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Monetary policy channels in Brazil through the lens of a semi-structural model ☆

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ABSTRACT

We develop and estimate a medium-sized, semi-structural model for the Brazilian economy during the inflation targeting period. The model describes fairly well key features of the economy and allows us to decompose the transmission mechanism of monetary policy. In the baseline decomposition, the transmission mechanism is broken down into *household interest rate*, *firm interest rate*, and *exchange rate channels*. In addition, we carry out an alternative decomposition that allows us to evaluate the *expectations channel* as well. In both procedures, the household interest rate channel is the most important for explaining the response of output to a monetary policy shock. In the baseline decomposition of inflation, both the household interest rate and the exchange rate channels are the main transmission channels. However, in the alternative decomposition, the expectations channel accounts for the bulk of the inflation response.

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1. Introduction

We still lack a good understanding of the monetary policy transmission mechanism in emerging market economies, especially if we compare it with what we know about developed countries.[1] This paper attempts to fill in this gap by identifying and measuring the relevant monetary policy transmission channels in Brazil during the inflation targeting regime.

Throughout the 1980s and early1990s, Brazil experienced high inflation and macroeconomic instability. During those years, the transmission channels worked very poorly, and as a result monetary policy was unable to ensure its effectiveness. The end of high inflation in 1994 (Lopes, 1998) and the shift to a floating exchange rate regime and inflation targeting in 1999 were major changes that helped to restore the transmission channels. Yet, until recently any attempt to better identify these channels was restricted by the small sample size.

However, as the data span grew larger and better identification tools were developed, it became possible to conduct a thorough analysis of the monetary transmission mechanism in countries like Brazil.[2] In this paper, we use nine years of data (1999–2008), which is a fairly large amount of information relative to what we had a few years ago. Furthermore, we rely on the methodology of Altissimo et al. (2002), henceforth ALS, for identifying and measuring the transmission channels. Based on the work of Mauskopf and Siviero (1994), ALS proposed a fairly general approach for decomposing the overall response of an economic model to a shock into the contributions associated with its distinct channels. In the case of linear models, the channel decomposition is exact because the sum of the individual effects that transit through each channel exactly equals the overall effect. Since the mid-1990s many researchers and central banks — including BIS (1995), van Els et al. (2001), and McAdam and Morgan (2001) — have used this approach to quantify the transmission channels of monetary policy.

We proceed in two steps to decompose the monetary policy channels. First, we develop and estimate a medium-sized, semi-structural model that describes fairly well key features of the Brazilian economy, in particular of the transmission mechanism in place. Although not derived from first principles, in many aspects the model resembles reduced-form versions of the current generation of dynamic stochastic general equilibrium (DSGE) models with new Keynesian features. In particular, the model allows agents' expectations and financial variables

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[1] A classical review of the transmission mechanism in mature economies is provided by Mishkin (1995). The main transmission channels include not only the traditional interest rate channel, highlighted by Taylor (1995), but also the credit channel (Bernanke and Gertler, 1995), the exchange rate channel in the case of open economies (Obstfeld and Rogoff, 1995), and asset price channels in the case of financially developed economies (Meltzer, 1995).

[2] For other developing countries, see BIS (1998) and BIS (2008). However, these studies are either qualitative or incapable of providing precise measures of the various monetary policy channels, as we do in this paper.

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to play an important role in the economy's dynamics. In the second step, we apply ALS' methodology to decompose the overall transmission mechanism into three distinct operating channels.

The first one is the *household interest rate channel*, which propagates monetary policy shocks to the household lending rate and from this to household consumption. The second is the *firm interest rate channel*, which captures the effects on firms' external financing costs, and hence on investment. Together, these two channels comprise the traditional *interest rate channel*. The third is the *exchange rate channel*, which captures – via an uncovered interest parity (UIP) condition – the effects of monetary policy shocks on the real exchange rate and then the resulting effects on the marginal cost of production and on net exports. Since expectations play an important role in the model, we also evaluate what we call the *expectations channel*, which measures the effects of monetary policy shocks via changes in inflation expectations.

When we do not explicitly identify the expectations channel, the main results of the decomposition are as follows. The household interest rate channel accounts for 62% of the fall in output one year after a monetary

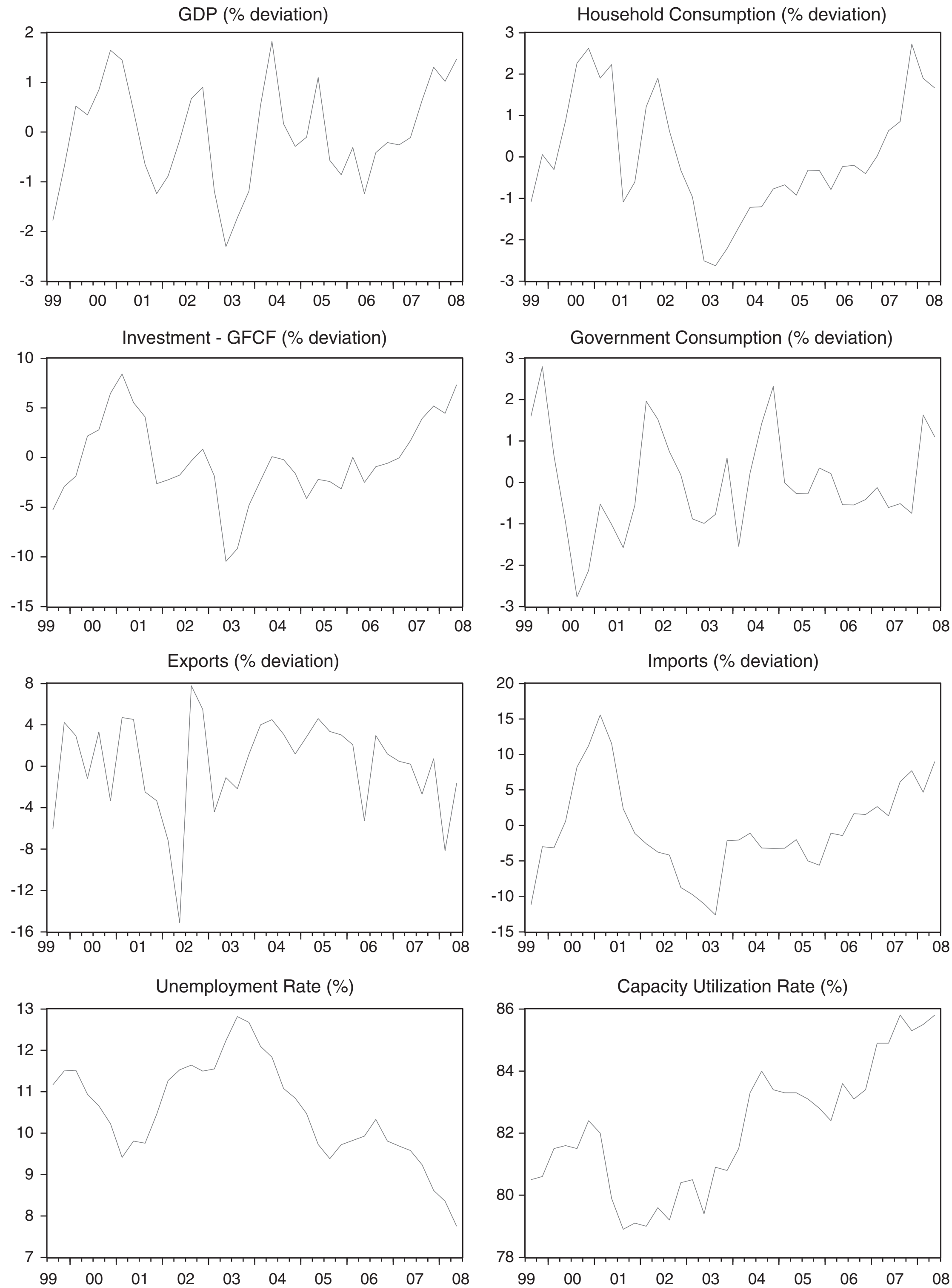

Fig. 1. Data series.

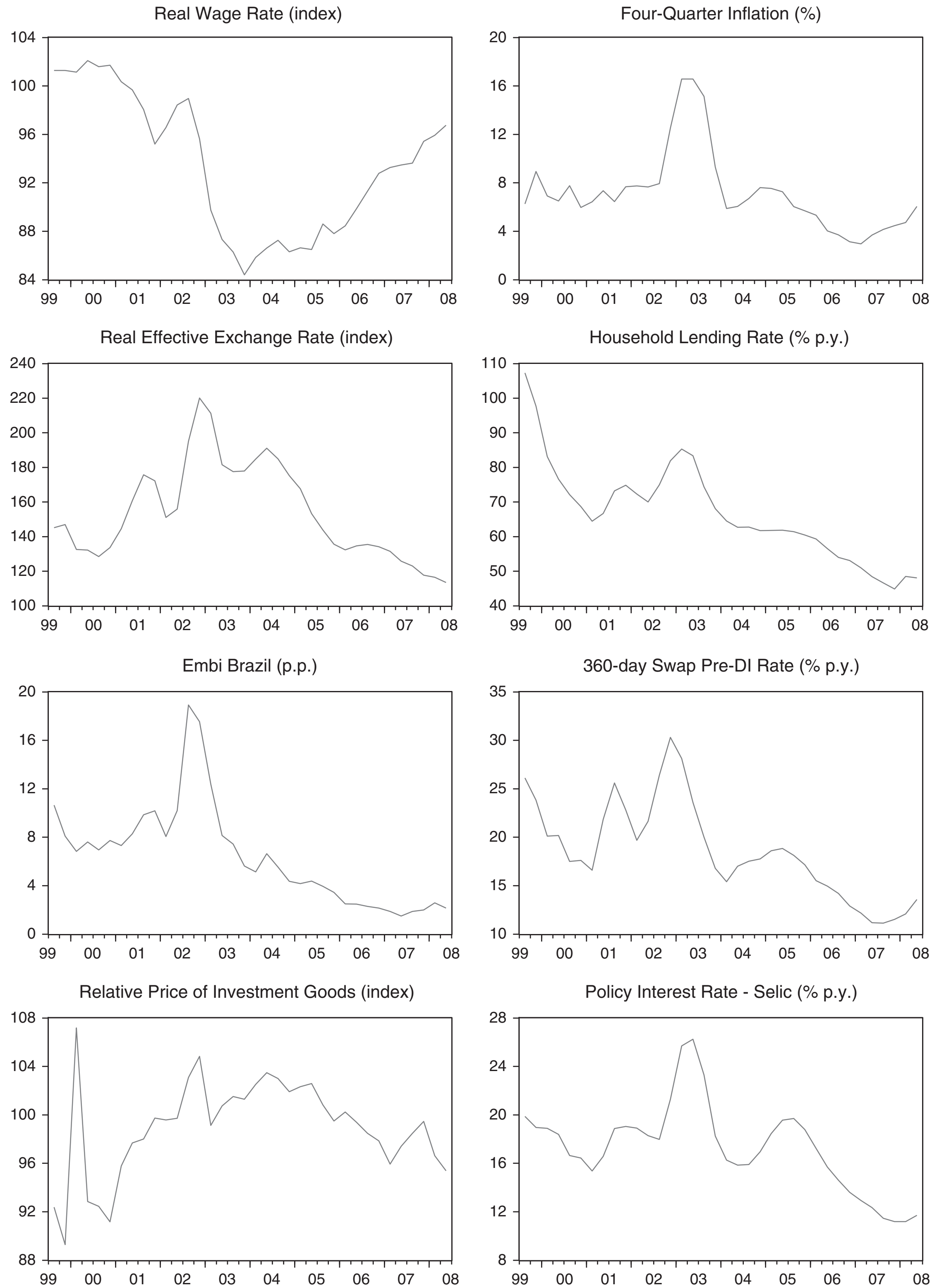

Fig. 1 (*continued*).

policy tightening. The firm interest rate channel accounts for only 24% of the fall in output over the same horizon. This smaller magnitude reflects the low share of investment in GDP and also the fact that a significant fraction of private investment in Brazil is financed by state-owned development banks at below market interest rates, which tends to weaken this particular channel. Turning to inflation, the household interest rate and exchange rate channels are the most relevant ones, each accounting for about 40% of the drop in inflation at horizons ranging from one to three years. This result is in line with the fact that the exchange rate is a key driving force of the Brazilian domestic inflation.

