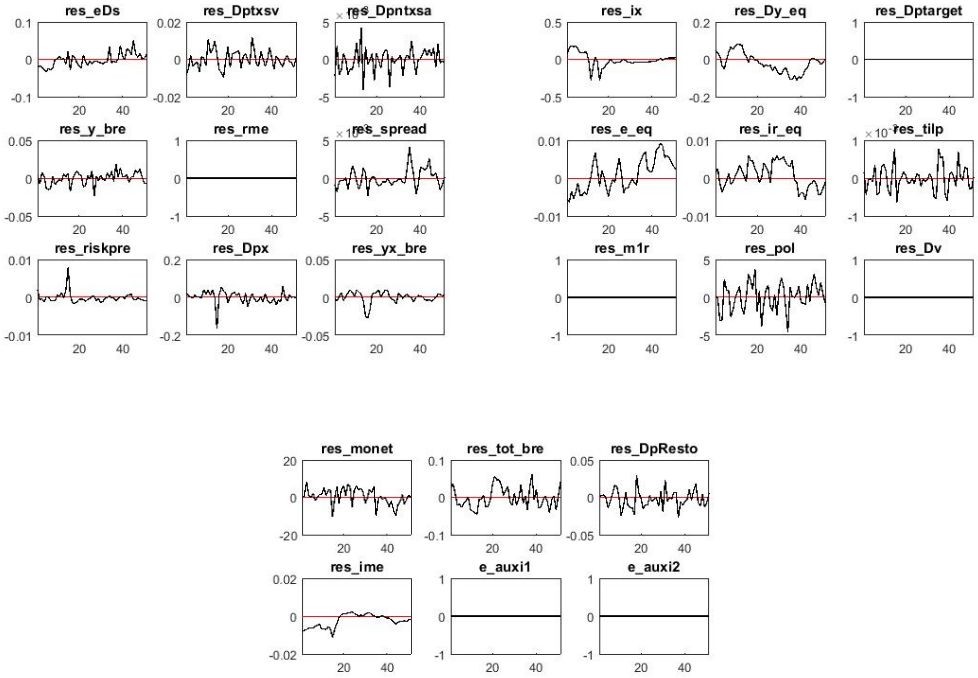


Figure 3.4: MCMC Univariate convergence diagnostics- McCallum

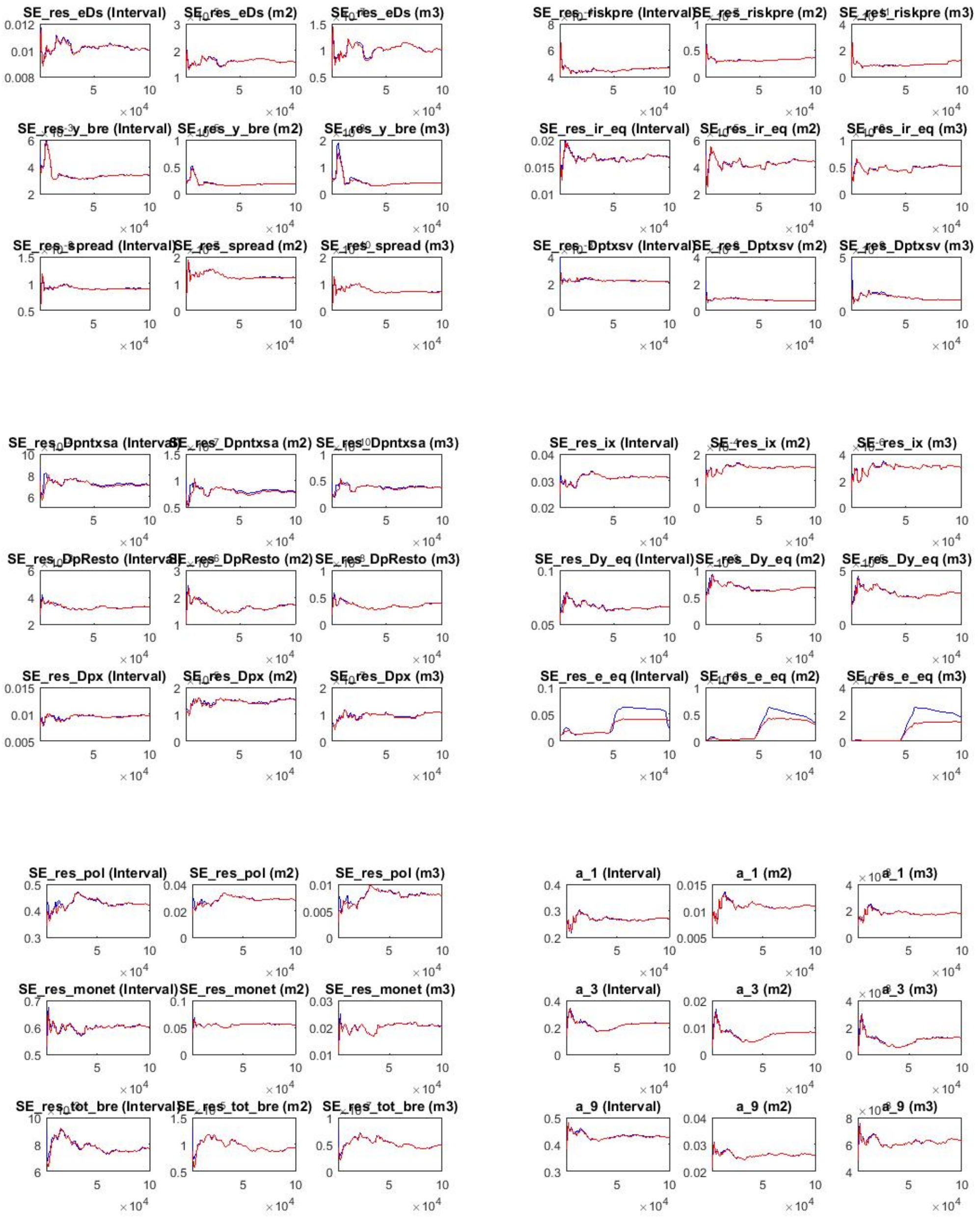


Figure 3.5: MCMC Univariate convergence diagnostics - McCallum (cont.)

