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Bayesian Estimation of a Simple Macroeconomic Model for a Small Open and Partially Dollarized Economy

Jorge Salas*

* Central Bank of Peru

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Jorge Salas†
Central Bank of Peru

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Abstract

I describe a simple new-keynesian macroeconomic model for a small open and partially dollarized economy, which closely resembles the Quarterly Projection Model (QPM) developed at the Central Bank of Peru (Vega et al. (2009)). Then I use Bayesian techniques and quarterly data from Peru to estimate a large group of parameters.

The empirical findings provide support for some of the parameters values imposed in the original QPM. In contrast, I find that another group of coefficients – e.g., the weights on the forward-looking components in the aggregate demand and the Phillips curve equations, among several others – should be modified to be more consistent with the data.

Furthermore, the results validate the operation of different channels of monetary policy transmission, such as the traditional interest rate channel and the exchange rate channel. I also find evidence that in the most recent part of the sample (2004 onwards), the expectations channel has become more prominent, as implied by the estimated values of the forward-looking parameters in the aggregate demand and the Phillips curve equations.

JEL Codes: E52, E58, F41, C11

Keywords: Monetary Policy; Partial Dollarization; Bayesian Estimation

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†E-mail: jorge.salas@bcrp.gob.pe

1 Introduction

In recent years, several central banks have developed small macroeconomic models to simulate policy outcomes and forecast future developments. These tools belong to a generation of models that merge the real business cycle tradition with the new keynesian paradigm, in what is known as the new neoclassical or new keynesian synthesis (Galí (2008)). In short, these are general equilibrium and rational expectations models consisting of a core set of behavioral equations, which lack explicit microeconomic foundations but have a well-grounded economic interpretation (see Berg et al. (2006)). I will refer to these as ”simple” or ”small” macroeconomic models hereafter.

In this paper I describe a simple macroeconomic model suited to the analysis of a small open and partially dollarized economy, which closely resembles the Quarterly Projection Model (QPM) developed at the Central Bank of Peru (Vega et al. (2009)). This framework preserves the main blocks of the workhorse closed-economy model, namely: (i) a dynamic IS curve or aggregate demand equation, (ii) a hybrid Phillips curve or aggregate supply equation, and (iii) a Taylor-type policy rule for the short-term interest rate. In an open economy context, however, both domestic inflation and demand are affected by the exchange rate. In turn, the exchange rate is determined by a fourth equation: (iv) an uncovered interest rate parity (UIP) condition modified by a risk-premium term. Further, the terms of trade and foreign output are included among the determinants of aggregate demand.

The model differs crucially from otherwise standard small open economy models because, in addition to the aforementioned features, it includes characteristics of a partially dollarized economy[1]. In particular, as agents are able to take loans in dollars, the domestic interest rate in foreign currency enters into the aggregate demand equation. Moreover, due to the coexistence of financial dollarization (Ize and Levy Yeyati (2003)) and currency mismatches[2], balance sheet effects associated to large exchange rate swings are likely to emerge (Céspedes et al. (2004)). Thus, exchange rate depreciation can reduce the ability to repay foreign-currency denominated debt. To prevent these outcomes, central banks in several emerging economies actively intervene in the foreign exchange market, as Calvo and Reinhart (2002) and Reinhart and Reinhart (2008) show[3]. Therefore, a managed floating regime is considered in the model by allowing for backward-looking behavior in exchange rate expectations.

Whereas the structure of the model follows closely Vega et al. (2009), I apply a very different strategy to parameterize it. On one hand, those authors employ an ”eclectic” set of techniques – uniequational model estimations, calibration, use of reference values from the literature, or plain judgement based on their understanding of the economy – to determine the parameters of the model[4]. A similar procedure, in fact, has been

[1] Partial dollarization refers to the preference for holding or storing dollars (or more generally, any foreign currency) observed in many emerging economies. See, e.g., Reinhart et al. (2003).

[2] Currency mismatch is the extent to which either households, firms or the government hold assets in domestic currency and liabilities in a foreign currency.

[3] According to Morón and Winkelried (2005) and Batini et al. (2008), smoothing exchange rate movements is theoretically optimal for small open economies with partial dollarization. Faia and Monacelli (2008) and De Paoli (2009) report a similar finding in their studies of small open economies in the presence of home bias.

[4] See their working paper version – Macroeconomic Models Department (2009).

usually followed by central bank researchers when building this type of models. In contrast, I choose a formal Bayesian approach to estimate a large group of the parameters. This is the main contribution of the paper. Indeed, small macroeconomic models have rarely been estimated under Bayesian methods, and to my knowledge, this is the first estimation exercise applied to a small open and partially dollarized economy case.

The Bayesian approach allows to include *priors* about the parameters. In this way, I take advantage of pre-sample information in order to make inference about their *posterior* values – in particular, I take into account the views of the Central Bank of Peru researchers to build the distribution priors. Hence, Bayesian techniques provide a formal strategy to confront the data with the original parameterization imposed by the QPM modelers. These techniques are thus complementary to the mixed parameterization approach that central bankers have typically applied when dealing with these models (Berg et al. (2006)).

The utilization of Bayesian econometrics is also advantageous since classical methods are inappropriate when dealing with short time series – a problem that worsens in the case of emerging countries, where reliable economic data is only available for a few years. In fact, the Bayesian approach is essentially appealing as it uses the entire available information in the data, whatever the size of the sample be, in an efficient manner. Difficulties with classical estimation are further exacerbated because the model abounds in contemporaneous relations among variables, complicating the identification of parameters. In this sense, the use of priors in the estimation process is helpful as it facilitates the highly non linear computational problem faced here.

For this exercise, I employ quarterly Peruvian data over the period 2000:1 - 2008:3. Peru is a prototypical case of an emerging economy with partial dollarization. Illustratively, by late 2008, around 44 percent of broad money and 53 percent of credit to the private sector were denominated in foreign currency, reflecting high financial dollarization. To less extent, transaction dollarization and dollar-price indexation are also quite significant in the economy (Armas et al. (2007)). Additionally, Peru has a managed floating exchange rate regime. In effect, as Armas and Grippa (2006) emphasize, the Central Bank has an explicit policy of foreign exchange market interventions in order to smooth exchange rate fluctuations, pursuing to minimize the balance-sheet-effect risk[5].

The empirical findings show that while the posterior modes of some parameters are similar to their values in the original QPM, another group of coefficients should instead be updated to be more consistent with the data – although most of these adjustments would be rather moderate. Some of the most striking differences appear in the parameters associated to the forward-looking components in the aggregate demand and the Phillips curve equations, as their estimates imply that they are quantitatively more important than in the original QPM.

Moreover, the results support the existence of an upward-slopping aggregate supply curve, implying that in spite of dollarization, monetary policy has indeed short-run real effects. I find empirical support for different channels of monetary policy transmission, among them the traditional interest rate and the exchange rate channels. Interestingly

[5]An econometric study by Humala and Rodríguez (2009) supports this view. They show that for the period 1994-2007 foreign exchange intervention in Peru has been consistent with the goal of reducing excess volatility of the exchange rate, having no influence over its long-run trend.

also, in the second half of the sample (2004:1 onwards), the expectations channel has become more relevant, as implied by the estimated values of the forward-looking parameters in the aggregate demand and the Phillips curve equations. Last, in line with the above reasoning, exchange rate expectations are not purely rational but also appear to have a significant inertial component.

This paper is related to the literature on small structural macroeconomic models used by a number of central banks (see Berg et al. (2006) for a survey, and the references cited in Armas and Grippa (2006)). Likewise, it is also related to the series of papers initiated with Carabenciov et al. (2008), as part of an IMF project to estimate a small quarterly Global Projection Model (”GPM”) using Bayesian techniques. Nevertheless, although several extensions of the GPM have already been published[6], none of them has included yet partially dollarized economies in the setup, as I do in this paper.