Taking into account the role of expectations, we find that the household interest rate channel still remains the most relevant transmission mechanism for output. However, we also find that the expectations channel emerges as the major channel of monetary policy to inflation.

This finding is consistent with the importance attributed to inflation expectations for conducting monetary policy in Brazil (Bevilaqua et al., 2008).

The contributions of our work are twofold. To our knowledge, we are the first to estimate a medium-sized, macroeconometric model for Brazil using a sample period covering only the inflation targeting regime. In developing our model, we borrowed many insights from Muinhos and Alves (2003), Bank of England (2000), and Garcia et al. (2003), but also improved upon many dimensions that greatly increased the adherence of the model to the data. The model successfully replicates business cycle statistics (unconditional second moments) and impulse responses to relevant macroeconomic shocks. Secondly, we also believe this paper is the first to document the relative contribution of the individual monetary policy channels under the inflation targeting framework in Brazil. Previous works have focused on the effects of monetary shocks, usually relying on standard VAR models, which give a sense of the overall transmission mechanism but are less adequate for measuring individual transmission channels.

This paper is organized as follows. Section 2 provides a brief overview of the Brazilian economy in the last two decades. Section 3 describes the estimated model. Section 4 presents the quantitative results, and Section 5 concludes.

2. Brazilian economy: brief overview

The Brazilian economy experienced high inflation for more than two decades. In June 1994, the monthly inflation rate reached 47.43%, which in annual terms amounted to 10,444.6%. The high-inflation period was marked by weak monetary and fiscal institutions, macroeconomic instability, low credibility of economic policy, and balance of payments crises. The main purpose of monetary policy was to protect the value of government bonds and bank deposits against inflation as to avoid dollarization, financial disintermediation, and massive capital outflows. The credit market was underdeveloped, and the maturities of financial system assets and liabilities were very short. Such an environment led to extremely high uncertainty, shortening the planning horizon of government and private agents.

The end of high inflation, brought about by the Real Plan in July 1994, was the first step to restore the monetary policy transmission channels and widen agents' planning horizon. However, monetary policy became focused on defending the exchange rate pegged system. Policy interest rates reacted strongly to external events, such as the Mexican, Asian and Russian crises, in order to maintain international reserves and preserve the monetary regime. Nevertheless, the growing economic imbalances, compounded by the external crises, led to the Brazilian exchange rate crisis in January 1999.

The policy regime changed markedly in that year, toward a floating exchange rate, sound fiscal policy, and implementation of fully-fledged inflation targeting. The new policy regime meant an important structural change in the economy, including objectives, transparency and transmission mechanisms of monetary policy, which became focused on achieving the inflation target. The system went through a stress test in 2002–2003 with the confidence crisis related to presidential elections. At that time, the exchange rate skyrocketed and agents feared a disruption of the policy regime. The new government, however, maintained the policy framework, and managed to bring inflation back to the target. The consolidation of the regime and the accumulation of international reserves, from 2004 onward, made the economy more resilient to external shocks. Moreover, the Central Bank of Brazil (BCB) has built up credibility over the years, as indicated by several studies (see, e.g., Bevilaqua et al., 2008, and Carvalho and Minella, 2012). On the fiscal front, the public sector has fulfilled the high targets for the primary surplus, in place since 1999. Credit to households and working capital financing have grown at a fast pace, boosted by macroeconomic stability, low inflation, and institutional changes in the credit market, such as better conditions for the recovery of collateral and the introduction of payroll-deductible loans. Nevertheless, in order to finance long-term investments, firms continue to rely on state-owned development banks, since the private market for long-term financing is still relatively thin in Brazil.

Against this background, one of the foremost questions is whether the textbook transmission mechanisms started to work properly in the economy after those deep changes. The model we develop in this paper tries to identify and measure these transmission channels, without ignoring the typical features of emerging market economies like Brazil. For instance, our model takes into account the fact that both the exchange rate and investment strongly respond to the country-risk premium, which in the model functions as an empirical proxy for macroeconomic instability.

Fig. 1 shows the major time series we have used in the model estimation. GDP and aggregate demand components are presented as percentage deviations from the trend, estimated by the Hodrick–Prescott (HP) filter, whereas the other variables are reported without any transformation. The graphs illustrate some of the patterns that have guided our estimations. For instance, they show a strong comovement between the main interest rates — the policy rate, the household lending rate, and the 360-day swap pre-DI rate, which is a key driving force of investment in the model.[3] We can notice that the swap rate tends to anticipate the future path of the policy rate, thus influencing aggregate demand in a forward-looking manner. In addition, real wages are negatively affected by inflation and the exchange rate, which in turn is tightly linked to the country-risk premium, as previously mentioned. The graphs also make evident that consumption and investment display the expected comovement over the business cycles as illustrated by the 2002–2003 confidence crisis.

3. Model

The model describes a small open economy through the following five blocks of behavioral equations and identities, with the corresponding variables of interest:

- *Monetary policy*: policy interest rate;
- *Financial variables*: household lending rate, firm interest rate, real exchange rate, country-risk premium, and net foreign assets (NFA);
- *Aggregate demand*: household consumption, investment, government consumption, exports, and imports;
- *Aggregate supply*: inflation, real wage, employment, unemployment rate, capacity utilization rate, and relative price of investment;
- *Rest-of-the-world (ROW) variables*: world imports, world inflation, world interest rate, and foreign investors' risk aversion.

The model is linear in the variables because we want to have an exact decomposition of the transmission channels. Fig. 2 provides an overview of the model structure.

We estimate the model equation by equation using two-stage least squares (2SLS) and ordinary least squares (OLS), and quarterly data for the period 1999Q3–2008Q2. All series are filtered with the HP filter. The resulting series are deviations or log-deviations from the trend. Inflation and interest rates are expressed as percent per quarter in the estimations. Details of the data sources and variable transformations are presented in Appendix A.

The main estimation results are presented in the following sections. For the sake of clarity, we summarize the estimation details in Table 1, which provides information on the sample period, estimation method, list of instruments (in the case of 2SLS regressions), and diagnostic tests. All regressions include a constant term, which is usually not statistically significant and thus is not reported. Whenever required, we use time dummies to control for outliers as well as exogenous events such

[3] In the swap contract, a cash flow based on a predetermined interest rate – the swap rate – is exchanged for a flow based on the average daily interbank (DI) rate over the contract period.

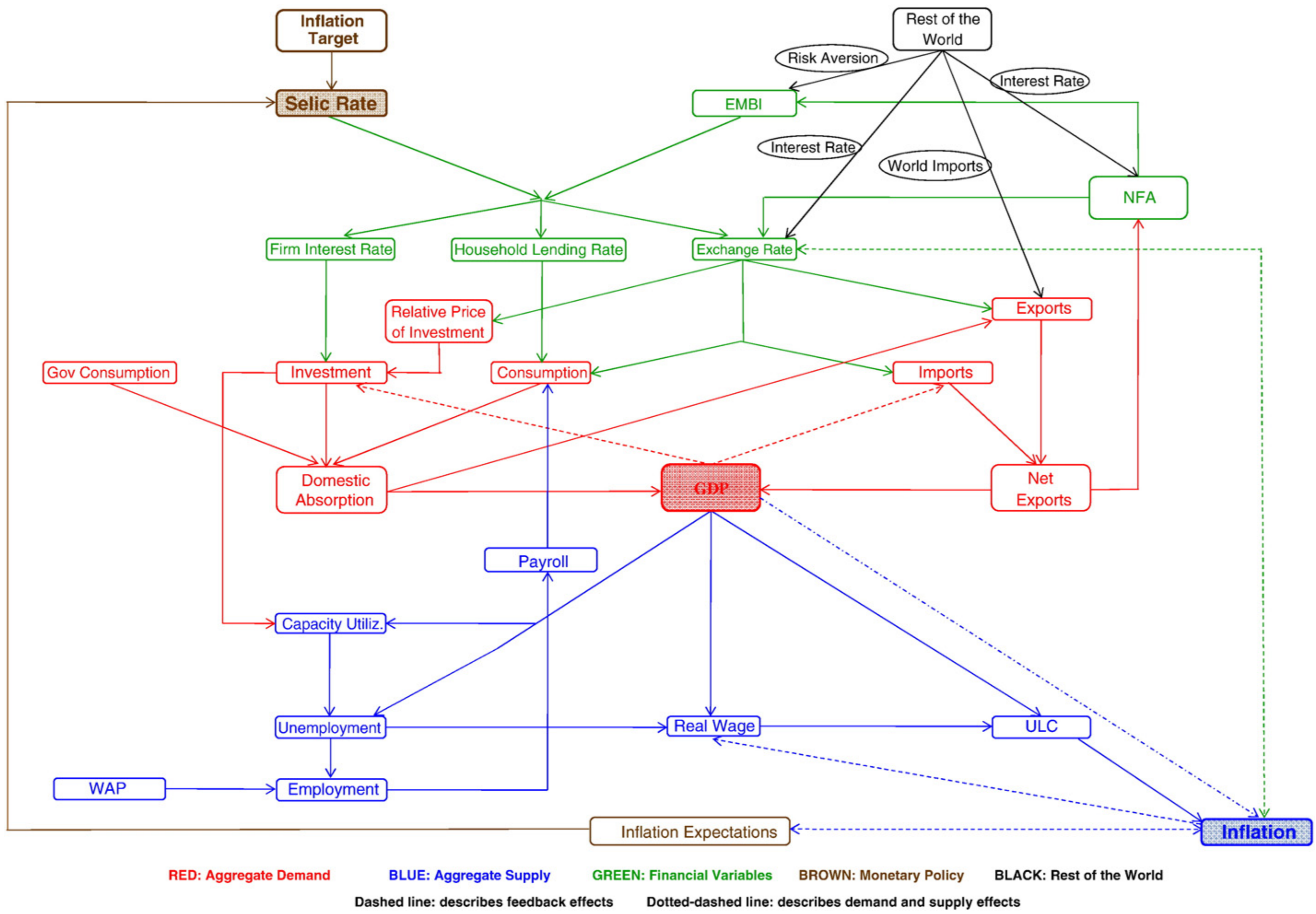

Fig. 2. Model structure.

as strikes and power outages. In the equations, dummy variables are represented by d_{yyQx} where the subscripts yy and x denote, respectively, the year and the quarter that the dummy refers to.