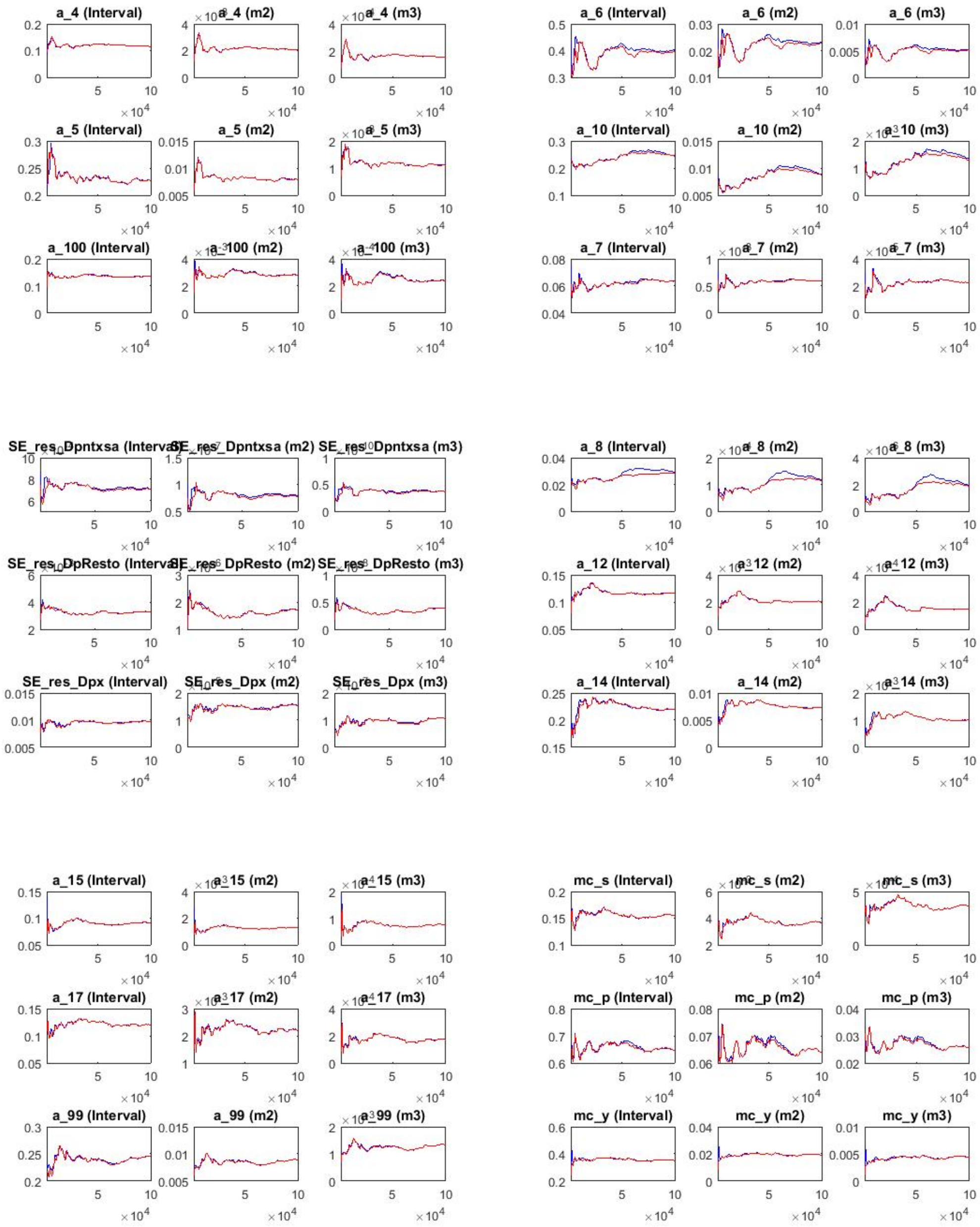


Figure 3.6: MCMC Univariate convergence diagnostics - McCallum (cont.)