Finally, the macroeconomic modelling of a partially dollarized economy connects this paper to a number of studies that follow a dynamic stochastic general equilibrium (DSGE) approach, including Castillo et al. (2006), Batini et al. (2008) and Castillo et al. (2009). But while that literature considers explicit microfoundations, here I propose a model that lacks them. Small macroeconomic models are indeed simpler tools than state-of-the-art DSGE models, and it is precisely because of their simplicity that they are deemed useful, especially for policymaking and forecasting purposes; whereas, in contrast, *”the use of DSGE models still remain in the periphery of the formal policy decision making process in most central banks.”* (Tovar (2008), p.1).

The remainder of the paper is organized as follows. Section 2 presents the structure of the model. Section 3 briefly describes the Bayesian approach and shows the estimation results. Section 4 presents some additional exercises, such as the estimation of the model using a shorter sample period as well as different specifications of the shock equations. I also report the estimation of the output gap based on an extension of my baseline model. Section 5 concludes.

2 The model

The model is a smaller version of the QPM developed at the Central Bank of Peru and fully described in Vega et al. (2009). It is a short-run model in the sense that variables are written in gap terms, i.e. as deviations from their equilibrium or long-run values; in turn, equilibrium variables are exogenous, independent autoregressions of order one. Furthermore, it belongs to the group of new keynesian models that based on nominal and real rigidities allow for a role of aggregate demand in output determination, and incorporate rational expectations.

The structure describes the cyclical behavior of a small open and partially dollarized economy, in a dynamic stochastic environment[7]. Partial Dollarization, as detailed below, explains the inclusion of the domestic interest rate in dollars as a determinant

[6] See, e.g., Canales-Kriljenko et al. (2009) for a model that integrates a Latin American block to the structure of the GPM.

[7] To some extent, the explicit microfoundations of this model can be found in Galí and Monacelli (2005), Castillo et al. (2006), and Castillo et al. (2009).

of aggregate demand. In addition, central bank interventions in the foreign exchange market are implicitly modeled as inertia in the determination of the exchange rate.

Similarly to the related literature, the core block of the model has four behavioral equations[8].

- **Aggregate demand**

  Equation 1 is the aggregate demand equation, where all variables (unless otherwise stated) are in gap terms. It describes the output gap (y_t) dynamics.

$$\begin{gathered} y_t = a_y y_{t-1} + a_{re} y_{t+1} + a_{rmc} (\beta_r r_{t-1} + \beta_{rs} r^{\$}_{t-1}) + \\ a_{tot} \left[\gamma tot_t + (1-\gamma)\, tot_{t-1}\right] + a_q q_t + a_{fis} fis_t + a_{y^*} y^*_{t-1} + \varepsilon^y_t \end{gathered} \tag{1}$$

  According to this expression, the output gap is a function of its past (y_{t-1}) and future developments (y_{t+1}). Long-term real domestic interest rates in home and foreign currency (r_{t-1} and $r^{\$}_{t-1}$, respectively) are also considered. They enter in first lags, and are affected by a common coefficient, a_{rmc}. However, each of these interest rates receives a different weight in the equation, since the parameters β_r (the weight on r_{t-1}) and β_{rs} (the weight on $r^{\$}_{t-1}$) are not necessarily equal. This formulation resembles a "monetary condition index". Additionally, the equation includes international relative prices, namely, the terms of trade (the price of exports relative to the price of imports, tot_t) and the real exchange rate (q_t, where an increase indicates real depreciation vis-à-vis a basket of currencies)[9]. An explicit measure of foreign demand is considered too, in the form of the lagged weighted average of trade partners' output gaps (y^*_{t-1}). Finally, a role for fiscal policy is allowed, by including the variable fis_t, defined as the first difference of a structural budget balance measure or "fiscal impulse" (a rise of this indicator suggests an expansionary fiscal policy)[10]. ε^y_t denotes a disturbance term (demand shock).

- **Aggregate supply or Phillips curve**

  The aggregate supply equation, which can also be interpreted as a Phillips curve, determines core inflation, π^c_t.

$$\pi^c_t = b_{p^*} \left(\pi^m_t - \Delta q_{ss}\right) + (1-b_{p^*}) \left[b_p \pi^c_{t-1} + (1-b_p)\, \pi_{t+1}\right] + b_y y_{t-1} + \varepsilon^\pi_t \tag{2}$$

  Following equation 2, domestic core inflation depends on foreign-sourced inflation (π^m_t, to be explained below). To guarantee the correct determination of the real exchange rate in the model, its steady state in first difference (Δq_{ss}) is subtracted from π^m_t. Inflation is also a function of a backward as well as a forward-looking component (π^c_{t-1} and π^c_{t+1}, respectively). Thus, higher values of the parameter b_p imply greater importance of the backward-looking element,

[8] See complete model in Appendix A. To alleviate notation, x_{t+1} denotes the expectation $E_t[x_{t+1}]$.

[9] The empirical evidence for Peru indicates that these two variables are not highly correlated, and thus they appear to convey differentiated information.

[10] See Moreno and Lema (2008) for methodological details on the construction of this variable.

and lower values indicate dominance of the forward-looking element. The output gap enters into the equation with one lag (y_{t-1}), and ε_t^{π} is a disturbance term (supply or cost-push shock). It is worth noting that equation 2 implies a vertical Phillips curve in the long run (i.e., the homogeneity assumption holds).

In turn, foreign-sourced or imported inflation, π_t^m, depends on its past (π_{t-1}^m), foreign CPI inflation (π_t^*) expressed in domestic currency units (thus the multiplication by Δs_t[11]), and a lagged measure of imported raw materials and intermediate goods inflation (π_{t-1}^{rm}) also expressed in domestic currency.

$$\pi_t^m = c_p \pi_{t-1}^m + c_{pf}\left(4\Delta s_t + \pi_t^*\right) + \left(1 - c_p - c_{pf}\right)\left(4\Delta s_{t-1} + \pi_{t-1}^{rm}\right) + \varepsilon_t^m \tag{3}$$

Importantly, the contemporaneous exchange rate pass-through is represented by the product of the coefficients b_{p^*} and c_{pf}, multiplied in turn by 4 to express it in annual terms.

- **Monetary (interest-rate) policy rule**

  Equation 4 describes a Taylor-type rule that defines the short-term interest rate (i_t), which is the monetary policy instrument in the model. Inflation and inflation expectations are anchored by this rule.

$$i_t = f_i\, i_{t-1} + (1 - f_i)\left[\bar{\imath}_t + f_p\left(\pi_{4,t+4}^c - \bar{\pi}\right) + f_y y_t\right] + \varepsilon_t^i \tag{4}$$

  The rule is inertial in the sense that the interest rate depends on its first lag (i_{t-1}). In addition, it is a function of the deviation of expected year-on-year inflation (4 quarters ahead), $\pi_{4,t+4}^c$, from inflation target, $\bar{\pi}$; and the current output gap, y_t. In the long run, when both output gap and inflation deviation from its target are zero, the interest rate converges to its neutral or equilibrium level, $\bar{\imath}_t$. The disturbance term ε_t^i represents a monetary policy shock.

- **Modified uncovered interest rate parity**

  The nominal exchange rate is defined by an interest rate parity condition, as shown in equation 5.

$$4\left(s_{t+1}^e - s_t\right) = i_t - i_t^* - rp_t + \varepsilon_t^s \tag{5}$$

  The expected quarterly exchange rate variation ($s_{t+1}^e - s_t$), multiplied by 4 to transform it into annual terms, is linked to the differential between the short-term interest rate in domestic currency, i_t, and its foreign currency (i.e., dollar-denominated) equivalent, i_t^*. This parity condition is modified by introducing a risk- premium term, rp_t. Finally, the disturbance term is denoted by ε_t^s.

  Exchange rate expectations (s_{t+1}^e) are determined as the weighted average of a backward-looking (s_{t-1}) and a forward-looking component (s_{t+1}), as in equation 6.

$$s_{t+1}^e = \rho s_{t-1} + (1 - \rho) s_{t+1} + \varepsilon_t^e \tag{6}$$

[11]Moreover, the multiplication by 4 allows to transform the quarterly rate of change of the exchange rate into annual terms.