We selected the final equations on the basis of economic theory, Brazilian economy empirical features, regression fit, and statistical significance of the coefficients. The estimated coefficients have the expected sign, and the regressions pass most of the diagnostic tests.

3.1. Monetary policy

The description of monetary policy is the starting point of our model. Consistent with the inflation targeting framework, the monetary authority sets the nominal interest rate r_t, called the Selic rate, to stabilize expected inflation around the inflation target. The estimated reaction function thus resembles an inflation forecast-based rule, augmented by a smoothing component as follows:

$$r_t = \underset{(0.13)}{1.13} r_{t-1} - \underset{(0.12)}{0.51} r_{t-2} + (1 - \underset{(0.13)}{1.13} + \underset{(0.12)}{0.51}) \left(\underset{(0.45)}{1.57} \left(E_t \pi^4_{t+4} - \bar{\pi}^4_{t,t+4} \right) + \bar{\pi}^4_{t,t+4} \right) + \underset{(0.17)}{\hat{\varepsilon}^R_t}, \quad (1)$$

where E_t is the expectation operator, $\pi^4_{t+4} \equiv \frac{1}{4} \sum_{j=1}^{4} \pi_{t+j}$ is the cumulative inflation for the next four quarters, $\bar{\pi}^4_{t,t+4}$ is the inflation target for the next four quarters, $\hat{\varepsilon}^R_t$ is the estimated discretionary component of the policy rule, and the numbers in parentheses under the estimated coefficients are Newey–West corrected standard errors. The value in parentheses under $\hat{\varepsilon}^R_t$ is the estimated standard deviation of the residuals, which we use for simulating the model. As mentioned before, regression diagnostics are presented in Table 1.

The estimated coefficient on inflation is larger than one, satisfying the Taylor principle, generally required for uniqueness and stability (Woodford, 2003). In practice, it suggests that the BCB is committed to meeting the inflation target. Minella et al. (2003) also find similar results for Brazil but using a shorter sample period.

The choice of the inflation forecast horizon in Eq. (1) reflects the inherent lags in the transmission mechanism, which are embedded in the model, the setting of the inflation target for the yearly inflation, and the fact that central banks should act in a forward-looking manner. In particular, the BCB emphasized the forward-looking nature of its decisions in the period under consideration.

The data did not support the inclusion of an output gap term in Eq. (1). This result does not necessarily imply that the monetary authority does not care about output stabilization. As argued by Batini and Haldane (1999), there is no need for any explicit output gap term to enter rules like Eq. (1) as the interest rate smoothing and an appropriately chosen targeting horizon already embody a certain degree of output stabilization.

Eq. (1) also suggests that the monetary authority has some preference for interest rate smoothing – the sum of the coefficients on the lagged interest rate is 0.62[4] – which, however, is not as large as some of the estimates available in the literature for other countries.[5]

[4] Including two lagged terms helps to eliminate serial correlation in the residuals.

[5] See, for example, Adolfson et al. (2007), Clarida et al. (1998), Medina and Soto (2007), Páez-Farrell (2009), and Smets and Wouters (2003, 2007).

Table 1
Regression diagnostics.

Equation	Equation number	Symbol	Sample period	Number of obs	Estimation method	Instrument list	Adjusted R-squared	LM test 1 lag	LM test 4 lags	White het. test	Normality test
Monetary policy											
Policy interest rate	1	r	2000Q3–2008Q2	32	2SLS	$r_{t-1}, r_{t-2}, E_{t-1}\pi^4_{t+3}, E_{t-2}\pi^4_{t+2}, \pi^4_{t-1}, \pi^4_{t-2}, \pi^4_{t,t+4}, \pi^4_{t-1,t+3}, \pi^4_{t-2,t+2}, q_{t-1}, q_{t-2}, ulc_{t-1}, ulc_{t-2}, y_{t-1}, y_{t-2}$	0.91	0.64 [0.42]	1.92 [0.75]	9.93 [0.36]	4.58 [0.10]
Financial variables											
Household lending rate	2	r^H	1999Q3–2008Q2	36	2SLS	$r^H_{t-1}, r^H_{t-2}, r_{t-1}, r_{t-2}, \pi_{t-1}, \pi_{t-2}, r^F_{t-1}, r^F_{t-2}, s^*_{t-1}, s^*_{t-2}$	0.92	0.89 [0.35]	1.25 [0.87]	22.9 [0.06]	1.16 [0.56]
Firm interest rate	3	r^F	2000Q3–2007Q3	33	2SLS	$r^F_{t-1}, r_{t-1}, r_{t-2}, r_{t-3}, \pi_{t-1}, \pi_{t-2}, \pi_{t-3}, s_{t-1}, s^*_{t-2}, s^*_{t-3}$	0.92	0.03 [0.87]	4.44 [0.35]	14.5 [0.15]	0.84 [0.66]
Real exchange rate	4	q	2000Q3–2008Q1	31	2SLS	$q_{t-1}, q_{t-2}, r_{t-1}, r_{t-2}, \pi_{t-1}, \pi_{t-2}, E_{t-1}\pi_t, E_{t-2}\pi_{t-1}, s^*_{t-1}, s^*_{t-2}, s^*_{t-3}, \Delta b^{Y*}_{t-1}, \Delta b^{Y*}_{t-2}, CA^Y_{t-1}, CA^Y_{t-2}$	0.96	0.25 [0.62]	3.28 [0.51]	8.30 [0.31]	1.47 [0.48]
Country-risk premium	5	s^*	1999Q3–2008Q2	36	2SLS	$s^*_{t-1}, s^*_{t-2}, v^*_t, v^*_{t-1}, v^*_{t-2}, \Delta b^{Y*}_{t-1}, \Delta b^{Y*}_{t-2}, CA^Y_{t-1}, CA^Y_{t-2}$	0.68	0.33 [0.56]	2.63 [0.62]	16.4 [0.06]	0.15 [0.93]
Aggregate supply											
Household consumption	7	c	2000Q3–2008Q2	32	2SLS	$E_{t-1}\pi^4_{t+3}, E_{t-2}\pi^4_{t+2}, r^H_{t-1}, r^H_{t-2}, q_{t-1}, q_{t-2}, w_{t-1}+n_{t-1}, w_{t-2}+n_{t-2}$	0.93	0.17 [0.68]	6.41 [0.17]	12.0 [0.75]	0.57 [0.75]
Investment	8	i	2000Q2–2008Q2	33	OLS		0.77	0.02 [0.88]	6.40 [0.17]	19.1 [0.51]	0.48 [0.79]
Exports	9	x	1999Q3–2008Q2	36	OLS		0.48	0.43 [0.51]	3.98 [0.40]	8.90 [0.63]	2.74 [0.25]
Imports	10	m	1999Q3–2008Q2	36	2SLS	$m_{t-1}, y_{t-1}, y_{t-2}, r^F_{t-1}, r^F_{t-2}, q_{t-1}$	0.77	0.11 [0.74]	3.19 [0.53]	16.4 [0.06]	0.64 [0.73]
Aggregate supply											
Inflation	11	π	2000Q1–2007Q2	30	2SLS	$\pi^4_{t-1}, \Delta ucl_{t-1}, \Delta ulc_{t-2}, \Delta q_{t-1}, \Delta q_{t-2}, (y_{t-1}+y_{t-2})/2, r^F_{t-1}, r^F_{t-2}$	0.78	0.20 [0.65]	4.93 [0.29]	10.2 [0.86]	3.42 [0.18]
Real wage	13	w	1999Q3–2008Q2	36	2SLS	$w_{t-1}, y_{t-1}, y_{t-2}, r^F_{t-1}, r^F_{t-2}, \pi_{t-1}, (u_{t-2}+u_{t-3}+u_{t-3})/3$	0.84	0.00 [0.96]	0.29 [0.99]	8.19 [0.88]	2.15 [0.34]
Unemployment	15	u	1999Q3–2008Q2	36	2SLS	$u_{t-1}, y_{t-1}, y_{t-2}, r^F_{t-1}, r^F_{t-2}, (u^K_{t-1}+u^K_{t-2}+u^K_{t-3}+u^K_{t-4})/4$	0.90	1.72 [0.19]	6.12 [0.19]	23.2 [0.06]	1.37 [0.50]
Capacity utilization rate	16	u^K	1999Q3–2008Q2	36	2SLS	$u^K_{t-1}, y_{t-1}, y_{t-2}, r^F_{t-1}, r^F_{t-2}, (i_{t-1}+i_{t-2}+i_{t-3}+i_{t-4})/4$	0.61	0.52 [0.47]	1.93 [0.75]	6.95 [0.64]	0.40 [0.82]
Relative price of investment	17	q^I	2000Q3–2008Q2	32	2SLS	$q^I_{t-1}, q^I_{t-2}, q_{t-1}, q_{t-2}, r_{t-1}, r_{t-2}, \pi_{t-1}, \pi_{t-2}, E_{t-1}\pi_t, E_{t-2}\pi_{t-1}, s_{t-1}, E_{t-1}\pi^*_{t-2}, E_{t-2}\pi^*_{t-3}$	0.39	0.30 [0.59]	3.79 [0.43]	18.0 [0.00]	8.21 [0.02]

LM test is the Lagrange multiplier test for the absence of serial correlation in the residuals. White test is for the absence of heteroskedasticity in the residuals. Normality test is the Jarque–Bera χ^2 test for normality in the residuals.
For each test, the number outside square brackets is the value of the test statistics, whereas the number inside square brackets is the corresponding p-value. Large p-values mean that the null hypothesis being tested is not rejected at conventional significance levels.

3.2. Financial variables

Monetary policy shocks enter the model through three equations or "points of entry", which we identify with the monetary policy channels in the baseline channel decomposition (see Subsection 4.3 below). The first equation describes the behavior of the household lending rate r_t^H:

$$r_t^H = \underset{(0.12)}{0.89} r_{t-1}^H - \underset{(0.08)}{0.26} r_{t-2}^H + \underset{(0.11)}{0.34} r_t + \underset{(0.09)}{0.50} s_t^* + \underset{(0.26)}{\hat{\varepsilon}_t^H}, \tag{2}$$

which depends on its own lagged values, the policy interest rate, and the country-risk premium s_t^* – defined as the spread of Brazilian sovereign bond yields over those of the U.S. treasury bonds of equivalent maturities. We interpret $\hat{\varepsilon}_t^H$ as innovations affecting the consumer loan market. Adding other macro fundamentals, such as inflation and output, did not improve the regression.