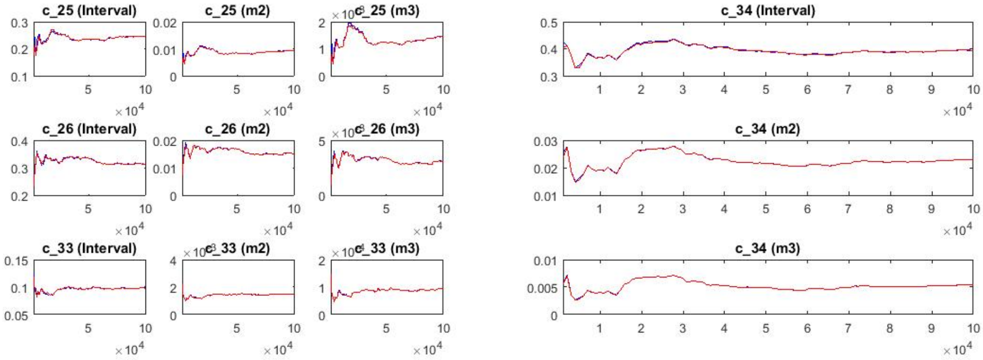
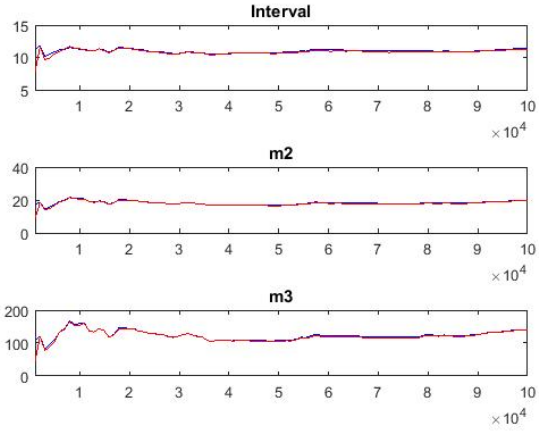