Then, the parameter ρ (bounded between 0 and 1) implicitly measures the extent to which the exchange rate is smoothed by foreign exchange market interventions. In particular, the higher ρ is, the larger is the degree of exchange rate smoothing, arguably reflecting substantial central bank interventions in the foreign exchange market. This modeling approach is related to the ”portfolio balance channel” of foreign exchange interventions (Henderson (1979), Henderson (1984), Dornbusch (1980), Dornbusch (1984)), summarized as follows by Reinhart and Reinhart (2008): *”If domestic and foreign assets are imperfect substitutes in investors' portfolios, then changes in relative asset shares could affect the foreign exchange risk premium, blunting pressures on the exchange rate to change”* (op. cit., p.12) [12].

3 Estimation

Small macroeconomic models have typically been parameterized following an eclectic approach (see Berg et al. (2006), although a notable exception is the IMF project called ”Global Projection Model” initiated with Carabenciov et al. (2008)). In contrast, I use Bayesian methods to estimate a large group of parameters[13]. As mentioned before, these procedures allow to use efficiently the information existing in the data and learn directly from it. Moreover, the Bayesian approach permits to take advantage of pre-sample information, represented in this case by the views of the Central Bank of Peru researchers about the QPM parameters. Thus, I take these views into account in order to build priors for some parameters. Working with priors is particularly advantageous when dealing with short-length data because classical methods would expectedly fail under these conditions.

The advantages of Bayesian techniques are accentuated as the model abounds in contemporaneous relations among variables, complicating even more the identification of parameters under classical approaches. Finally, the number of stochastic shocks can be greater than the number of observable variables, unlike classical estimation methods (e.g., maximum likelihood), which is particularly useful in the case of forecasting models.

It is fair to admit that in spite of its advantages, Bayesian inference has some weaknesses. However, as Fernández-Villaverde (2009) states, its main limitations appear when dealing with non-parametric and semiparametric approaches, for which classical procedures are preferable. Conversely, and in line with the aforementioned arguments, the profession has increasingly chosen to use Bayesian methods for econometric problems such as the estimation of DSGE models, like I also do in this paper.

In the rest of this section I describe the data and the main results of the estimation.

[12] Admittedly, there is no conclusive evidence on the validity of this theoretical argument; however, Schadler et al. (1993) report that for a sample of developing countries there is some scope for sterilized intervention policies in the short run. For further empirical evidence, see Domínguez and Frankel (1993).

[13] Fernández-Villaverde (2009) provides an excellent insight on Bayesian econometrics and its application to the estimation of general equilibrium models.

3.1 Data

The model is estimated with Peruvian data over the sample period 2000:1 to 2008:3. It has 14 observable variables. These are the following: output gap, real exchange rate gap, terms of trade gap, foreign output gap, fiscal impulse, core inflation, total inflation, non-core inflation, wholesale imported inflation, imported raw materials and intermediate goods inflation, foreign CPI inflation, nominal exchange rate (quarterly rate of change), interbank interest rate, and 3-month US dollar Libor rate. It is relevant to state that quarterly rates of inflation were all transformed into annual terms. The source of the data is mainly the Central Bank of Peru (see further description in Appendix B).

True, some of those variables are not strictly observable, particularly all the gap variables and the fiscal impulse. Nevertheless, these have been treated as such in the estimation exercise to exploit their informational content[14]. Gap variables were computed with the Hodrick-Prescott filter, where I added extra observations to avoid beginning and end-of-sample problems.

3.2 Parameters estimates

The model has 28 parameters to estimate with Bayesian techniques. The QPM modelers' judgment provides a valuable criterion to set bounds on the domains of many priors (either on one or both sides). This helps to alleviate the computational problem and explains why Beta and, less frequently, Gamma prior distributions are used in most cases. Additionally, Inverse Gamma distributions are used as priors of the standard deviations of the structural shocks to guarantee that they are strictly positive.

In some cases the mean priors are close to the values used in the parameterization of the Central Bank of Peru's QPM, as reported in Macroeconomic Models Department (2009)[15]. However, in many other cases the mean priors reflect my own judgement, particularly for those parameters lacking substantial empirical study[16]. Also, by setting loose prior distributions (i.e., relatively high standard deviations), data has a large role in determining the posterior distributions. On the other hand, some parameters are kept fixed in the exercise as they proved to be too difficult to identify in the data (see table 1), although most of them are not part of the core equations.

Posterior estimates are obtained with the Metropolis-Hastings algorithm, where the variance was tuned to have an acceptance rate of roughly 20-30 percent. The results are based on 50,000 draws from the posterior distribution. This is indeed a relatively low number, but there was an exhaustive search for good initial parameters values. Thus, the estimates are stable and their convergence was checked using all usual tests.

The estimation results are reported in tables 2 - 5 and 7 (prior distribution, prior mean and standard deviation, posterior mode, and the 5 and 95 percentile values of the

[14]An alternative procedure would be using these observable variables in levels and estimating their equilibrium levels as part of the estimation process. This is the route adopted, for instance, by Carabenciov et al. (2008) and Canales-Kriljenko et al. (2009).

[15]See appendix A.6 therein. It is worth mentioning, however, that some parameters have been updated by the QPM modelers after the publication of that paper.

[16]For instance, most parameters in the aggregate demand equation, the parameter in the exchange rate expectations equation, among others.

posterior distribution) and in figures 1 - 4 (prior and posterior distributions in graphs). The results regarding some parameters of second-order importance are not reported but are available upon request.

In the aggregate demand equation (table 2, figure 1), the posterior mode coefficient on the inertial component is larger than on the forward-looking component. Notably, however, the weight on the lead output gap is greater than zero, in contrast to the QPM version of Vega et al. (2009) where this term was neglected. Also, given the values assumed for β_r and β_{rs}, as well as the posterior mode coefficient a_{rmc}, the weight on the real interest rate gap in domestic currency is roughly 8 percent, whereas the weight on its foreign currency equivalent is 4 percent. As for the other foreign-determined variables, only the posterior variance of the terms of trade gap coefficient is considerably tighter than its prior, implying that data conveys meaningful information about this parameter, but not about the coefficients associated to the foreign output gap and the real exchange rate gap. In any case, the estimated modes for these three coefficients lie in a range between 0.04 and 0.08[17]. Finally, the estimated mode on the fiscal variable weight is rather high (0.25).

Table 3 and figure 2 show the results of the Phillips equation. Here again, as in the aggregate demand equation, the posterior coefficient on the backward-looking component is greater than on the forward-looking component. In particular, given the estimated mode values of b_{p^*} and b_p, these weights are 0.65 and 0.30, respectively[18]. Furthermore, the posterior coefficient on the output gap is 0.10, lower than the prior. Foreign-sourced (or "imported") inflation is also relevant to determine core inflation dynamics, as implied by the mode of b_{p^*}. Thus, for instance, the estimate of the contemporaneous exchange rate pass-through coefficient is 12 percent. This figure is in line with previous empirical evidence, as surveyed by Rossini and Vega (2007).

In addition, the posterior coefficients of the monetary policy rule are consistent with usual international evidence (table 4, figure 3): interest rate smoothing is far from trivial, whereas the response to inflation is higher than the coefficient on the output gap[19]. However, since the posterior and prior variances of the output gap coefficient are almost the same, the data reveals to be unhelpful to identify this particular parameter.

Table 5 and figure 4 show that both lagged and lead terms are relevant to explain the expected exchange rate, where the posterior mode coefficient is higher on the backward-looking component. This may reflect the role of central bank interventions in smoothing exchange rate volatility.

Overall, these findings provide a formal benchmark to contrast the views of practitioners and policymakers at the Central Bank of Peru, as exposed in the original QPM

[17]Arguably, if the coefficient on the real exchange rate gap were negative, currency depreciations would have contractionary effects, in line with the existence of a balance sheet effect. My baseline estimation rules out such a result by imposing a Gamma prior distribution restricted on positive values for that coefficient. However, in an alternative estimation exercise I use a Normal prior distribution centered on a mean value close to zero, and the posterior distribution still falls in a region of strictly positive values.

[18]Some simple calculations based on Macroeconomic Models Department (2009) yield that the corresponding figures in the original QPM are 0.85 and 0.07, respectively.