The lagged values reflect the fact that most household lending contracts in Brazil are negotiated at preset interest rates whose average responds slowly to credit market innovations. This interest rate inertia also emerges in DSGE models by assuming that banks face some cost of adjusting their lending rates, as in Gerali et al. (2010). The inertia helps to account for the slow pass-through from the policy rate. Notice that the short-run (within the quarter) pass-through is only 0.34, whereas the long-run pass-through is $0.34/(1-0.89+0.26) \simeq 0.92$, which is not statistically different from unity. Therefore, the coefficients of Eq. (2) imply that the interest rate pass-through is incomplete in the short-run but full in the long run.[6] The lags also contribute to a hump-shaped response of household consumption to monetary policy shocks. The addition of the sovereign spread in Eq. (2) helps to control for macroeconomic uncertainty, which affects loan pricing.

The equation describing the interest rate relevant for firms' investment decisions is the second point of entry for monetary policy shocks in the model. Because the market for long-term credit is not well developed in Brazil, we use the 360-day swap pre-DI rate as a proxy for firms' average lending rate. In fact, market lending rates in Brazil are highly correlated with the swap rate. For instance, the contemporaneous correlation between the swap rate and the average interest rate on firms' borrowing of about one-year maturity is 0.779. Furthermore, since the DI rate follows the policy rate very closely, the swap rate ends up reflecting agents' expectations over the future path of the policy rate. As a result, it tends to anticipate the stance of monetary policy expected for the year ahead, as we can see in Fig. 1.[7] In a nutshell, the swap rate is a better proxy for the opportunity cost of investment than market lending rates, which are mostly short-term.

As in Eq. (2), the main determinants of the firm interest rate are the country-risk premium and the policy interest rate. However, it is the expected path of r_t that enters the equation:

$$r_t^F = \underset{(0.11)}{0.39} r_{t-1}^F + \underset{(0.22)}{0.56} \left(\frac{1}{4} \sum_{j=0}^{3} r_{t+j} \right) + \underset{(0.10)}{0.38} s_t^* + \underset{(0.04)}{0.63} d_{01Q3} + \underset{(0.20)}{\hat{\varepsilon}_t^F}. \tag{3}$$

Due to data availability, we use the (properly instrumented) actual future policy rate in Eq. (3) instead of its expected value from a survey conducted by the BCB among professional forecasters.

As in Eq. (2), we also find incomplete pass-through for the firm lending rate in the short run, and cannot reject the hypothesis of full pass-through in the long run. Notice that the above equation resembles a term structure of interest rate in which the long rate r_t^F is a function of the expected short-term interest rates.

The third point of entry for monetary policy in the model is the uncovered interest rate parity (UIP) condition linking the real effective exchange rate q_t to the interest rate differential in real terms:

$$\begin{aligned} q_t = {} & \underset{(0.04)}{0.64} q_{t-1} + (1 - \underset{(0.04)}{0.64}) q_{t+1} - \left[(r_t - E_t \pi_{t+1}) - (r_t^* + s_t^* - E_t \pi_{t+1}^*) \right] \\ & - \underset{(0.05)}{0.27} \Delta b_t^{Y*} - \underset{(0.53)}{7.83} (d_{02Q1} + d_{02Q2}) + \underset{(1.79)}{\hat{\varepsilon}_t^Q}, \end{aligned} \tag{4}$$

where r_t^* is the world nominal interest rate, π_t^* is the world CPI inflation rate, $E_t \pi_{t+1}^*$ is one-quarter ahead expected world inflation (forecasts for U.S. inflation from the Survey of Professional Forecasters), and Δb_t^{Y*} is the change in the NFA-to-GDP ratio (instrumented by the current account-to-GDP ratio CA_t^Y). Because the nominal exchange rate is expressed in units of domestic currency per units of foreign currency units, an increase in q_t means a depreciation of the real exchange rate. Notice that we restrict the coefficient on the interest rate differential to be unity, as suggested by theory.

The above UIP condition differs in two aspects from the usual microfounded specifications. First, it is a hybrid version in that the current exchange rate is a function of its past and future values. Hybrid UIP conditions are now a common feature in many DSGE models. They tend to better fit the data and are able to generate a hump-shaped response of the real exchange rate to a monetary policy shock, which is commonly found in estimated VARs (Adolfson et al., 2008). Because of data availability, for the forward-looking term we use the (instrumented) actual exchange rate q_{t+1} instead of its expected value. Second, we include the change in NFA as an additional determinant of the real exchange rate, which improves the fit to the data and tries to capture the impact of the balance of payments position on the exchange rate. In this case, an increase in the NFA-to-GDP ratio tends to appreciate the real exchange rate.

We close the financial block with an equation for the country-risk premium and the law of motion of NFA. The literature on emerging-market bond spreads – e.g., Bellas et al. (2010) and Eichengreen and Mody (1998) – suggests that the country-risk premium depends upon idiosyncratic factors (e.g., debt level, credit ratings, domestic inflation, fiscal stance, economic growth) as well as common factors (e.g., contagion, world interest rate, investor's appetite for risk). In the case of Brazil, we find that the most important factors are NFA, as in most small open economy DSGE models, and foreign investors' risk aversion:

$$s_t^* = \underset{(0.07)}{0.16} v_t^* - \underset{(0.01)}{0.06} b_t^{Y*} + \underset{(0.01)}{0.03} b_{t-1}^{Y*} + \underset{(0.32)}{\hat{\varepsilon}_t^{S^*}}, \tag{5}$$

where v_t^* is Merrill Lynch's risk aversion index measuring the implicit volatility of financial instruments. Notice that the sum of the coefficients on the NFA is negative, implying that the country-risk premium falls when NFA improves, as expected. In fact, the substantial change in the levels of the country's net external debt — which went from high positive values to negative ones — seems to have been fundamental for the reduction in the Brazilian country-risk premium in the recent years. The law of motion of NFA, in turn, is a condition that pins down the change in the NFA as a function of net exports and net interest payments on external debt.

3.3. Aggregate demand

We begin the demand block with the linear version of the market clearing condition, in real terms:

$$y_t = s^C c_t + s^I i_t + s^G g_t + s^X x_t - s^M m_t, \tag{6}$$

where y_t is output, c_t is household consumption, i_t is investment, g_t is government consumption, x_t is exports, m_t is imports, and s^j are the corresponding shares. We match these long-run shares to the average

[6] Incomplete interest rate pass-through has also been found in many other countries, including emerging market economies like Chile (Berstein and Fuentes, 2003, Espinosa-Vega and Rebucci, 2003), and mature economies like the euro area (de Bondt, 2002, de Bondt et al., 2005).

[7] Fig. 1 also illustrates the well documented fact that the average levels of lending rates in Brazil are very high, even for Latin American standards. Afanasieff et al. (2002) investigate the determinants of high bank interest spreads in Brazil, and Souza-Sobrinho (2010) analyzes the welfare implications of such high spreads.

values over the sample period: $s^C = 0.622$, $s^I = 0.166$, $s^G = 0.198$, $s^X = 0.137$, and $s^M = 0.123$.

We estimate behavioral equations for each component of the aggregate demand. Household consumption depends on its past behavior, the ex-ante real household lending rate, current household income, and the real exchange rate:

$$c_t = \underset{(0.12)}{0.33}c_{t-1} - \underset{(0.09)}{0.54}\left(r_t^H - E_t\pi_{t+4}^4\right) + \underset{(0.04)}{0.19}y_t^H - \underset{(0.01)}{0.02}q_t - \underset{(0.21)}{2.15}d_{01Q3} + \underset{(0.12)}{1.44}d_{07Q4} + \underset{(0.36)}{\hat{\varepsilon}_t^C}, \tag{7}$$

where household income y_t^H is proxied by real payroll $w_t + n_t$, which we measure by the sum of wages w_t paid to people employed n_t. The real exchange rate is our proxy for the relative price of imported consumption goods. We use four-quarter-ahead inflation expectation instead of one-quarter-ahead inflation expectation because the average maturity of household loans is about a year.

Eq. (7) resembles aggregate consumption equations of DSGE models featuring habit formation, imported goods in the consumption basket, and heterogeneous households. For instance, Galí et al. (2004) assume two types of consumers, those who have access to credit markets and hence are able to smooth consumption overtime, and those who are credit-constrained and must consume their current income in a Keynesian fashion.

Turning to aggregate investment, we model the gross fixed capital formation (GFCF) and ignore the dynamics of inventory changes. Current investment is a function of its own past values, the ex-ante real interest rate relevant for investment decisions, aggregate output, the relative price of investment goods, and a measure of macroeconomic uncertainty:

$$i_t = \underset{(0.18)}{0.56}i_{t-1} - \underset{(0.66)}{1.37}\left(r_{t-1}^F - E_{t-1}\pi_{t+3}^4\right) + \underset{(0.59)}{1.10}y_{t-1} - \underset{(0.12)}{0.36}\left(\frac{1}{2}\sum_{j=1}^{2}q_{t-j}^I\right) - \underset{(1.04)}{2.15}\Delta s_{t-3}^* + \underset{(1.88)}{\hat{\varepsilon}_t^I}, \tag{8}$$

where q_t^I is the relative price of investment goods. The lagged term is easily justified by the time-to-build argument, or by assuming some capital adjustment cost as most DSGE models do. Christiano et al. (2005) and many others have emphasized that the presence of inertia in consumption and investment equations is crucial for generating hump-shaped responses to monetary policy shocks. As we mentioned before, we use the 360-day swap rate r_t^F as a proxy for firms' external financing cost, which in our view better captures the forward-looking nature of investment decisions. The addition of aggregate output in Eq. (8) describes the traditional accelerator effect, whereby firms try to adjust their capital levels to the optimum capital–output ratio. This effect arises in some DSGE models indirectly, through changes in firms' financial conditions — the so-called financial accelerator, as in Bernanke et al. (1999).

Notice that the estimated interest-rate elasticity of investment (−1.37) is almost three times larger than that of consumption. We conjecture that if private institutions accounted for a larger share of investment financing the interest-rate elasticity would be even higher and the impact of monetary policy shocks on aggregate investment would be stronger than what is suggested by our estimations.

We proxy macroeconomic volatility by the lagged change in the country-risk premium. Lastly, the relative price of investment goods q_t^I, measured by the ratio of the GFCF deflator to the GDP deflator, enters Eq. (8) with a negative sign because it represents the relative cost of producing new capital goods.