Figure 3.7: MCMC Multivariate convergence diagnostics - McCallum



3.2. Taylor model

Figure 3.8: Mode Check - Taylor

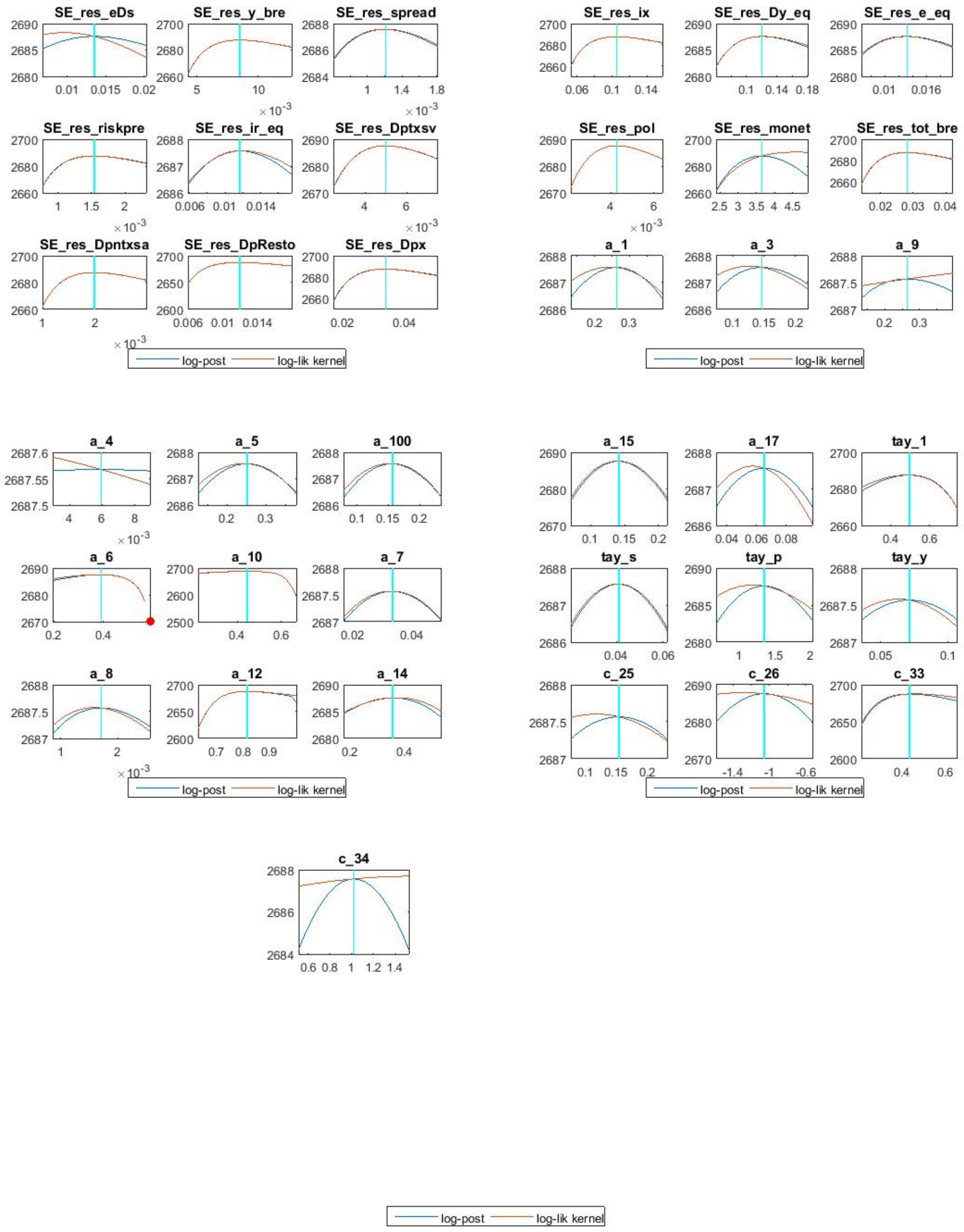


Figure 3.9: Priors and Posteriors - Taylor

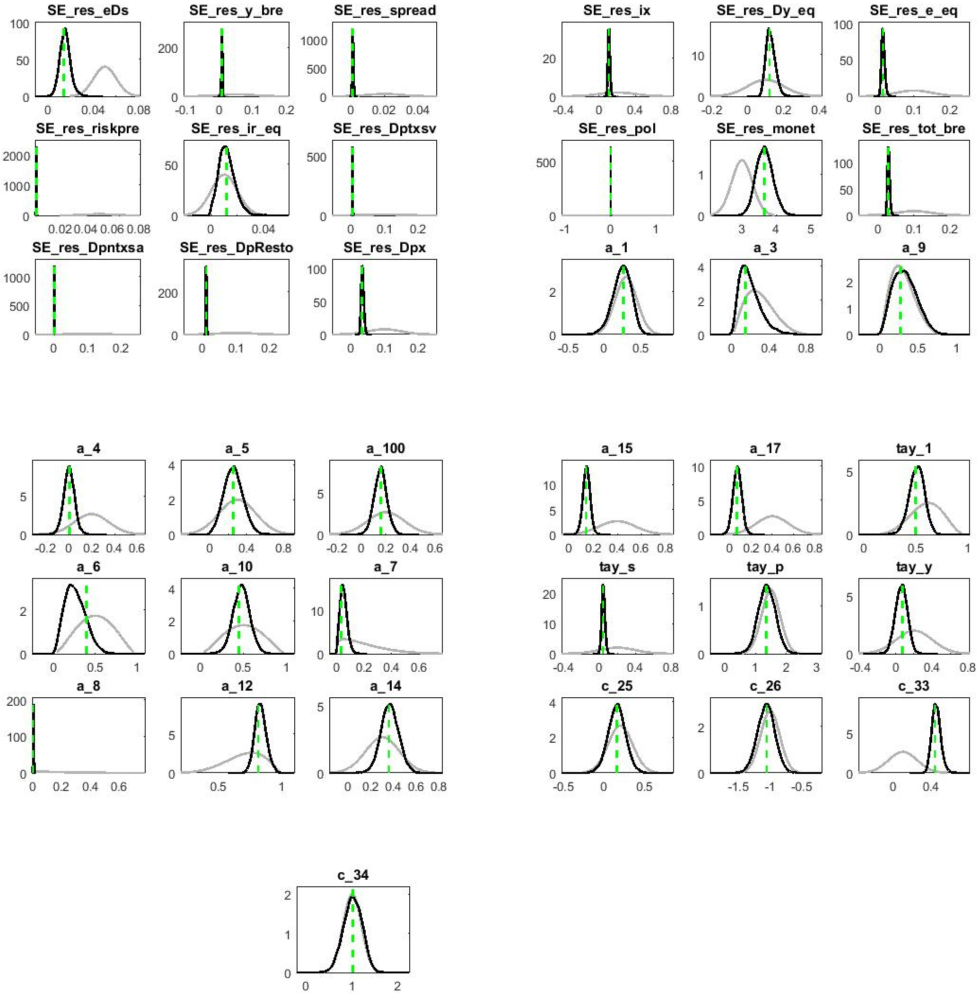