[19]In an alternative version of the model, I estimate the same rule including the (quarterly rate of change of the) exchange rate as an additional argument. The posterior mode is 0.58, and the 5 and 95 percentile values of its distribution are 0.33 and 0.80, respectively. In this alternative estimation, the rest of parameters estimates remain practically unchanged with respect to the baseline results.

parameterization. This is an important contribution in itself, considering that previous empirical evidence was too scarce to perform such a contrast. In this regard, conclusions are mixed (see table 6). On one hand, the posteriors of some parameters are impressively well aligned with those views, revealing that central bankers developed a good judgement to fix a number of coefficients even in the absence of a formal unique econometric strategy. On the other hand, though, Bayesian methods suggest that several QPM parameters should be modified to be more consistent with the data. These notably include the weights on the forward-looking components in both the aggregate demand and supply equations (a_{re} and $1 - b_p$, respectively), as well as other coefficients in the aggregate demand equation (e.g., a_{tot} and a_{fis}), the slope of the aggregate supply curve (b_y), the response to inflation gap in the monetary policy rule (f_p), and the parameter in the exchange rate expectations equation (ρ). Nevertheless, most of these adjustments would be rather moderate.

I further hypothesize that the sparsity of the data explains why posterior distributions are equal to the priors for a reduced group of parameters (specifically, a_q, a_{y*}, and f_y); that is, because of the limited length of the data, their inference appears to be too dependent on those priors. Importantly as well, the results suggest that despite high dollarization, monetary policy operates under different transmission mechanisms, such as the traditional interest rate, the exchange rate, and the expectations channels.

Finally, table 7 indicates the results for the parameters of the main structural shocks (those related to the core-block equations). The shocks have some degree of inertia, especially the aggregate demand and the UIP shocks, in light of the posterior autoregressive coefficients. Moreover, the standard deviations of the shocks in the aggregate demand and the Phillips curve equations are roughly of equal size, whereas unsurprisingly perhaps, that in the UIP equation is significantly larger. The standard deviation of the shock in the monetary policy rule is quite large, but this result is attributable to the high volatility of the short-term interest rate in the first two years of the sample period.

3.3 Second moments

A number of selected second moments have been computed (table 8). This is helpful in order to address the ability of the model to reproduce descriptive statistics, or more broadly, stylized facts in the data. In general, the performance of the model is satisfactory. In terms of standard deviations, the model underpredicts the volatility of output gap (and short-term interest rate, to less extent); conversely, it generates relative high volatility for core inflation as well as for the exchange rate. Also, as implied by the autocorrelation analysis, the model does a good job at matching the persistence of the same group of variables.

3.4 Impulse response functions

The model shows reasonable impulse response functions, as depicted in figures 5 - 8. These figures report 90 percent Bayesian confidence intervals for each of these functions.

A transitory shock to the short-term policy interest rate (figure 5) has the expected effect of reducing output gap. It also appreciates domestic currency, and subsequently real exchange rate appreciation further reduces output. Both the fall in demand and the direct exchange rate effect put downward pressure on inflation. The greatest impact on output is observed three quarters after the shock, whereas inflation reaches its lowest point after four quarters.

A positive aggregate demand shock (figure 6) leads to an increase in inflation. In the wake of these events, the interest rate rises, causing a decline in the exchange rate. The latter outcomes cause a gradual stabilization of output and inflation.

A shock to the disturbance term in the Phillips curve equation (figure 7) generates a stabilizing response from the policy interest rate. In turn, the exchange rate falls and output gap decreases. Accordingly, the rate of inflation starts to decline.

Finally, a negative exchange rate shock (i.e., nominal appreciation; figure 8) leads to falls in inflation and output, and thereby to a reduction in the policy interest rate.

4 Additional results

In this section I briefly present three additional exercises. First, I compare the parameters estimates of the full sample to the results based on a shorter sample period. Then I use a different version of the model, where the structural shocks are specified as pure *i.i.d.* processes, and estimate it both for the full and the sub sample periods. As a final exercise, I extend the model to allow for the estimation of the output gap.

4.1 Shorter sample period

The baseline estimation relies upon the sample period 2000:1 - 2008:3. Using a shorter sample allows to check whether the parameters have changed in the most recent years. This outcome is likely as a result of the gradual consolidation of the Inflation Targeting regime (adopted by the Peruvian authorities in 2002), and the fact that foreign exchange intervention policies have arguably softened in recent years. Besides, not only Peru but several emerging countries experienced a phase of strong economic growth by the mid-2000s (at least until the Subprime crisis worsened in late 2008), which may be related to some structural changes in these economies.

Table 9 compares baseline parameters estimates to the results for the sub-sample 2004:1 - 2008:3. Many parameters remain quite the same, but there are some noteworthy differences. In the Phillips curve equation, the posterior mode coefficient on the backward-looking component (b_p) is clearly lower in the shorter sample. This finding indicates that inflation inertia has decreased, reinforcing the expectations channel – and implying that the required policy interest rate adjustment after a cost-push shock has become smaller. The estimates suggest that, for the short sample, 95 percent of a one-percent shock to the inflation rate wanes within 4 quarters, whereas the same deviation only disappears after 7 quarters according to the full sample estimation. The expectations channel is also reinforced by the larger coefficient on the forward-looking component of the output gap equation (a_{re}).

Additionally, the Phillips curve slope (b_y) is larger in the shorter sample. Considering that during this period the Peruvian economy experienced a boom, that result is consistent with a convex shape of the aggregate supply curve, which implies precisely that demand shocks have greater inflationary effects during boom phases[20].

In the policy interest rate equation, parameter inertia (f_i) is larger whereas the weight on expected inflation gap (f_p) decreases in the shorter sample period. Notice also that the standard deviation of the shock in the interest rate equation ($SD\ \varepsilon_t^i$) declines sharply. This is hardly surprising because the interbank interest rate have indeed become less volatile since the adoption of the Inflation Targeting regime in 2002.

Another interesting difference is found for the coefficient on the backward-component of exchange rate expectations, ρ, which is smaller in the short sample period, implying that forward-looking expectations have gained more weight (possibly as a result of changes in central bank intervention policies). This reinforces the exchange rate channel as the nominal exchange rate becomes more sensitive to current and expected interest rate differentials.

4.2 Alternative shock equations

In the original QPM (Vega et al. (2009)), the structural shocks (or disturbance terms) are specified as pure *i.i.d.* processes. Thus, to allow for a fairer comparison, I report an additional exercise where the model includes *i.i.d.* shocks instead of autoregressive processes. Table 10 sets out the results both for the full and the shorter sample periods.

Overall, the results are similar to the baseline model, although there are some exceptions. For instance, the inertia parameter in the output gap equation (a_y) is larger under the model with *i.i.d.* shocks. In the same equation, the posterior coefficient of the real interest rates (a_{rmc}) is appreciably lower. For the shorter sample period, comparing again to the baseline results, core inflation becomes even less persistent given the smaller estimate of b_p, and the weight on the backward-looking component of exchange rate expectations (ρ) also decreases.

4.3 Output gap estimation

In a final exercise, I have applied the Kalman smoother to an extended version of the baseline model in order to compute a model-consistent output gap. The main new feature of the extended model consists in the inclusion of an autoregressive process for the growth rate of potential output in annual terms ($\Delta\overline{Y}$) that converges to a certain steady state value, $\Delta\overline{Y}_{ss}$ (equation 7).

$$\Delta\overline{Y}_t = \lambda_y \Delta\overline{Y}_{t-1} + (1-\lambda_y)\Delta\overline{Y}_{ss} + \varepsilon_t^{\overline{Y}} \tag{7}$$

In addition, following Carabenciov et al. (2008), it allows for cross correlation between the error terms of the aforementioned growth rate of potential output equation and the output gap equation (i.e., $corr(\varepsilon_t^{\overline{Y}}, \varepsilon_t^y) > 0$). I also introduce an equation to define the quarterly growth rate of output in annual terms, ΔY (see equation 8 below),

[20]Bigio and Salas (2006) draw evidence on a convex aggregate supply curve in Peru, from a non-linear VAR analysis.

and subsequently include this variable in the dataset replacing the Hodrick-Prescott output gap series[21].

$$\Delta Y_t = \Delta \overline{Y}_t + 4(y_t - y_{t-1}) \tag{8}$$

The estimate of the output gap is presented in figure 9[22]. Throughout the sample, its evolution has two clearly defined phases. On the first one, the gap is persistently negative, implying downward pressures on inflation. But starting in 2006:3, the gap becomes positive and increases very fast, reaching a peak in 2008:1. Towards the end of the sample, output remains above its potential level, but the gap begins to decline.