The main determinant of Brazilian exports is the world demand m_t^*. To preserve parsimony, we consider in our specification the real exchange rate instead of the relative price of exports. We also allow for exports to depend negatively on domestic absorption because Brazilian firms tend to shift their sales to the domestic market whenever this is expanding faster than world markets. Taking these considerations into account, we estimate the following export demand equation:

$$x_t = \underset{(0.23)}{1.02}\left(\frac{1}{2}\sum_{j=0}^{1}m_{t-j}^*\right) - \underset{(0.34)}{0.63}\left(\frac{1}{2}\sum_{j=1}^{2}a_{t-j}\right) + \underset{(0.05)}{0.12}q_{t-1} + \underset{(1.82)}{12.89}\left(d_{02Q3} + d_{02Q4}\right) + \underset{(3.16)}{\hat{\varepsilon}_t^X}, \tag{9}$$

where a_t is domestic absorption, which is a function of total consumption (household's and government's) and investment. Notice that the estimated elasticity of exports to world income is about one in the long run. Also notice that the two estimated income elasticities in Eq. (9) imply that domestic absorption must expand almost twice as fast as the world demand for aggregate exports to be dominated by the dynamics of domestic sales relative to foreign sales.

For the sake of parsimony, aggregate imports also depend on the real exchange rate instead of the relative price of imports. They also depend positively on domestic demand, as in standard import demand equations:

$$m_t = \underset{(0.13)}{0.55}m_{t-1} + \underset{(0.90)}{1.98}y_t - \underset{(0.05)}{0.17}q_{t-1} + \underset{(3.01)}{\hat{\varepsilon}_t^M}, \tag{10}$$

We use aggregate expenditure y_t instead of domestic absorption as a proxy for domestic demand in Eq. (10) because Brazilian exports of manufactured and semi-manufactured goods, which account for about half of total exports, have a relatively large content of imported intermediate goods. Notice that the estimated income elasticity of imports is larger than one, a well-known stylized fact for Brazil. Given this highly procyclical nature of imports in Brazil, domestic booms are usually accompanied by a deterioration in the current account. Also notice that the real exchange rate enters both Eqs. (9) and (10) with the expected sign. The point estimates of the corresponding real exchange rate elasticities suggest that imports react more strongly to exchange rate movements than exports do, another observed fact in Brazil.

Our model does not include a detailed description of the fiscal side because we are not concerned about the interaction between monetary and fiscal policies. In fact, government consumption is the only fiscal variable appearing in the model, and we treat it as an exogenous ARMA(2,1) process, which does not affect the simulations presented in the next section.

3.4. Aggregate supply

The CPI inflation and its determinants are the key variables on the supply side of our model. The inflation equation is similar to the empirical counterparts of microfounded new Keynesian Phillips curves, in which current inflation depends on past and expected inflation and on real marginal cost (see, for instance, Galí and Gertler, 1999). We measure real marginal cost by the real unit labor cost – proxy for the cost of domestic inputs – and by the real effective exchange rate – proxy for the cost of imported raw materials (most of Brazilian imports consist of intermediate goods). Our specification also includes the HP-filtered output gap to control for possible missing factors, such as the cost of domestic raw materials:

$$\begin{aligned}\pi_t = {} & \underset{(0.13)}{0.45}\pi_{t-1}^4 + (1 - \underset{(0.13)}{0.45})\pi_{t+4}^4 + \underset{(0.08)}{0.20}\Delta ulc_{t-1} + \underset{(0.02)}{0.04}\Delta q_{t-1} \\ & + \underset{(0.09)}{0.20}\left(\frac{1}{2}\sum_{j=1}^{2}y_{t-j}\right) + \underset{(0.33)}{3.15}\left(d_{02Q4} + d_{03Q1}\right) + \underset{(0.49)}{\hat{\varepsilon}_t^{\Pi}},\end{aligned} \tag{11}$$

where ulc_t is the real unit labor cost, and $\pi_{t-1}^4 \equiv \frac{1}{4}\sum_{j=1}^{4}\pi_{t-j}$ is the four-quarter inflation up to period $t-1$. Using the moving average of lagged inflation, instead of the last quarter inflation, significantly improves the fit of the regression and helps to smooth out the high volatility of inflation at the quarterly frequency. Due to data availability and to improve the goodness of the fit, we use the (instrumented) actual future inflation π^4_{t+4} instead of its expected value from the BCB's survey. Notice that we impose the restriction that the sum of the coefficients on the inflation terms is equal to one, which is not rejected by the data. The estimated short-run pass-through of the real exchange rate is roughly in line with the available estimates in the literature, including those of Belaisch (2003), and Correa and Minella (2010). Also notice that the output gap term is statistically significant even in the presence of two components of the real marginal cost.

Turning to the driving forces of inflation, real unit labor cost is defined as real wage adjusted by labor productivity:

$$ulc_t = w_t - (y_t - n_t). \tag{12}$$

Our formulation for real wages describes their relationship with the business cycle and inflation:

$$w_t = \underset{(0.09)}{0.65} w_{t-1} + \underset{(0.21)}{1.04} y_t - \underset{(0.41)}{1.27}\left(\frac{1}{3}\sum_{j=2}^{4} u_{t-j}\right) - \underset{(0.14)}{0.49}\pi_{t-1} + \underset{(1.09)}{\hat{\varepsilon}^W_t}, \tag{13}$$

where the output gap and the unemployment rate u_t capture, respectively, wage procyclicality and the role played by labor market tightness. Eq. (13) implies that economic booms are accompanied by wage pressures. The negative coefficient on lagged inflation measures the change in wage purchasing power due to the staggered nature of labor contracts. In other words, real wages are negatively affected by inflation surprises. Even though Eq. (13) is data-driven, its determinants also appear on standard wage curves of DSGE models. The main driving force of wages in such equations is the marginal rate of substitution between consumption and leisure, which depends upon the level of consumption (or real income) as well as on the labor input. One key difference between Eq. (13) and its model-based counterpart is that the latter also includes expected wages reflecting the forward-looking nature of wage setting in DSGE models (e.g., Erceg et al., 2000).

Employment is the fraction of the labor force engaged in the labor market, $N_t = L_t(1 - U_t)$. Log-linearizing this identity around its long-run trend gives:

$$n_t = l_t - \frac{\overline{U}}{1-\overline{U}} u_t, \tag{14}$$

where n_t, l_t, and u_t are the corresponding log-linear deviations from trend of employment, labor force and the unemployment rate. $\overline{U}$ is the long-run unemployment rate which we match to the sample average (0.105). We model the labor force as an ARMA(2,1) process, ignoring, for simplicity, any feedback from the economic cycle, such as discouragement effects.

We relate the unemployment rate to the state of the business cycle and to the capacity utilization rate, u^K_t, as follows:

$$u_t = \underset{(0.04)}{0.66} u_{t-1} - \underset{(0.06)}{0.15} y_t - \underset{(0.03)}{0.12} y_{t-1} - \underset{(0.04)}{0.13}\left(\frac{1}{4}\sum_{j=1}^{4} u^K_{t-j}\right) + \underset{(0.20)}{\hat{\varepsilon}^U_t}, \tag{15}$$

The negative coefficients on the output gap describe the countercyclical behavior of unemployment, whereas the negative link with capacity utilization captures the comovement between capital and labor over the business cycle. In the background, we can think of these relations as coming from an inverted aggregate production function, with a high degree of complementarity between capital and labor.

We estimate a procyclical relation for the capacity utilization rate, which also depends on past investment decisions, as follows:

$$u^K_t = \underset{(0.12)}{0.44} u^K_{t-1} + \underset{(0.16)}{0.50} y_t - \underset{(0.03)}{0.13}\left(\frac{1}{4}\sum_{j=1}^{4} i_{t-j}\right) + \underset{(0.72)}{\hat{\varepsilon}^{U^K}_t}, \tag{16}$$

Firms strategically have some excess capacity in order to respond promptly to positive demand shocks and to secure market shares. On the other hand, past investment increases the current stock of physical capital thus relaxing the intensity of capital utilization.

Because the production of new capital goods is more intensive in imported goods than the aggregate production, the relative price of investment goods is largely affected by the real exchange rate. As a result, we estimated the following parsimonious formulation for q^I_t:

$$q^I_t = \underset{(0.17)}{0.38} q^I_{t-1} + \underset{(0.03)}{0.07} q_t + \underset{(1.47)}{\hat{\varepsilon}^{Q^I}_t}, \tag{17}$$

This equation is also consistent with the evidence that appreciations of the real exchange rate tend to boost imports of machinery and equipment and hence investment in Brazil (da Silva Filho, 2007).

Closing the model, the ROW variables are modeled as exogenous autoregressive processes and do not affect the simulations presented in the next section.

4. Results

We consider two solutions for the model. The *baseline solution* assumes that expectations E_t are model consistent. We use this solution when we simulate the model and also when we calculate the baseline decomposition of the transmission channels. The *alternative solution* assumes exogenous expectations and is used only to study the expectations channel in Subsection 4.5. Both solutions satisfy the Blanchard–Ahn conditions for existence and uniqueness and are computed using the Dynare program (Stéphane et al., 2011).

4.1. Business cycle properties

This subsection checks whether the model is capable of replicating key properties of the Brazilian business cycles during the inflation targeting period. In particular, we compare the moment conditions generated by the model with those of the data.[8] Table 2 records the simulation results for key selected variables with those of the data. Overall, the model replicates fairly well most empirical moments. First, the volatility of the variables in the model is very close to the empirical counterparts. Second, as in the data, consumption is more volatile than the output, and the volatility of investment is about three times larger than that of the output; Neumeyer and Perri (2005) document these and other stylized facts for several emerging market economies. Third, the rich lag structure of the model helps to replicate well the observed persistence, as measured by the first-order autocorrelations. Lastly, the model also generates cross-correlations with output that are roughly consistent with their empirical counterparts. However, the model is at odds with the data in some dimensions: it overestimates the cross-correlations between inflation and output, and misses the correct sign of the cross-correlations between net exports and output.[9]

We also compare the actual and simulated cross-correlation structures. Fig. 3 shows the cross-correlations of output (at different lags and leads) with aggregate demand components and with three supply side variables — capacity utilization rate, unemployment rate, and inflation rate. Overall, the model replicates well most empirical

[8] In order to get the model's second moments, we conduct a stochastic simulation using the estimated standard deviations of the error terms from the model equations. We turn on all shocks of the model and run 100,000 simulations, each having the same number of periods as in the sample (36 quarters). For each variable, we compute the average of the following second moments across the simulations: standard deviation, autocorrelation, and cross-correlations with output.

[9] The latter result may stem from the fact that world income in our model – given by the imports of Brazil's top-five trading partners – is more volatile than domestic output. Shocks to the world income tend to generate positive correlations between domestic output and net exports, dominating the possible negative correlations generated by the other shocks.

Table 2
Data and simulated moments.