Figure 3.10: Estimated shocks - Taylor

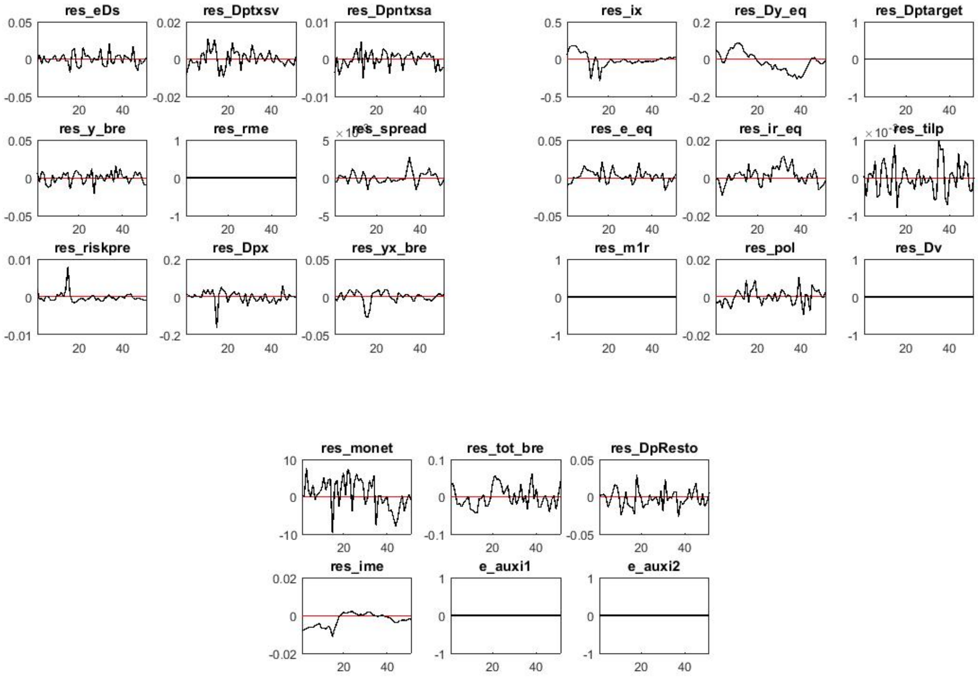


Figure 3.11: MCMC Univariate convergence diagnostics - Taylor

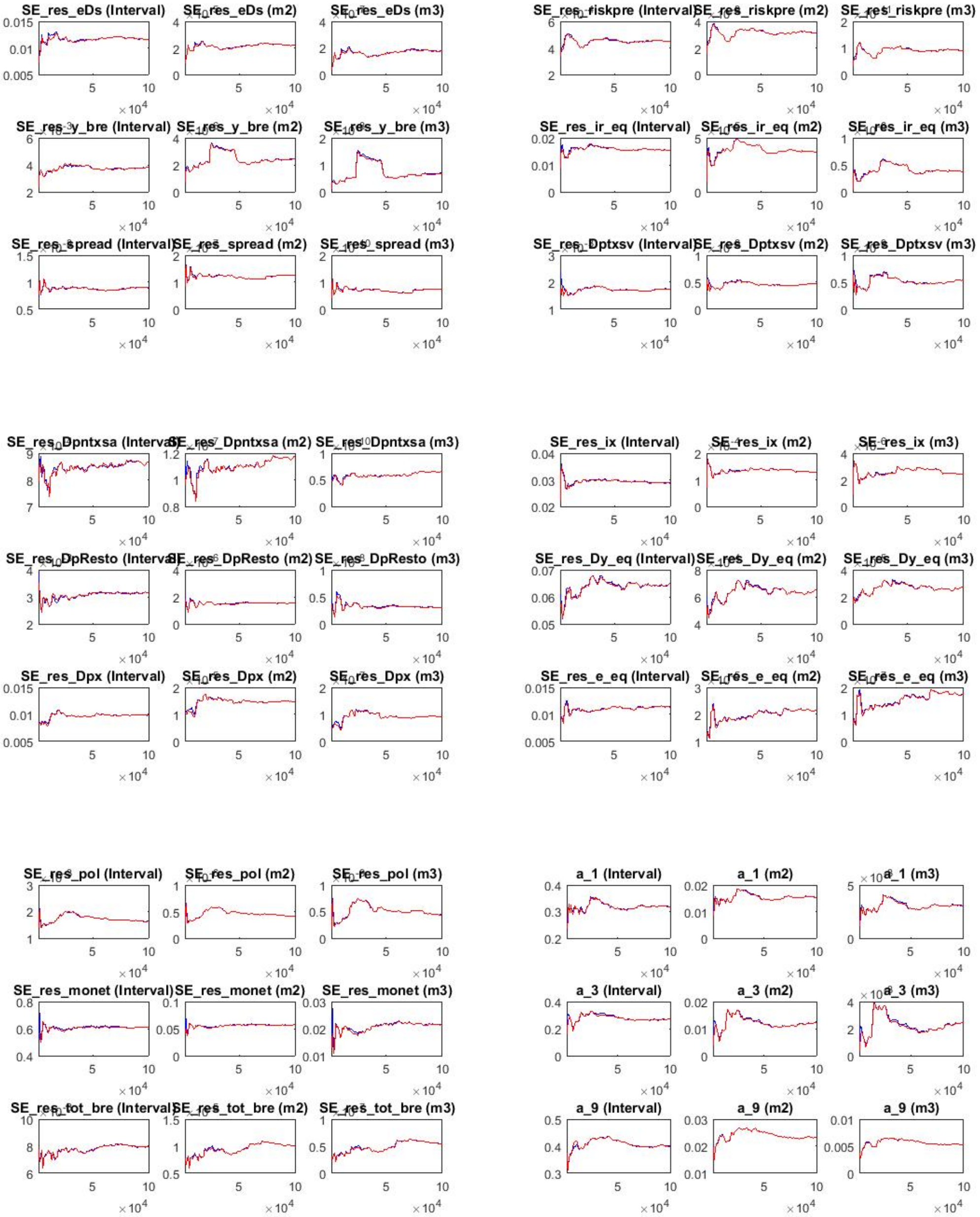


Figure 3.12: MCMC Univariate convergence diagnostics - Taylor (cont.)