The graph in figure 9 also compares the model-consistent output gap with the HP filter-based estimate. Despite showing similar patterns, there are important differences. On the first part of the sample, output is far below potential according to the model-consistent gap, unlike the HP output gap which even closes during some quarters in 2002-03. Furthermore, the HP gap exhibits more inertia. Thus, for instance, around 2006-07, this estimate takes 3 more quarters than the model-based gap to become positive. Then, by the end of the sample, the HP gap remains fairly stable, whereas the model estimate declines more clearly.

5 Conclusions

I have presented a small macroeconomic model in the tradition of the new keynesian synthesis. Because of their simplicity, models of this type are widely used at central banks and other economic policy institutions. The model described in this paper – an adapted version of the Central Bank of Peru's QPM – is of particular relevance for emerging open economies with partial dollarization.

In the context of the existing literature on small macro models for partially dollarized economies, a novel contribution here is that the key parameters have been estimated with formal Bayesian methods, using data from Peru. The estimation approach is conclusive about which prior views held by practitioners at the Central Bank of Peru are consistent with the data, as well as which are not and by how much. In particular, for instance, the forward-looking expectation terms in the aggregate demand and the Phillips curve equations are found to be quantitatively more relevant than in the original QPM.

Importantly also, the results imply that monetary policy has short-run real effects in spite of dollarization. I find empirical support for a number of channels of monetary policy transmission, such as the traditional interest rate, the exchange rate, and the expectations channels. Moreover, in light of usual criteria (impulse-response functions and theoretical moments), the model is reasonably well validated[23].

[21] The extended model considers the *i.i.d.* shocks specification. The rest of particular features of this model are less important, but can be requested to the author.

[22] The graph corresponds to an estimation where the sample period was extended until 2009:4. However, for the sake of consistence with the rest of the paper, I only show the results until 2008:3. It may be worth adding that extending the sample until 2009:4 did not bring about any significant changes in the estimated posterior modes with regard to the baseline estimation.

[23] I have not reported any forecasting assessment. However, some work in this direction has recently been

In addition to the estimation of structural parameters, the simulation techniques associated to Bayesian econometrics allow for other useful applications. One of them is the extraction of latent variables, such as the output gap, as I have briefly showed. But in fact, it is possible to extend the model even further to estimate other unobserved variables.

Another appealing extension would consist in computing model-based historical decompositions. Finally, the identification of a few parameters whose posteriors were found to be equal to their priors in this analysis (particulary, the coefficients on the real exchange rate and foreign output gap in the aggregate demand equation, and the weight on the output gap in the policy rule) also deserves more study. In this sense, it may be interesting to add new features to the model (e.g., financial-real linkages) and evaluate its potential improvement. I leave these issues for future research.

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made at the Central Bank of Peru. In particular, when several of the estimated parameters reported in this paper are included in the Central Bank's QPM, the resulting intra-sample root mean squared errors on both the output gap and core inflation decline considerably. Gains in forecasting ability are higher in the case of the output gap projection.

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A The complete model

In addition to the core block (equations 1 - 6), the model consists of the following equations:

Definitions

Long-term real domestic interest rate in home currency (Gap)

$r_t = rr_t - \overline{rr}_t$

Long-term real domestic interest rate in home currency (Level)

$rr_t = i_{4,t} - \pi^c_{4,t+4}$

Long-term nominal domestic interest rate in home currency - Term structure relationship with liquidity premium

$i_{4,t} = 0.25(i_t + i_{t+1} + i_{t+2} + i_{t+3}) + \varepsilon^{lp}_t$

Long-term real domestic interest rate in foreign currency (Gap)

$r^{\$}_t = rr^{\$}_t - \overline{rr}^{\$}_t$

Long-term real domestic interest rate in foreign currency (Level)

$rr^{\$}_t = i^*_{4,t} + (s^e_{t+4} - s_t) - \pi^c_{4,t+4}$

Long-term nominal interest rate in foreign currency - Term structure relationship with liquidity premium

$i^*_{4,t} = 0.25(i^*_t + i^*_{t+1} + i^*_{t+2} + i^*_{t+3}) + \varepsilon^{lpf}_t$

Year-on-year core inflation

$\pi^c_{4,t} = 0.25(\pi^c_t + \pi^c_{t-1} + \pi^c_{t-2} + \pi^c_{t-3})$

Multilateral real exchange rate (Gap)

$q_t = q_{t-1} + (s_t - s_{t-1}) + 0.25(\pi^*_t - \pi_t - \Delta\overline{q}_t)$

Total inflation

$\pi_t = \chi \pi^c_t + (1-\chi)\,\pi^{nc}_t$

Expectations

One-year-ahead exchange rate expectations

$s^e_{t+4} = \varpi s_{t-1} + (1-\varpi) s_{t+4} + \varepsilon^{e4}_t$

Exogenous variables

Terms of trade (Gap)

$tot_t = \lambda_{tot} tot_{t-1} + \varepsilon^{tot}_t$

Fiscal impulse

$fis_t = \lambda_{fis}\, fis_{t-1} + \varepsilon^{fis}_t$

Foreign output gap

$y^*_t = \lambda_{ys}\, y^*_{t-1} + \varepsilon^{ys}_t$

Short-term international interest rate

$i^*_t = \lambda_{is} i^*_{t-1} + (1-\lambda_{is})\,\bar{i}^*_{ss} + \varepsilon^{is}_t$

Risk premium

$rp_t = \lambda_{rp}\, rp_{t-1} + (1-\lambda_{rp}) rp_{ss}$

Neutral short-term interest rate

$\bar{i}_t = \lambda_i \bar{i}_{t-1} + (1-\lambda_i)\,\bar{i}_{ss}$

Long-term real domestic interest rate in home currency of equilibrium

$\overline{rr}_t = \lambda_{rr}\, \overline{rr}_{t-1} + (1-\lambda_{rr})\,\overline{rr}_{ss}$

Long-term real domestic interest rate in foreign currency of equilibrium

$\overline{rr}_t^{\$} = \lambda_{rrs}\,\overline{rr}_{t-1}^{\$} + (1-\lambda_{rrs})\,\overline{rr}_{ss}^{\$}$

Real exchange rate of equilibrium (quarterly rate of change)

$\Delta\overline{q}_t = \lambda_q\,\Delta\overline{q}_t + (1-\lambda_q)\,\Delta\overline{q}_{ss}$

Non-core inflation

$\pi_t^{nc} = \lambda_{nc}\,\pi_{t-1}^{nc} + (1-\lambda_{nc})\overline{\pi} + \varepsilon_t^{nc}$

Imported raw materials and intermediate goods inflation

$\pi_t^{rm} = \lambda_{rm}\,\pi_{t-1}^{rm} + (1-\lambda_{rm})\pi_{ss}^{*} + \varepsilon_t^{rm}$

Foreign CPI inflation

$\pi_t^{*} = \lambda_{\pi s}\,\pi_{t-1}^{*} + (1-\lambda_{\pi s})\pi_{ss}^{*} + \varepsilon_t^{\pi s}$

Shocks

Structural shocks (or disturbance terms), ε_t^j, are in every case of the following form:

$\varepsilon_t^j = \rho_j \varepsilon_{t-1}^j + \xi$

where j denotes a specific variable, and ξ is an i.i.d. shock

Measurement errors (μ_t)

Output gap

$y_t^{DATA} = y_t + \mu_{y,t}$

Core inflation

$\pi_t^{c,DATA} = \pi_t^c + \mu_{\pi,t}$

B Data

Output gap	Gross Domestic Product (SA, Mills. 1994 Nuevos Soles). Gap computed with HP filter (applied on log transformation).
Real exchange rate gap	Multilateral real exchange rate (Dec. 2001=100, quarterly average). Increase is depreciation. Gap computed with HP filter.
Terms of trade gap	Price of exports relative to price of imports (1994=100, quart. avg.). Gap computed with HP filter.
Foreign output gap	GDP (SA, 2000=100): USA, Canada, Chile, China, Germany, Japan, Switzerland. Sources: IFS and WEO databases. Gaps computed with HP filter. Weighted average (weights correspond to participation in foreign trade of year 2006; aggregate participation amounts to 61 percent of total trade.)
Fiscal impulse	First difference of a structural budget balance measure (see Moreno and Lema (2008)).
Core inflation	CPI core inflation (Dec. 2001=100, quarterly average).
Total inflation	CPI inflation (Dec. 2001=100, quarterly average).
Non-core inflation	CPI non-core inflation (Dec. 2001=100, quarterly average).
Wholesale imported inflation	WPI imported inflation (1994=100, quarterly average). Source: National Institute of Statistics.
Imported raw materials and intermediate goods inflation	Includes fuels and raw materials for agriculture and industry (1994=100, quarterly average).
Foreign inflation	Foreign CPI inflation (1994=100, quarterly average). Considers 20 trade partners.
Nominal exchange rate	Quarterly average. Increase is depreciation.
Interbank interest rate	Quarterly average.
3-month US dollar Libor rate	Quarterly average. Source: Bloomberg.