Variable	Standard deviation		Relative standard deviation		Autocorrelation		Cross-correlation with GDP	
	Data	Model	Data	Model	Data	Model	Data	Model
GDP	1.04	1.00	1.00	1.00	0.60	0.54	1.00	1.00
Consumption	1.44	1.15	1.38	1.14	0.77	0.71	0.61	0.60
Investment	4.20	3.57	4.02	3.55	0.77	0.66	0.78	0.52
Net exports/GDP	1.07	0.87	1.02	0.87	0.79	0.55	−0.24	0.26
Inflation rate	1.07	0.94	1.02	0.94	0.36	0.48	0.12	0.40
Unemployment rate	0.68	0.72	0.65	0.72	0.84	0.85	−0.37	−0.47
Capacity utilization rate	1.21	1.19	1.16	1.18	0.69	0.57	0.58	0.58
Unit labor cost	2.95	2.61	2.82	2.60	0.84	0.76	0.26	0.21
Real exchange rate	8.94	10.05	8.56	10.00	0.70	0.88	−0.13	−0.04

Note: data sample covers the period 1999Q3 to 2008Q2. All moments are generated by HP-filtered data. Relative standard deviation is normalized to that of GDP.

cross-correlations, except that of net exports and, to a less extent, that of inflation.

Our take from the simulations is that, overall, the model replicates quite successfully the major business cycle statistics, despite being at odds with the data in some aspects. Therefore, we see these results as validating the model specifications chosen in the previous section.

4.2. Impulse responses

In this subsection, we assess the overall impulse responses to a monetary policy shock, which are at the center of the channel decomposition presented in the next subsection.[10] Fig. 4 shows the responses to an increase of 100 basis points (0.25 percentage point per quarter) in the policy interest rate, whose own response is determined by the estimated Taylor rule. The first row of the figure displays the dynamics of the policy rate, four-quarter inflation rate and unemployment rate. The second row shows the responses of the aggregate demand components, whereas the last row depicts the dynamics of the driving forces of inflation.

The responses have the expected sign and hump shapes. The monetary policy shock simultaneously affects the two market interest rates (not shown) and the real exchange rate. On impact, real interest rates go up because nominal interest rates rise and expected inflation falls, which reduces consumption and investment via Eqs. (7) and (8), respectively, and hence GDP. Eqs. (13) and (15) imply that the initial output contraction depresses real wages and increases the unemployment rate, both of which contribute to reducing the real payroll, which decreases consumption even further. Additionally, the fall in output reduces investment through the accelerator effect. On impact, the exchange rate appreciates because the policy shock widens the interest rate differential. The monetary tightening also has a negative net effect on real unit labor cost as real wages fall by more than labor productivity. Since the three driving forces of inflation in Eq. (11) – real unit labor cost, exchange rate and output gap – fall with the monetary policy shock, inflation goes down unambiguously.

Turning to magnitudes, the troughs of output and four-quarter inflation are 0.2 and 0.6 percentage points, and occur in the third and fifth quarters, respectively. The timing of the responses is in line with that estimated by Catão et al. (2008), although our magnitudes are slightly higher than theirs. The troughs of inflation and output occur more quickly than in mature economies probably due to the shorter duration of credit contracts in Brazil. A quick response of output is also found in VAR estimations. For instance, Minella (2003) finds that output, measured by industrial production, starts to respond with only a one-month lag to a monetary policy shock.

The net effect on trade balance depends on several factors, some of which display opposite signs. Exports fall because the negative effect from the real exchange rate appreciation dominates the positive effect arising from the fall in domestic absorption. As for imports, the income effect prevails over the price effect, that is, the relatively high income elasticity implies a substantial reduction in imports from the output downturn, which more than offsets the favorable effect from the exchange rate appreciation. As a result, imports fall by more than exports and output, contributing to a mild trade surplus in the first year. As time goes by, output returns to its steady-state value more quickly than the exchange rate, so that the expenditure switching effect prevails, and net exports turn negative before recovering back to the long-run equilibrium. Thus in the case of monetary policy shocks the model generates a countercyclical trade balance in the first year, consistent with the findings of Neumeyer and Perri (2005) for small open emerging market economies.

In a nutshell, monetary policy is able to have a significant effect on inflation, whereas the temporary loss of output and employment represents the underlying stabilization costs. Overall, the impulse responses are qualitatively similar to those generated by standard VAR models. However, unlike the VARs, our model also provides a sensible economic story for the monetary policy transmission mechanism.

4.3. Decomposition of monetary policy channels

We now turn to the decomposition of the monetary policy channels in Brazil. As mentioned in the Introduction section, the key feature of ALS' approach for computing the channels is that the decomposition is exact, i.e., the sum of the individual contributions is equal to the overall effects, thus leaving no unexplained residuals. The only relevant requirement is that the model must be linear.[11] Additionally, ALS' approach can be successfully applied not only to backward-looking models but also to forward-looking models like ours. We identify and quantify the transmission channels following the steps below:

- *Step 1*. We identify all the empirically relevant channels in the model. The number of channels is equal to the number of equations that are *directly* affected by the policy rate, excluding the Taylor rule. Each of these equations is a "point of entry" for the monetary policy shock. In our model, they correspond to Eqs. (2), (3), and (4) (see also Fig. 2);
- *Step 2*. We redefine the policy rate that enters each of these equations as r^j, where $j=1,2,3$ are the corresponding points of entry;
- *Step 3*. For each of these redefined variables, there is a corresponding central bank's reaction function, each specified as in Eq. (1). We then

[10] For the effects of monetary policy shocks in Brazil using a VAR approach, see Céspedes et al. (2008), Minella (2003), and Sales and Tannuri-Pianto (2007).

[11] ALS' approach also works for non-linear models as long as the residuals, due to the inexact decomposition, do not affect the relative contribution of the individual channels.

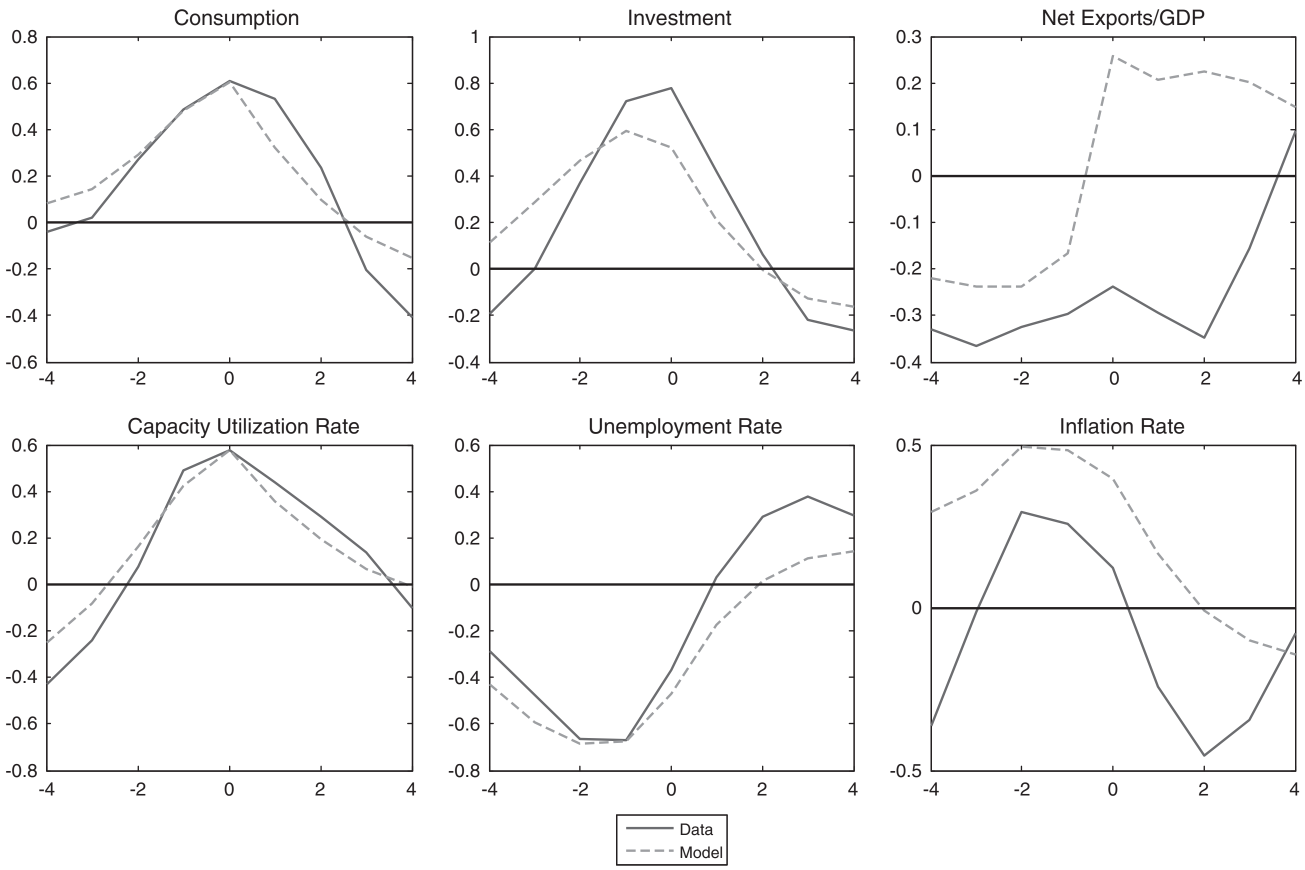

Fig. 3. Cross-correlations between GDP (at quarter j) and variable (i).