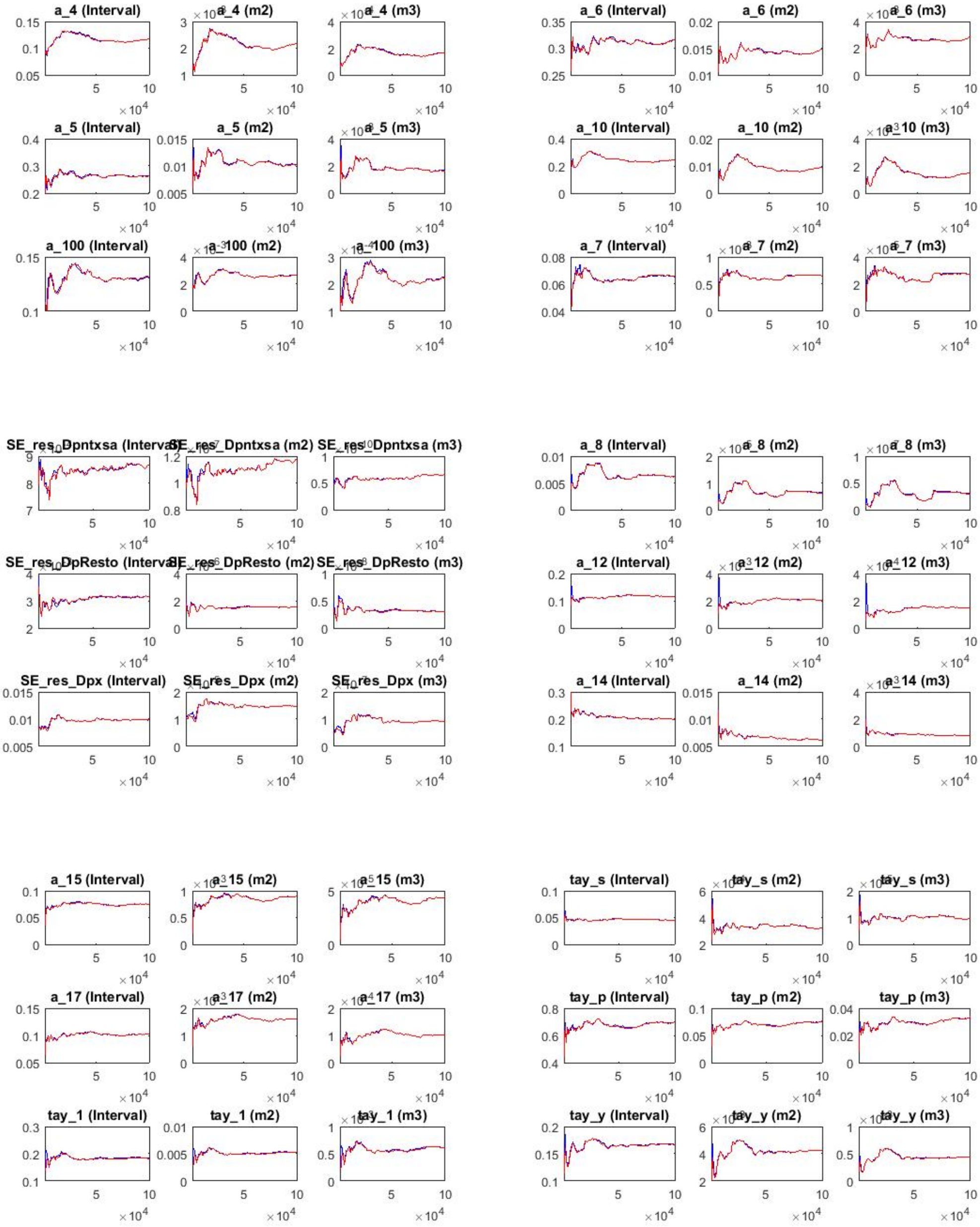


Figure 3.13: MCMC Univariate convergence diagnostics - Taylor (cont.)

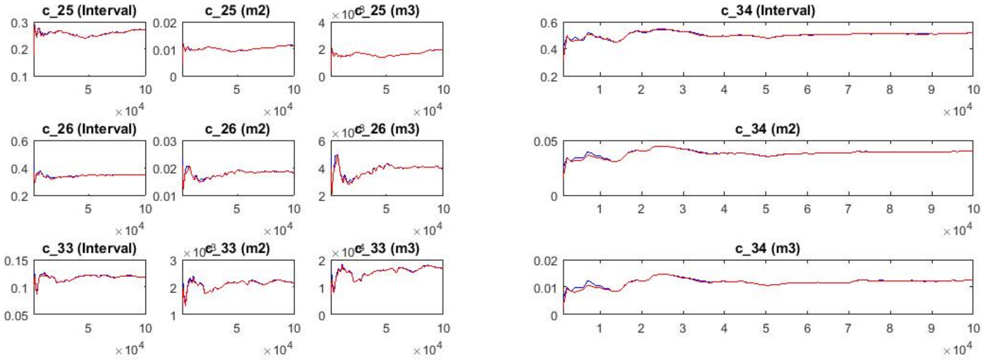
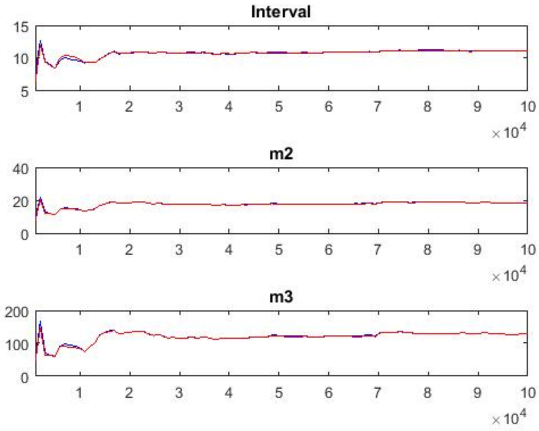


Figure 3.14: MCMC Multivariate convergence diagnostics - Taylor



Appendix 4

Volatile and administered prices shock impulse response function

The shock is inflationary and so in both models the reaction of the monetary policy is a rise in the short term interest rate. The nominal amount of money increases less than the spike in inflation, which implies a fall in the real amount of money. The McCallum model presents a more contractive reaction which makes the real exchange rate gap and output gap fall deeper, pushing the prices to return to the level previous to the shock. This is achieved by a change in the relative prices, where non tradables present a permanent fall equal to the rise of the volatile and administered prices. In the Taylor model the prices converge to a level higher than the one before the shock by allowing higher tradable inflation as the output gap presents a minor fall.