Table 1: Calibrated parameters and steady state values

Parameters	**Values**
β_r	0.30
β_{rs}	0.15
γ	0.48
χ	0.61
ϖ	0.80
λ_{tot}	0.80
λ_{fis}	0.50
λ_{ys}	0.90
λ_{is}	0.90
λ_{rp}	0.70
λ_i	0.50
λ_{rr}	0.95
λ_{rrs}	0.95
λ_q	0.90
λ_{nc}	0.40
λ_{rm}	0.70
$\lambda_{\pi s}$	0.25
ρ_{lp}	0.95
ρ_{lpf}	0.95
ρ_e	0.30
ρ_{e4}	0.60
ρ_{tot}	0.40
ρ_{fis}	0.00
ρ_{ys}	0.00
ρ_{is}	0.60
ρ_{nc}	0.00
ρ_{rm}	0.00
$\rho_{\pi s}$	0.00
$SD\ \ \varepsilon_t^{lp}$	0.90
$SD\ \ \varepsilon_t^{lpf}$	0.60
$SD\ \ \varepsilon_t^{e}$	0.50
$SD\ \ \varepsilon_t^{e4}$	0.60
$SD\ \ \varepsilon_t^{is}$	0.40
$SD\ \ \varepsilon_t^{nc}$	5.00
$SD\ \ \varepsilon_t^{rm}$	5.00
$SD\ \ \varepsilon_t^{\pi s}$	6.00
$\overline{\pi}$	2.00
$\bar{i}_{ss}^{*}(=\overline{rr}_{ss}+\overline{\pi})$	4.50
rp_{ss}	1.00
$\bar{i}_{ss}(=\overline{rr}_{ss}^{\$}+\pi_{ss}^{*})$	5.50
$\overline{rr}_{ss}(=\overline{rr}_{ss}^{\$}+rp_{ss})$	3.50

Continued on next page

Table 1: (Continued)

Parameters	**Values**
$\overline{rr}^{\$}_{ss}$	2.50
$\Delta\overline{q}_{ss}$	0.00
π^{*}_{ss}	2.00

Table 2: Prior and posterior distributions: Aggregate demand equation

$$y_t = a_y y_{t-1} + a_{re} y_{t+1} + a_{rmc} (\beta_r r_{t-1} + \beta_{rs} r^{\$}_{t-1}) +$$
$$a_{tot} [\gamma tot_t + (1-\gamma) tot_{t-1}] + a_q q_t + a_{fis} fis_t + a_{y^*} y^*_{t-1} + \varepsilon^y_t$$

	Prior			Posterior	
	Distrib.	Mean	Std. Dev.	Mode	90% interval
a_y	Beta	0.55	0.15	0.49	0.28 / 0.61
a_{re}	Beta	0.40	0.15	0.16	0.10 / 0.28
a_{rmc}	Beta	0.40	0.15	0.28	0.12 / 0.52
a_q	Gamma	0.06	0.025	0.06	0.03 / 0.10
a_{tot}	Beta	0.10	0.05	0.04	0.02 / 0.07
a_{y*}	Gamma	0.10	0.05	0.08	0.02 / 0.18
a_{fis}	Beta	0.40	0.15	0.25	0.13 / 0.37

Table 3: Prior and posterior distributions: Phillips curve equation

$$\pi^c_t = b_{p^*} (\pi^m_t - \Delta q_{ss}) + (1-b_{p^*}) [b_p \pi^c_{t-1} + (1-b_p) \pi_{t+1}] + b_y y_{t-1} + \varepsilon^\pi_t$$
$$\pi^m_t = c_p \pi^m_{t-1} + c_{pf} (4\Delta s_t + \pi^*_t) + \left(1 - c_p - c_{pf}\right) \left(4\Delta s_{t-1} + \pi^{rm}_{t-1}\right) + \varepsilon^m_t$$

	Prior			Posterior	
	Distrib.	Mean	Std. Dev.	Mode	90% interval
b_{p*}	Beta	0.11	0.05	0.05	0.03 / 0.09
b_p	Beta	0.50	0.20	0.68	0.56 / 0.91
b_y	Beta	0.20	0.08	0.10	0.05 / 0.20
c_p	Beta	0.30	0.10	0.31	0.21 / 0.41
c_{pf}	Beta	0.65	0.15	0.58	0.47 / 0.68

Table 4: Prior and posterior distributions: Monetary policy equation

$$i_t = f_i\, i_{t-1} + (1 - f_i)\, \left[\bar{\imath}_t + f_p\, (\pi^c_{4,t+4} - \bar{\pi}) + f_y y_t\right] + \varepsilon^i_t$$

	Prior			Posterior	
	Distrib.	Mean	Std. Dev.	Mode	90% interval
f_i	Beta	0.70	0.10	0.66	0.53 / 0.75
f_p	Beta	1.50	0.40	1.93	1.34 / 2.43
f_y	Beta	0.50	0.10	0.51	0.35 / 0.68

Table 5: Prior and posterior distributions: Exchange rate expectations equation

$$s^e_{t+1} = \rho s_{t-1} + (1 - \rho) s_{t+1} + \varepsilon^e_t$$

	Prior			Posterior	
	Distrib.	Mean	Std. Dev.	Mode	90% interval
ρ	Beta	0.60	0.12	0.66	0.54 / 0.79

Table 6: Parameters values: Original QPM (Vega et al. (2009)) vs. Bayesian estimation

Parameters	QPM values	Estimated values
a_y	0.50	0.49
a_{re}	0.00	0.16
a_{rmc}	0.26	0.28
a_q	0.02	0.06
a_{tot}	0.09	0.04
a_{y*}	0.01	0.08
a_{fis}	0.15	0.25
b_{p*}	0.08	0.05
b_p	0.92	0.68
b_y	0.20	0.10
f_i	0.70	0.66
f_p	1.50	1.93
f_y	0.50	0.51
ρ	0.50	0.66

Table 7: Prior and posterior distributions: Selected structural shocks parameters (autoregressive coefficients and standard deviations)

	Prior			Posterior	
	Distrib.	Mean	Std. Dev.	Mode	90% interval
ρ_y	Beta	0.50	0.10	0.47	0.33 / 0.65
ρ_π	Beta	0.15	0.05	0.12	0.06 / 0.21
ρ_i	Beta	0.15	0.05	0.12	0.07 / 0.21
ρ_s	Beta	0.30	0.10	0.39	0.23 / 0.55
$SD\ \varepsilon_t^y$	Invg	0.65	0.15	0.49	0.41 / 0.64
$SD\ \varepsilon_t^\pi$	Invg	0.75	0.25	0.52	0.44 / 0.73
$SD\ \varepsilon_t^i$	Invg	4.20	0.60	4.23	3.40 / 5.38
$SD\ \varepsilon_t^s$	Invg	1.60	0.30	1.60	1.38 / 1.94