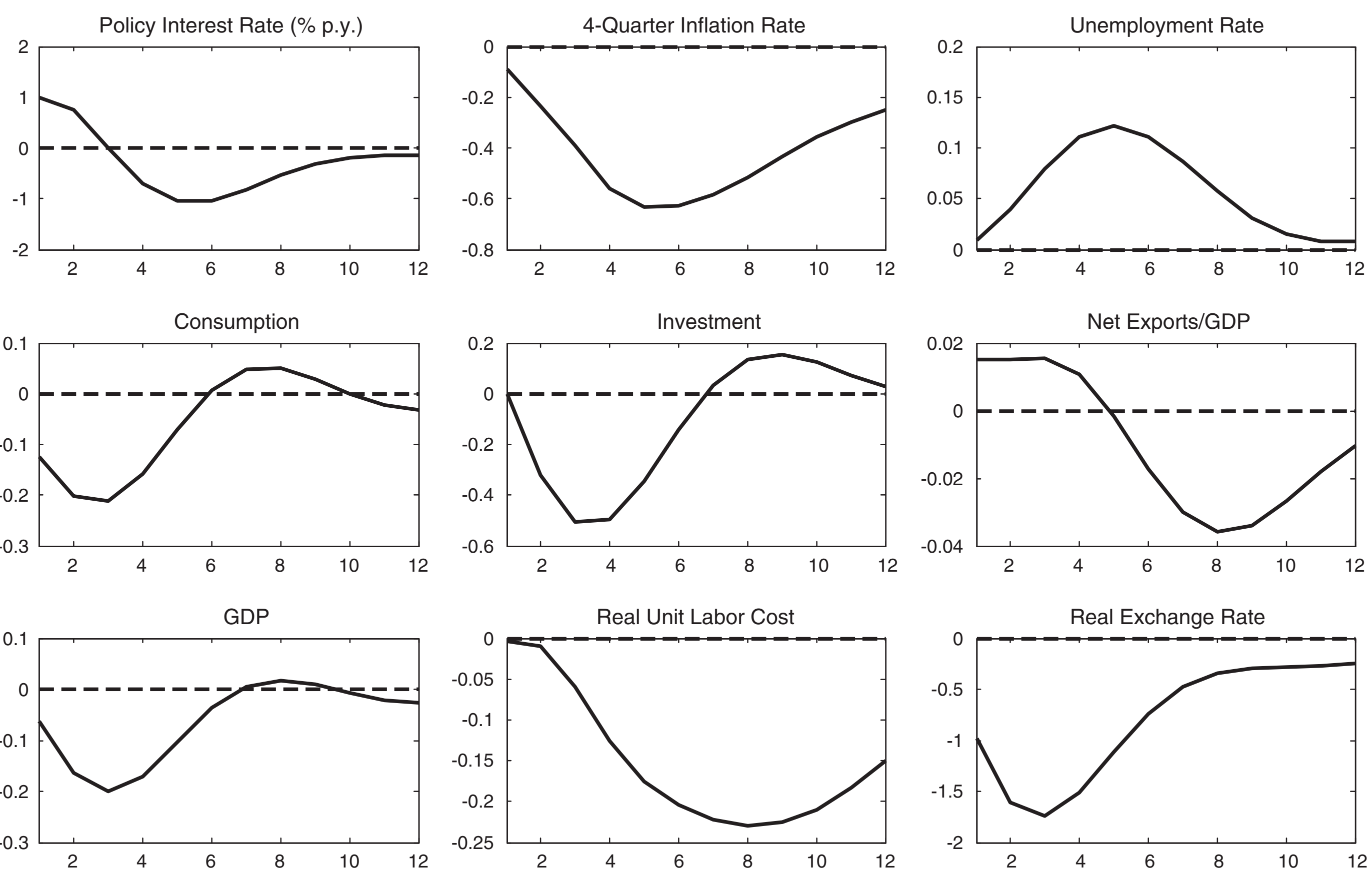

Fig. 4. Impulse responses to a monetary policy shock.

interact a dummy variable ("flag") with the shock term of each policy reaction function, which takes values 0 or 1. The flag f^j takes value 1 if we want to identify channel j in the simulations, and 0 otherwise;

- *Step 4*. We run as many simulations as the number of channels (or flags). In each simulation only one flag is activated, whereas all others are set to zero. Therefore, each simulation will identify and quantify the effects of the channel associated with the activated flag.

4.4. Baseline decomposition

As mentioned before, the policy rate enters the model through the equations describing the household lending rate (Eq. (2)), firm interest rate (Eq. (3)), and the exchange rate (Eq. (4)), corresponding to the three channels in our model: *household interest rate*, *firm interest rate*, and *exchange rate* channels. The first channel captures the intertemporal effects of monetary policy on consumption decisions; the second describes the effects through firms' external financing costs; and the third describes the effects on the real exchange rate and the resulting effects on the real marginal cost of firms and aggregate demand. In this subsection, we focus on the decomposition without identifying the expectations channel.

Fig. 5 presents the impulse responses corresponding to each channel, following the same 100 basis point increase in the policy rate described in the previous subsection. In each panel, the solid line represents the household interest rate channel, the dashed line describes the firm interest rate channel, and the dotted–dashed line represents the exchange rate channel. The sum of the individual effects is equal to the overall effect of the shock shown in Fig. 4.

As expected, the three channels contribute to the *fall in output* in the first five quarters after a monetary policy tightening. An increase in the policy rate immediately raises the household and firm lending rates (not shown) in both nominal and real terms, and appreciates the real exchange rate. Higher interest rates reduce consumption and investment, whereas the lower exchange rate reduces net exports. Note, however, that the exchange rate channel stimulates consumption and investment because the exchange rate appreciation lowers import costs. In terms of relative contribution to the fall in output, the household interest rate channel dominates the other two.

Similarly, the three channels contribute to the fall in inflation over the relevant horizons (up to three years). The two interest rate channels reduce inflation by lowering output and real unit labor cost — key driving forces of domestic inflation. In turn, the exchange rate channel affects inflation both directly via the pass-through to domestic prices (supply side) and indirectly through the output gap (demand side). The relative contributions of the household interest rate and exchange rate channels are roughly identical and are the most relevant ones over the relevant horizon.

The channel decomposition also allows disentangling the opposing effects of monetary policy shocks on net exports, mentioned in Subsection 4.2. On one hand, the exchange rate channel tends to drive net exports down by reducing exports and boosting imports. On the other hand, the interest rate channels tend to stimulate net exports by reducing output and domestic absorption. The combination of the three channels leads to the non-trivial dynamics of the trade balance previously mentioned.

Table 3A presents the *cumulative* effects on output and inflation stemming from each individual channel, at four-, eight- and twelve-

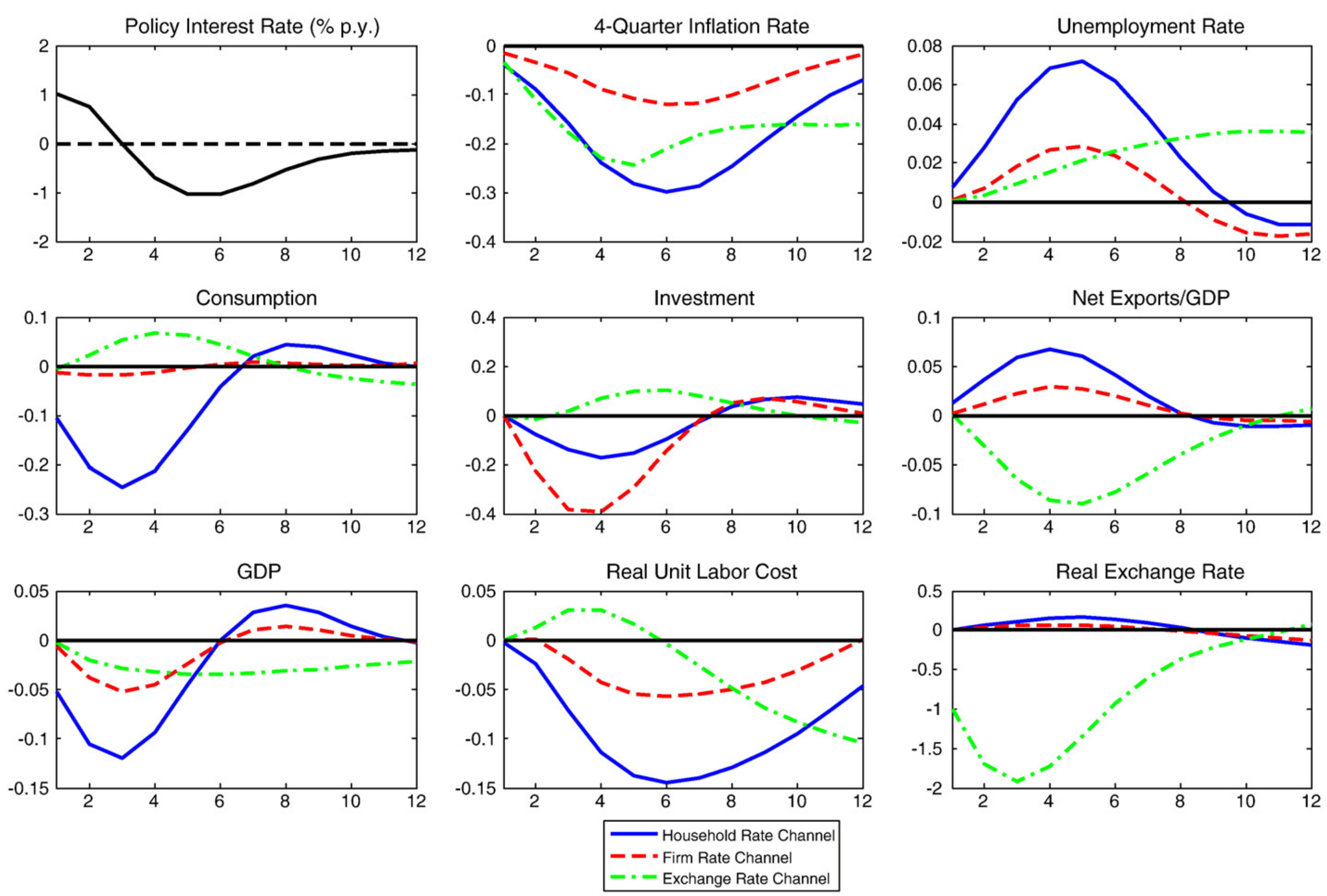

Fig. 5. Baseline channel decomposition.

Table 3A
Baseline decomposition. Relative contribution of each channel to GDP and inflation (%).

Channel	4 quarters	8 quarters	12 quarters
GDP			
1. Household interest rate	62.1	49.3	40.9
2. Firm interest rate	23.9	20.2	17.2
3. Exchange rate	14.1	30.4	41.9
Total	100.0	100.0	100.0
Inflation			
1. Household interest rate	42.7	45.2	42.0
2. Firm interest rate	16.0	17.7	15.8
3. Exchange rate	41.3	37.1	42.2
Total	100.0	100.0	100.0

quarter horizons. The household interest rate channel is responsible for 62% of the fall in output in the first year and about half of the fall in the first two years. The firm interest rate channel accounts for only 24% of the output downturn in the first year, and the exchange rate, for 14%. The latter channel turns out to be more relevant at longer horizons, reflecting the fact that the real exchange rate moves slowly to its long-run level in our model. In contrast, interest rates adjust rather quickly around their long-run equilibrium values, despite the incomplete pass-through in the short run.

The table also shows that the household interest rate and the exchange rate channels are equally important for explaining the behavior of inflation, each accounting for around 40% in all horizons. The important role played by the exchange rate channel in the decomposition is consistent with the fact that real exchange rate movements were a key driving force of domestic inflation over the sample period. Therefore, monetary policy has become more effective relative to the previous period of managed exchange rate regime, when changes in the policy rate were not followed by movements in the real exchange rate. As a result, inflationary pressures warranted a stronger reaction by the central bank.

Two factors explain why the firm interest rate channel plays a secondary role in the decomposition of both output and inflation. First, although investment falls more than consumption, its share in GDP is lower than that of consumption. In fact, the investment share in Brazil is lower than in other emerging market economies with similar levels of development. Second, a large fraction of private investment is financed through state-owned development banks, whose lending decisions and loan pricing are not driven by market conditions. We conjecture that if private institutions accounted for a larger share of investment financing, the interest-rate elasticity of investment would be higher and the firm interest rate channel would be stronger than what is suggested by our estimations.