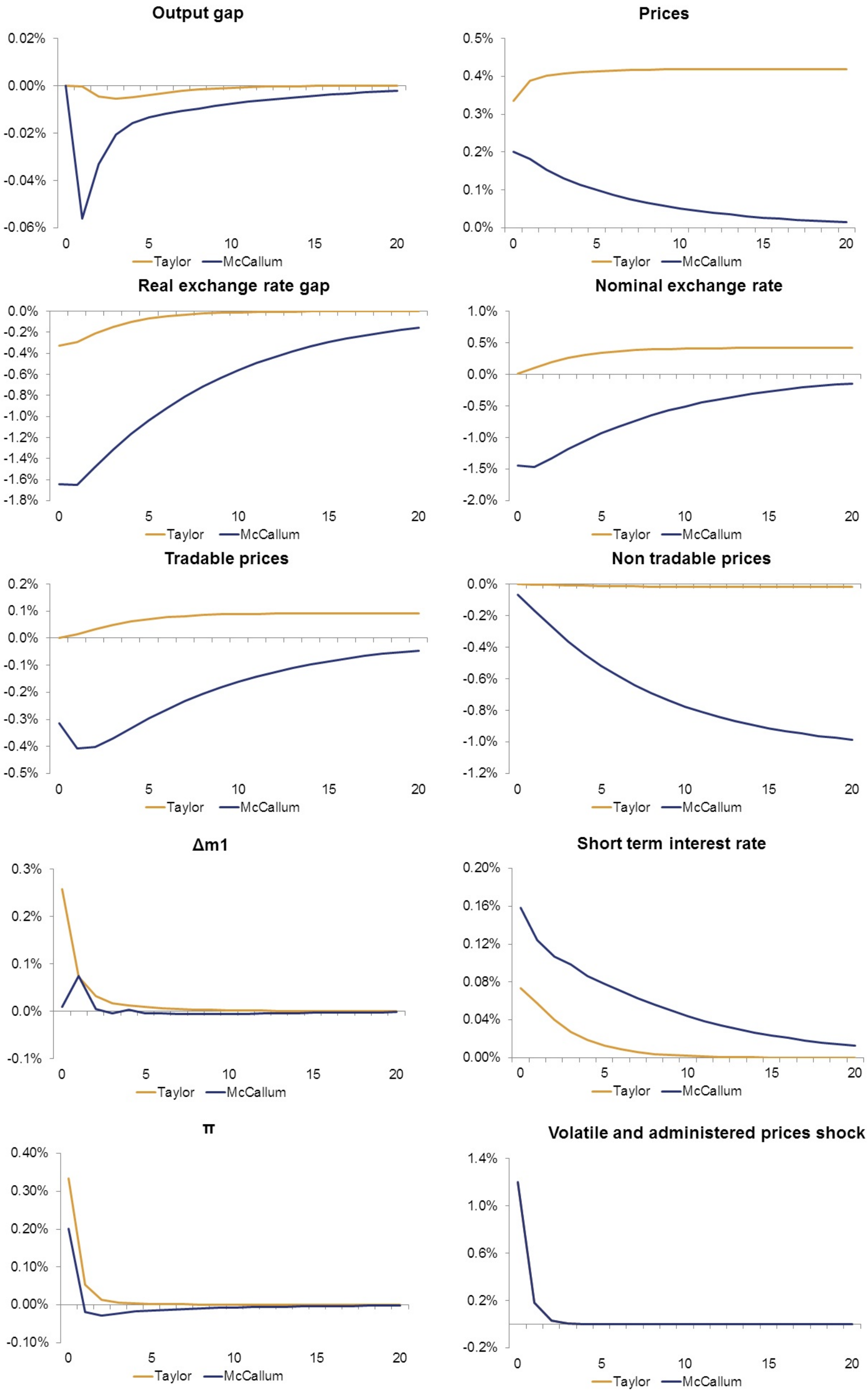


Figure 4.1: Volatile and administered prices shock

Appendix 5

Alternative evaluation of shocks and loss function

In this annex we present a different way of calculating and aggregating the variances of the variables after the shocks. The methodology consists of considering the moment reproduced by the model for inflation and output as they are the variances of our target variables. In order to assign the variance produced by each shock we use the asymptotic variance decomposition. The main results and conclusions remain the same as in the core document, but present changes in some of the magnitudes.

Table 5.1: Variances of inflation and output after the shocks of the model

	Inflation		**Output Gap**	
Shocks	Taylor	McCallum	Taylor	McCallum
Exchange rate	0.02	0.04	0.00	0.00
Tradable costs	0.07	0.03	0.00	0.00
Non tradable costs	0.02	0.00	0.00	0.00
Demand	0.00	0.01	0.64	0.70
Domestic interest rate spread	0.00	0.00	0.00	0.00
Risk premium	0.01	0.00	0.00	0.00
Foreign inflation	0.02	0.04	0.00	0.01
Foreign output gap	0.00	0.00	0.18	0.18
Foreign interest rate	0.01	0.00	0.00	0.00
Potential output growth	0.00	0.00	0.00	0.00
Equilibrium real exchange rate	0.03	0.00	0.00	0.00
Equilibrium real interest rate	0.01	0.00	0.21	0.16
Long term interest rate	0.00	0.00	0.00	0.00
Money demand	0.00	0.11	0.00	0.01
Terms of trade	0.00	0.00	0.17	0.15
Volatile and administered prices	0.26	0.10	0.00	0.00
Dollarised domestic interest rate	0.00	0.00	0.01	0.00
Monetary policy	0.01	0.11	0.00	0.01
Supply	0.35	0.13	0.00	0.01
Demand	0.00	0.01	0.64	0.70
International	0.03	0.04	0.35	0.34
Financial	0.03	0.15	0.01	0.02
Monetary impulse	0.01	0.11	0.00	0.01
Long term trends	0.04	0.00	0.21	0.16
Weighted sum	0.46	0.44	1.21	1.24

Appendix 6

Variables and shocks of the model

Table 6.1: Variable of the model

Variables	Description
y	Output
x	Nominal output
y^*_{gap}	Foreign output gap
tot_{gap}	Terms of trade gap
q	Real exchange rate
π	Inflation
π^{core}	Core inflation
π^{ntx}	Non tradable inflation
π^{tx}	Tradable inflation
π^{target}	Inflation target
δ	Nominal quarterly depretiation
π^*	Foreign inflation
π^{fva}	Administered and volatile goods inflation
s	Exchange rate
ρ	Risk premium
i^{sr}	Short run interest rate
i^{lr}	Long run interest rate
spread	Interest rate spread
i^*	Foreign interest rate
r	Domestic real interest rate
r^{me}	Foreign currency real interest rate
i^{me}	Foreign currency nominal interest rate
m1'	Money amount
m1r	Real money amount
v	Money velocity