Table 8: Second moments

	Data	Model
Standard Deviation		
Output gap (y_t)	2.71	1.95
Core inflation (π_t^c)	1.43	2.25
Short-term interest rate (i_t)	3.53	3.18
Exchange rate variation (Δs_t)	1.80	2.40
Autocorrelation		
Output gap (y_t)	0.95	0.88
Core inflation (π_t^c)	0.87	0.89
Short-term interest rate (i_t)	0.88	0.85
Exchange rate variation (Δs_t)	0.24	0.43

Table 9: Posterior distributions: Full sample (2000Q1-2008Q3) and sub-sample (2004Q1-2008Q3)

	Full sample		Sub-sample	
	Mode	90% interval	Mode	90% interval
b_{p*}	0.05	0.03 / 0.09	0.04	0.02 / 0.08
b_p	0.68	0.56 / 0.91	0.51	0.37 / 0.80
b_y	0.10	0.05 / 0.20	0.17	0.08 / 0.28
c_p	0.31	0.21 / 0.41	0.30	0.18 / 0.40
c_{pf}	0.58	0.47 / 0.68	0.60	0.49 / 0.71
a_y	0.49	0.28 / 0.61	0.45	0.22 / 0.63
a_{re}	0.16	0.10 / 0.28	0.18	0.10 / 0.32
a_{rmc}	0.28	0.12 / 0.52	0.28	0.10 / 0.51
a_q	0.06	0.03 / 0.10	0.06	0.03 / 0.06
a_{tot}	0.04	0.02 / 0.07	0.04	0.02 / 0.11
a_{y*}	0.08	0.02 / 0.18	0.08	0.02 / 0.17
a_{fis}	0.25	0.13 / 0.37	0.37	0.21 / 0.50
f_i	0.66	0.53 / 0.75	0.85	0.76 / 0.91
f_p	1.93	1.34 / 2.43	1.62	1.00 / 2.18
f_y	0.51	0.35 / 0.68	0.52	0.35 / 0.68
ρ	0.66	0.54 / 0.79	0.54	0.41 / 0.68
ρ_y	0.47	0.33 / 0.65	0.47	0.33 / 0.65
ρ_π	0.12	0.06 / 0.21	0.12	0.07 / 0.22
ρ_i	0.12	0.07 / 0.21	0.16	0.08 / 0.26
ρ_s	0.39	0.23 / 0.55	0.32	0.18 / 0.47
$SD\ \ \varepsilon_t^y$	0.49	0.41 / 0.64	0.48	0.40 / 0.66
$SD\ \ \varepsilon_t^\pi$	0.52	0.44 / 0.73	0.53	0.44 / 0.79
$SD\ \ \varepsilon_t^i$	1.60	1.38 / 1.94	0.33	0.27 / 0.45
$SD\ \ \varepsilon_t^s$	4.23	3.40 / 5.38	3.81	3.08 / 4.91

Table 10: Posterior distributions in alternative model with *i.i.d.* shocks: Full sample (2000Q1-2008Q3) and sub-sample (2004Q1-2008Q3)

	Full sample		Sub-sample	
	Mode	90% interval	Mode	90% interval
b_{p*}	0.04	0.02 / 0.08	0.04	0.02 / 0.08
b_p	0.62	0.52 / 0.87	0.35	0.22 / 0.56
b_y	0.09	0.05 / 0.17	0.20	0.12 / 0.30
c_p	0.31	0.21 / 0.41	0.31	0.19 / 0.41
c_{pf}	0.59	0.49 / 0.69	0.62	0.51 / 0.73
a_y	0.60	0.45 / 0.68	0.67	0.49 / 0.79
a_{re}	0.16	0.10 / 0.24	0.26	0.10 / 0.32
a_{rmc}	0.21	0.11 / 0.39	0.16	0.06 / 0.31
a_q	0.04	0.02 / 0.08	0.09	0.05 / 0.13
a_{tot}	0.02	0.01 / 0.04	0.01	0.01 / 0.03
a_{y*}	0.07	0.03 / 0.17	0.07	0.02 / 0.16
a_{fis}	0.26	0.15 / 0.37	0.24	0.21 / 0.45
f_i	0.71	0.58 / 0.79	0.83	0.73 / 0.89
f_p	1.83	1.23 / 2.36	1.62	1.08 / 2.21
f_y	0.52	0.35 / 0.68	0.52	0.37 / 0.69
ρ	0.73	0.60 / 0.84	0.37	0.30 / 0.51
$SD\ \ \varepsilon_t^y$	0.55	0.46 / 0.74	0.51	0.43 / 0.74
$SD\ \ \varepsilon_t^\pi$	0.49	0.42 / 0.68	0.53	0.44 / 0.75
$SD\ \ \varepsilon_t^i$	1.62	1.42 / 1.93	0.37	0.29 / 0.51
$SD\ \ \varepsilon_t^s$	5.48	4.65 / 6.57	4.26	3.52 / 5.46