4.5. The role of expectations

Both the literature and policymakers have emphasized the role played by expectations in macro dynamics (e.g., Woodford. 2003 and Bank of England, 1999). In particular, there is a widespread view that inflation expectations work as an important transmission mechanism of monetary policy. However, identifying and measuring the so-called expectations channel are a difficult task because it is entangled with the other transmission channels. To better understand how the expectations channel is intertwined with the other channels, consider the case of the Phillips curve. Solving it forward, we find that agents' expectations of future inflation are translated into expectations of the driving forces of inflation (unit labor cost, real exchange rate, and output gap). The behavior of these driving forces can be fully decomposed into non-expectations channels, apparently leaving no role for a separate expectations channel.

In order to get a sense of this channel, we run the previous model (*baseline model*) assuming that private agents' inflation expectations do not respond to the monetary policy shock (*exogenous-expectation model*).[12] These impulse responses provide the overall contribution of non-expectations channels. We then compare the responses of output and inflation in the baseline model with those coming from the exogenous-expectation model. The difference between the two is our proxy for the contribution of the expectations channel to the behavior of the model variables.

Fig. 6 compares the overall impulse responses from the baseline model with those under exogenous expectations. Although the responses display a similar pattern in both cases, they still differ in terms of timing and magnitude. For instance, output falls by more in the baseline model because real interest rates react more strongly to a monetary policy tightening than in the exogenous-expectations model. The reason is that expected inflation goes below the inflation target after the shock in the baseline model but by assumption remains constant in the exogenous-expectations model. Similarly, the reaction of inflation is faster and stronger in the baseline model because of the higher fall in output and because expectations regarding future inflation reduce current inflation, whereas they play no role in the exogenous-expectations model.

Table 3B reveals that the expectations channel is more relevant for output dynamics in the short run (up to a year), but weakens substantially as the time horizon increases. This happens because model-consistent expectations tend to adjust rather quickly to shocks. Over longer horizons, however, the model's internal dynamics – constrained by the estimated lags of the transmission mechanism – become more relevant for the propagation of the initial monetary policy shock. Interestingly, the household interest rate channel is robust to the explicit consideration of the expectations channel, still accounting for about a third or more of the output response, depending on the time horizon.

On the other hand, the expectations channel is the single most important channel for inflation. It accounts for about three quarters of the inflation response in all horizons. We interpret this number as an upper bound for the true contribution of the expectations channel because actual inflation expectations probably move less than in our baseline model. Even considering that our decomposition may overstate the true contribution of the expectations channel, it is in line with the theoretical view emphasizing the role played by expectations in macro dynamics. Moreover, it provides further empirical evidence that expectations are indeed a key element in the transmission mechanism, consistent with previous findings regarding their role in the credibility of the inflation targeting regime and the conduct of monetary policy in Brazil (Bevilaqua et al., 2008 and Carvalho and Minella, 2012).

5. Concluding remarks

To our knowledge, we are the first to document the channel decomposition of monetary policy in Brazil using an economic model and covering the inflation targeting regime. We develop, estimate and use the model to decompose the monetary policy effects into four important individual channels. We found that the household interest rate channel is the most important for output dynamics, whereas this channel together with the exchange rate channel are the most relevant for inflation dynamics. However, when we consider the expectations channel in the decomposition, it emerges as the most important one for understanding the responses of inflation to monetary policy decisions.

Looking into the future, we anticipate that other channels may become relevant as the Brazilian economy develops and its financial markets deepen. Among the potential competing channels, we highlight the so-called wealth and credit channels. The increasing appetite of the

[12] In our setup, private sector's inflation expectations appear in Eqs. (4), (7), (8) and (11).

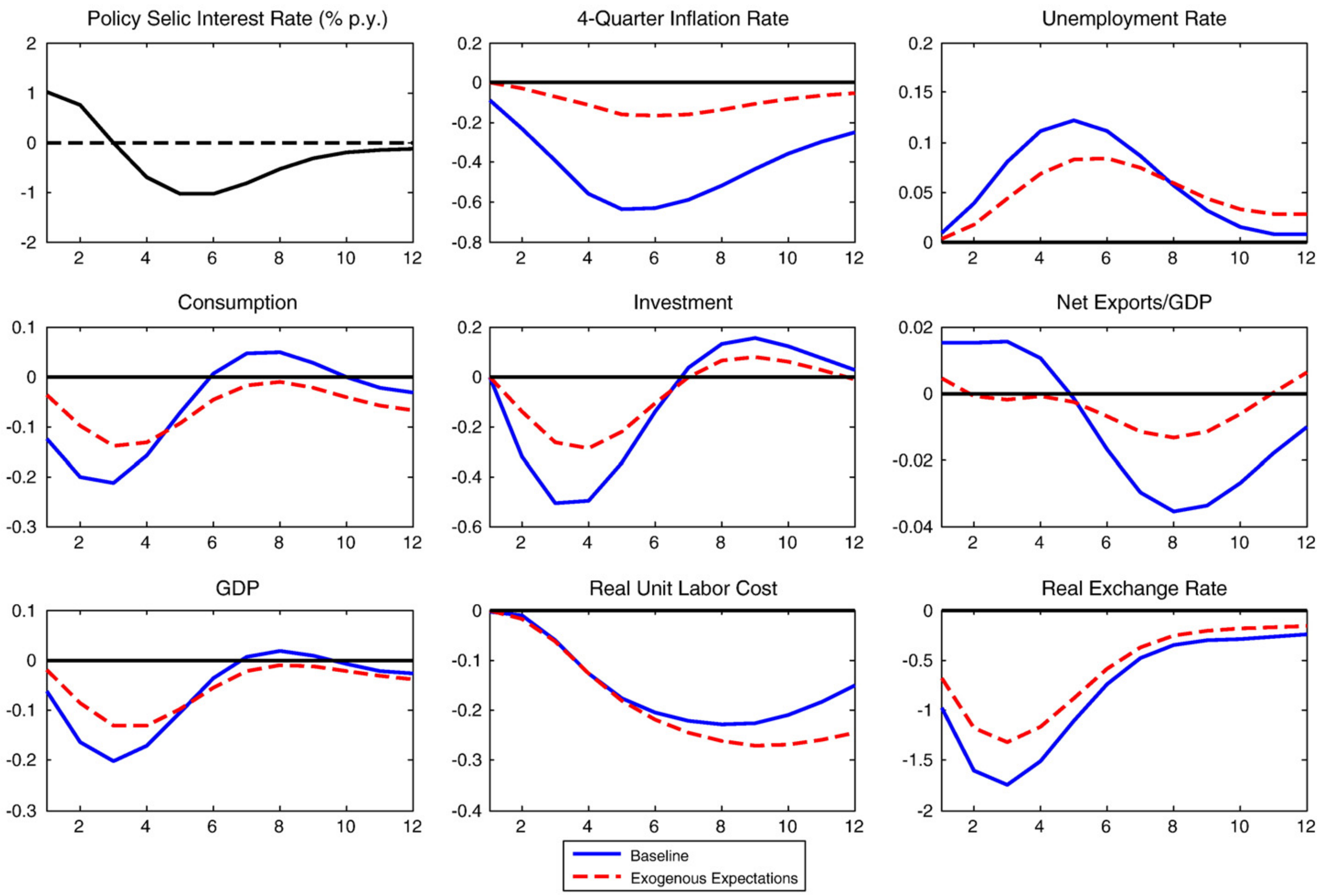

Fig. 6. Channel decomposition with and without the expectations channel.

emerging middle class for the stock market, together with the growing share of government bonds with fixed interest rates and longer maturities, may strengthen the wealth channel in Brazil. Moreover, the rapid development of the credit market has become an important element in the country's business cycle.[13] The recent worldwide financial crisis leaves no doubt about the importance of understanding better the credit channel and all related financial linkages.

Appendix A

The variables and the corresponding sources used in the estimation are the following. GDP and aggregate demand components are chain-weighted seasonally adjusted series from the National Accounts, calculated by the Brazilian Institute of Geography and Statistics (IBGE). This institution also provides the labor market data – wage, employment, unemployment rate, and working-age population – and the CPI-based inflation – the Broad National Consumer Price Index (IPCA). Data on the real effective exchange rate, Selic interest rate, household lending rate – which is a weighted average of lending rates on consumer loans – and NFA (proxied by net external debt) comes from the BCB. Data on inflation expectations is also taken from the BCB, through a survey with professional forecasters. The 360-day swap pre-DI rate (our proxy for firms' external financing costs) is provided by the Brazilian Mercantile & Futures Exchange (BM&F), and the capacity utilization rate by the Getulio Vargas Foundation (FGV). Country-risk premium is measured by the EMBI Brazil, calculated by JP Morgan, and the foreign investors' risk aversion (Ravi) is calculated by Merrill Lynch. Our proxies for the world inflation and the world interest rate are the U.S. CPI inflation and the federal funds rate, respectively. World imports are a weighted average of the total import volumes of the European Union, the United States, China, Argentina and Japan – Brazil's top-five trading partners – and come from the IMF's International Financial Statistics (IFS) and from national bureaus of statistics.

Table 3B
Decomposition identifying the expectation channel. Relative contribution of each channel to GDP and inflation (%).

Channel	4 quarters	8 quarters	12 quarters
GDP			
1. Household interest rate	41.4	37.2	32.9
2. Firm interest rate	15.9	15.1	13.1
3. Exchange rate	4.4	24.9	40.6
4. Expectation	38.4	22.7	13.5
Total	100.0	100.0	100.0
Inflation			
1. Household interest rate	6.4	10.4	9.3
2. Firm interest rate	1.7	4.0	3.5
3. Exchange rate	12.5	8.8	10.0
4. Expectation	79.4	76.7	77.2
Total	100.0	100.0	100.0

[13] The assessment of the credit channel, however, involves the use of different tools and datasets. So far, the empirical evidence about the credit channel in Brazil is not conclusive. The results seem to be sensitive to differences in methodology, datasets and sample periods. See, for instance, Coelho et al. (2010), Souza-Sobrinho (2003), and Takeda et al. (2005).

The sample period is 1999Q3–2008Q2. All series are filtered with the HP filter, using the 1996Q1–2008Q2 period to reduce the beginning-of-the-sample problem associated with this filter. Variables displaying a seasonal pattern were seasonally adjusted either by the original source or by us using U.S. Census Bureau's X12 method. We take the natural log of all series, except for net exports, Ravi and net external debt. In the case of the inflation rate, inflation target and interest rates, we use the log of the gross rates, and express them as percentage per quarter in the estimations.

Because data on inflation expectations is available from 2000 onward, the sample period is shorter for some equations. Most lagged values were also restricted to start in 1999Q1, therefore excluding the period of the managed exchange rate regime (1995–1998). As we can see in Table 1, actual sample periods may be shorter than 1999Q3–2008Q2 due to the availability of instruments. These are used with parsimony in the 2SLS regressions and satisfy two selection criteria: they are pre-determined in time, and have high correlation with the instrumented variables.

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