Table 6.2: Shocks of the model

Shocks	Description	Classification
$\epsilon_{y_{gap}}$	Demand shock	Demand
ϵ_{ρ}	Risk premium shock	Financial
$\epsilon_{i^{lr}}$	Long run interest rate shock	Financial
$\epsilon_{i^{me}}$	Foreign currency interest rate shock	Financial
ϵ_{monet}	Money demand shock	Financial
ϵ_{s}	Exchange rate shock	Financial
ϵ_{spread}	Interest rate spread shock	Financial
ϵ_{π^*}	Foreign inflation shock	International
ϵ_{i^*}	Foreign interest rate shock	International
$\epsilon_{tot_{gap}}$	Terms of trade shock	International
$\epsilon_{y^*_{gap}}$	Foreign output gap shock	International
$\epsilon_{q_{eq}}$	Equilibrium real exchange rate shock	Long run trends
$\epsilon_{r_{eq}}$	Equilibrium real interest rate shock	Long run trends
ϵ_{mc}	Monetary policy shock (McCallum model)	Monetary impulse
ϵ_{tay}	Monetary policy shock (Taylor model)	Monetary impulse
$\epsilon_{\pi^{fva}}$	Administered and volatile cost shock	Supply
$\epsilon_{\pi^{ntx}}$	Non tradable cost shock	Supply
$\epsilon_{\pi^{tx}}$	Tradable cost shock	Supply
$\epsilon_{y_{eq}}$	Potential output shock	Supply

Appendix 7

Estimation results - comparison with previous estimations

The two papers considered use neo-keynesian models. However, different dynamic homogeneity and steady state convergence restrictions are imposed. Salas (2011) and Güenaga (2017) impose restrictions over the coefficients, namely, that the sum of the coefficients of forward and backward looking variables is equal to one. On the other hand, in the present paper all the variables are expressed as differences over their steady state values, which prevents the use of coefficient restrictions. The differences in some of the estimated coefficients can be explained by this fact.

In the IS curve the backward looking component and the interest rate channel have smaller coefficients in this paper. The percentage of dollarized credits are greater than the results arrived by Güenaga (2017), and is closer to the value that the author expected when she introduced it. The results regarding the exchange rate channel were explained previously. The external demand and the terms of trade channel are greater than the results in the other papers.

Regarding the Phillips Curve previous estimations seem to be more similar to the results of the McCallum model. This paper's estimation of the demand and exchange rate channels are greater than the one performed by Güenaga (2017) for Uruguay, but are smaller than the one that Salas (2011) arrives for Perú.

The forward looking component of the Fisher parity is similar in the estimations performed for Uruguay and greater than the Peruvian one. The equation for tradable prices is the one that presents greater differences among the estimations. They stem primarily from the different restrictions imposed to achieve convergence.

The Taylor rule estimated coefficients are similar between the papers. In the McCallum rule the main difference is that the reaction to the inflation deviations is greater in this paper which estimates its coefficients whereas in Güenaga (2017) they were calibrated. Finally, the money demand is similar between the models that have a McCallum rule.

Table 7.1: Estimated parameters

Equation	Parameter	Taylor	McCallum	Salas (2011)	Güenaga (2017)
IS Curve	a_1	0.26	0.31	0.49	0.40
	a_r	0.15	0.12	0.28	0.34
	c_r	0.26	0.31	-	0.11
	a_q	0.01	0.03	0.06	-0.003
	a_y	0.25	0.24	0.08	0.07
	a_t	0.16	0.15	0.04	-
Phillips Curve	a_6	0.39	0.65	0.65	0.50
	a_{10}	0.44	0.20	0.35	0.50
	a_7	0.03	0.04	0.1	0.014
	a_8	0.00	0.01	-	0.014
Fisher parity	a_s	0.81	0.88	0.66	0.81
Tradable prices	a_{14}	0.36	0.28	0.31	0.75
	a_{15}	0.14	0.22	0.58	0.25
	a_{17}	0.07	0.15	0.58	0.25
Taylor Rule	α_1	0.50	-	0.66	-
	α_s	0.04	-	-	-
	α_p	1.35	-	1.96	-
	α_y	0.07	-	0.5	-
McCallum Rule	β_1	-	0.22	-	1.0
	β_s	-	-0.31	-	-
	β_p	-	-2.09	-	-0.50
	β_y	-	-0.50	-	-0.50
Money demand	c_y	0.15	0.14	-	0.45
	c_i	-1.06	-1.21	-	-0.96
	c_{mce}	0.44	0.36	-	0.36
	c_{imce}	1.02	0.16	-	0.27

Appendix 8

Main changes introduced in the model

In this Annex I present the main modifications introduced in the model estimated in Güenaga (2017). As aforementioned, these were introduced in order to achieve the best fit of the data while trying to reduce the restrictions imposed.

The IS Curve is modified to incorporate the terms of trade gap channel and as a result of the estimation the forward looking component was left out. In the Phillips Curve and the tradable prices equation the main difference is that all the variables are expressed as differences from their steady state values. In addition, this allowed to separate the effect of changes in the exchange rate and changes in international inflation in the tradable prices equation.

In the money market, the McCallum rule was estimated and had two modifications. First nominal output was separated in prices and real output, and the reaction to deviations from their equilibrium values were estimated separately. Also, dollarization was introduced in the rule in order to reflect the exchange market interventions performed by the central bank. As dollarization was incorporated on the supply side of the market, it had to be removed from the demand for money.