Figure 1: Prior and posterior distributions: Aggregate demand equation

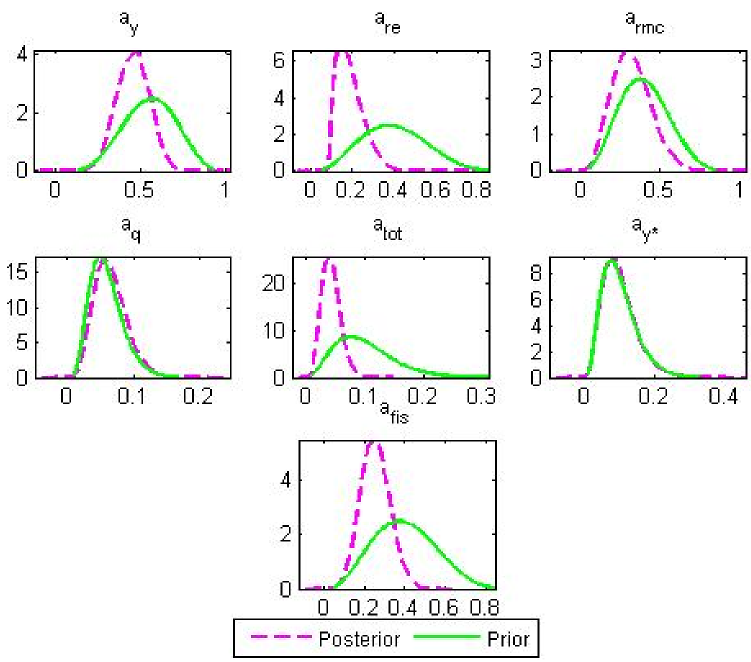

Figure 2: Prior and posterior distributions: Phillips curve equation

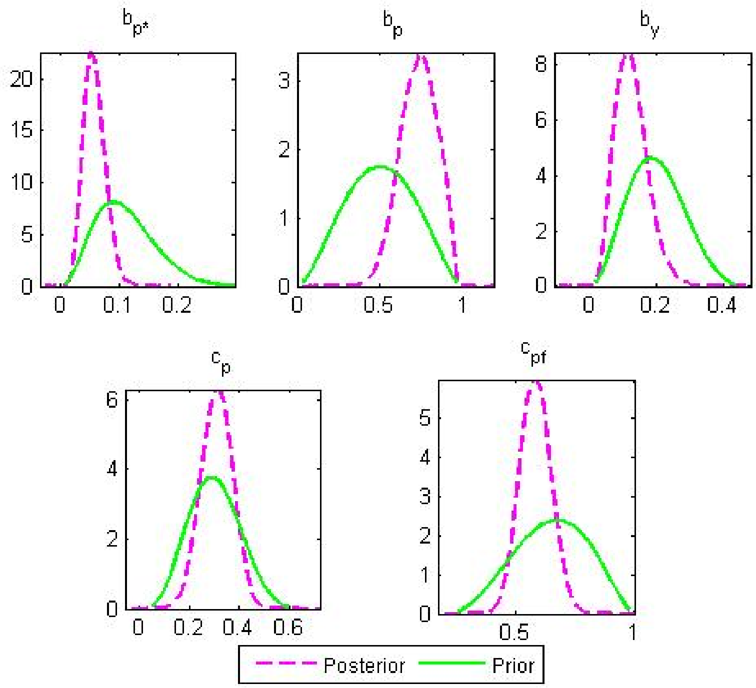

Figure 3: Prior and posterior distributions: Monetary policy equation

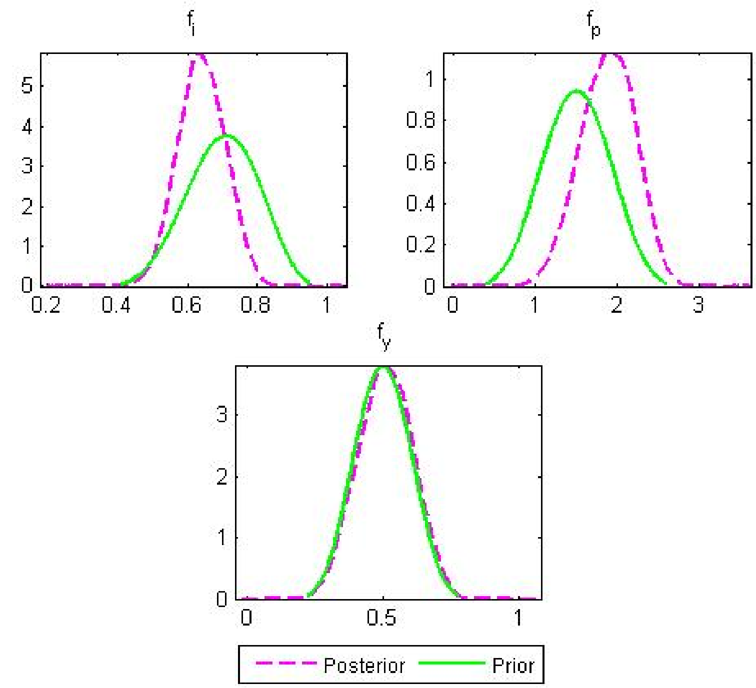

Figure 4: Prior and posterior distributions: Exchange rate expectations equation

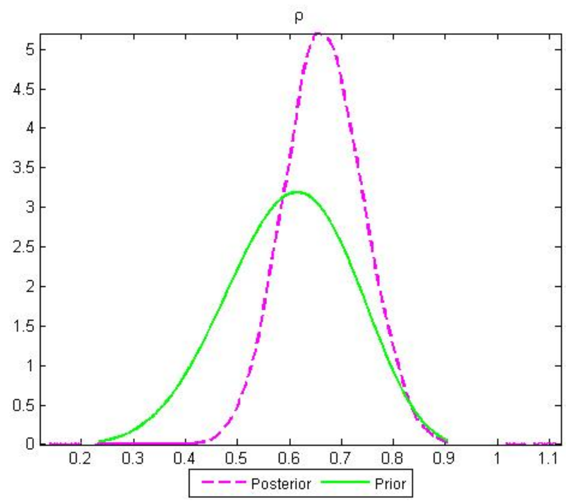

Figure 5: Monetary policy shock

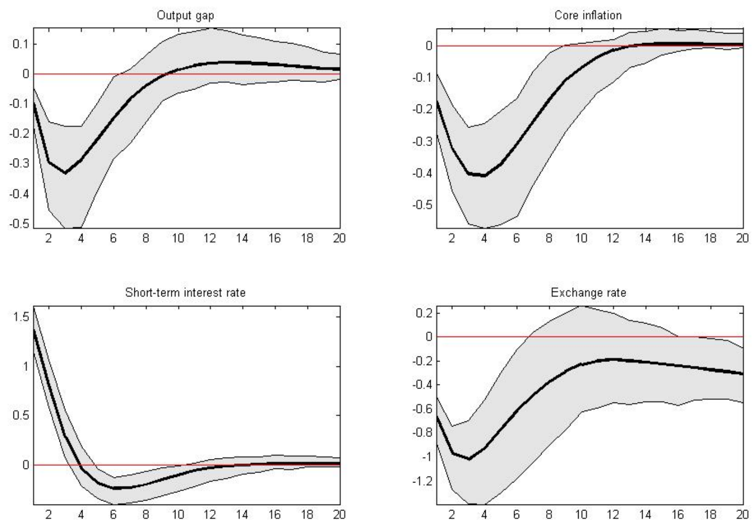

Figure 6: Aggregate demand shock

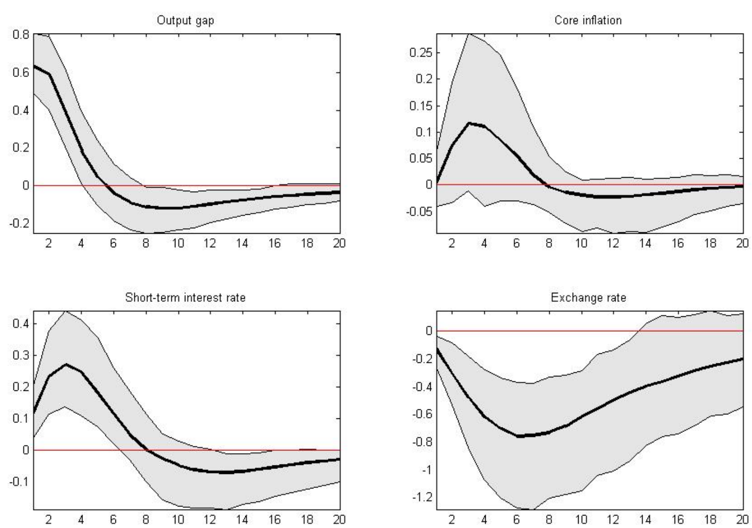

Figure 7: Core inflation shock

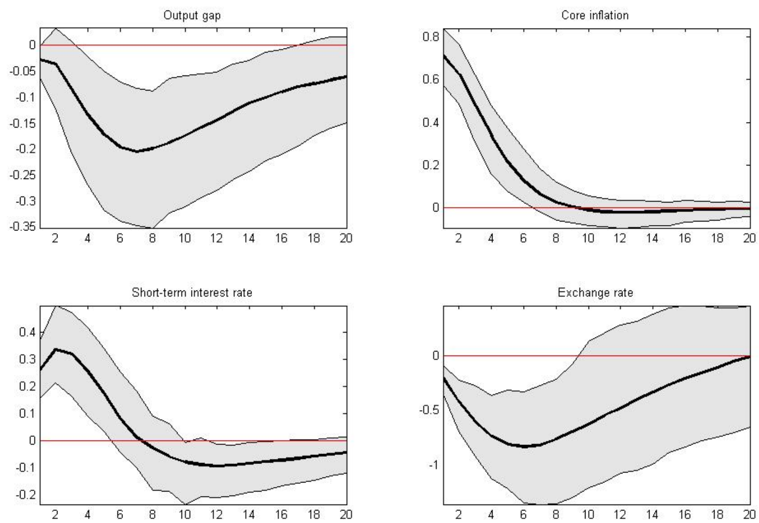

Figure 8: Exchange rate shock

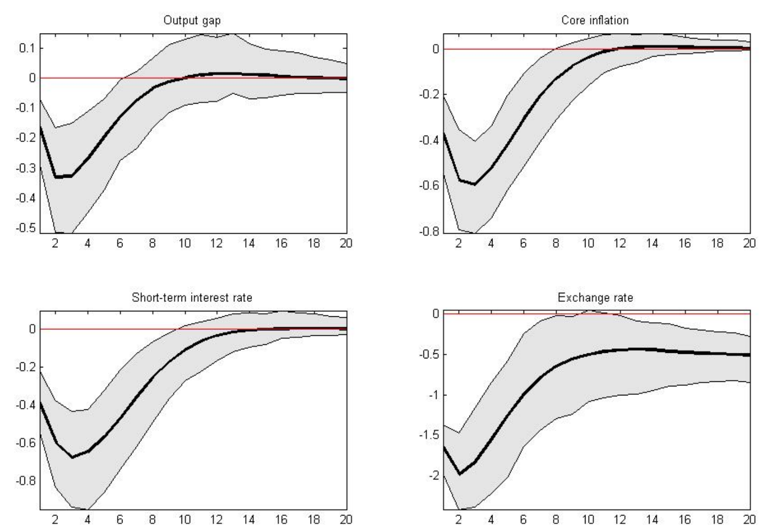

Figure 9: Output gap estimates (in percent terms) based on extended model and HP filter