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Has the Central Bank of Brazil's reaction function become destabilizing?

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Has the Central Bank of Brazil's reaction function become destabilizing?

Abstract

The purpose of this paper is to estimate a forward-looking monetary policy reaction function for the Brazilian economy over the 2003 to 2016 period. Additionally, we test whether the two main parameters of this reaction function, the gaps between expected inflation and output and their respective target levels, changed under Alexandre Tombini's chairmanship of the Central Bank of Brazil. The main results of the study suggest that: i) the monetary policy rule followed by the Central Bank of Brazil was not destabilizing; ii) during the Tombini era, the output gap parameter increased and the expected inflation gap decreased, but the monetary policy rule remained compatible with macroeconomic stability, and iii) there is evidence that the Central Bank of Brazil took exchange rate shocks into consideration in its reaction function.

Keywords: Taylor rule, macroeconomic stability, Central Bank of Brazil, monetary policy.

JEL Classification: E31, E37, E52, E58.

1. Introduction

Taylor (1993) argued that complex decision-making in monetary policy could be described by a simple algebraic rule in which the monetary authority takes the following variables into account in order to determine the short-run interest rate: i) long-run policy rate; ii) deviations between the inflation rate and its target; and iii) the log difference between actual output and its potential level (measured by a log-linear trend). The "Taylor rule", as it became known, adapted very well to data for the US economy for the 1987-1992 period, although both parameters for this rule and the long-run policy rate were obtained informally. Over the last two decades, however, several researchers have focused on estimating the parameters of Taylor-type reaction functions using certain econometric methodology. Some examples of this literature can be found in Goodhart (1997), Judd and Rudebusch (1998) and Clarida, Galí and Gertler (1998 and 2000), while this approach has also been used to set out a desirable monetary policy.

In the case of Brazil, following the adoption of an inflation targeting regime in July 1999, estimates for the Central Bank of Brazil's (CBB)¹ reaction function have not been in short supply, although such studies have used varied specifications, methodologies, databases and periods. Not surprisingly, the results found in the literature are sometimes contradictory, and it is difficult to compare the econometric estimates reported within them. The most recent studies come from Medeiros, Portugal and Aragón (2016), who used monthly data from January 2000 to December 2013, and from Barbosa, Camêlo and João (2016), who estimated the CBB's reaction function using monthly data from January 2003 to December 2015.

¹ Minella et al (2003), Holland (2005), Soares and Barbosa (2006), Teles and Brundo (2006), Gonçalves and Fenolio (2007), Barcellos Neto and Portugal (2007), Mello and Moccero (2009), Aragón and Portugal (2010), Moura and Carvalho (2010), Sánchez-Fung (2011), Aragón and Medeiros (2014), Moreira (2015), Barbosa, Camêlo and João (2016) and Medeiros, Portugal and Aragón (2016) .

Medeiros, Portugal and Aragón (2016) considered a nonlinear reaction function for the CBB and found evidence that i) there was a structural break in the Taylor rule parameters in the third quarter of 2003; ii) there was an increase in the CBB's response to the output gap and a reduction in its reaction to the inflation gap during the Meirelles-Tombini period (2003-2015); and iii) the CBB reacted to movements in the exchange rate during the Meirelles-Tombini era. Barbosa, Camêlo and João (2016) estimated a Taylor rule under the hypothesis that the long term equilibrium interest rate is time varying and found evidence that the inflation gap parameter decreased and the output gap coefficient increased during the first Dilma Rousseff presidential administration (2011-2014). As well as verifying that a change in the CBB's reaction function occurred during the Dilma Rousseff administration, the empirical evidence established by the authors did not reject the hypothesis that the CBB took account of the real exchange rate in its decision-making process.

This work aims to contribute to this literature, setting out new evidences for the CBB's reaction function, paying particular attention to the monetary policy's stabilizing role. To this end, we consider the case of a small open economy and use monthly data from the 2003.01 to 2016.12 period. In our econometric estimations, we take the long term equilibrium interest rate to be constant, as is more commonly seen in the related literature, and consider different output gap measures. In addition, following the contributions of Barcellos Neto and Portugal (2007), Gonçalves and Fenolio (2007) and Barbosa, Camêlo and João (2016), using a dummy variable, we test whether the coefficients for the inflation expectations and the output gap, which are the main coefficients of the Taylor-type reaction function, changed over a specific period. The central concern of this paper is to verify whether there were statistically significant differences in these parameters during Alexandre Tombini's time at the CBB² (January 2011 to May 2016), and whether the CBB reaction function became destabilizing, in the sense described by Clarida, Galí and Gertler (1998 and 2000). In these authors' definition, the monetary policy is stabilizing if the central bank systematically raises the real and nominal interest rates in response to higher expected inflation.

The paper is structured as follows: Section 2 presents the motivations for the study, with some preliminary evidence and descriptive analysis. Section 3 describes our policy rule specification and the database used in the empirical analysis. In Section 4, the main results are presented and compared to the existing literature. In Section 5 we conduct certain robustness checks, while the main conclusions are summarized in the final section.

2. Motivation and background

The main motivation for this work is the hypothesis of changing CBB reaction function parameters during the Alexandre Tombini era. If the monetary authority became lenient

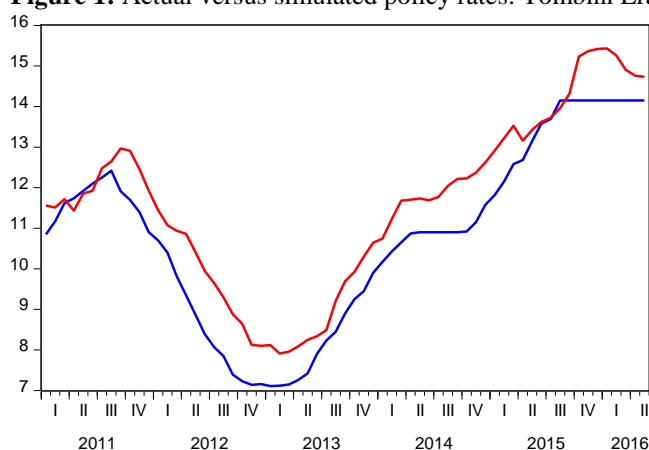
² Henrique Meirelles was Chairman of the CBB from 2003 to 2010 and was Alexandre Tombini's predecessor. Tombini left the presidency of the CBB following Dilma Rousseff's impeachment. Ilan Goldfajn has been Chairman since June 2016.

in order to combat inflation during this period, changes in the nominal interest rates were not sufficient to anchor expected inflation to its target. This tends to create a high inflation rate and, for this to be controlled, a significant social cost, in terms of output and employment, has to be paid, so that the economy can converge towards stability.

The CBB was not able to meet its inflation target in the Tombini era. In January 2011, following a year of strong economic growth, expected inflation for the next 12 months was approximately 5.7%, while in January 2016, in the midst of a deep recession, expected inflation rose to 7.3%, almost 3 percentage points above the established inflation target for that year. At the same time, the mean squared error of the deviation of inflation expectations from the target (a measure of expected inflation variability) was 3 times greater in the Tombini era in comparison with the Meirelles one (2.43% versus 0.79%). This deterioration in expectations had an impact on the CBB's credibility. According to the credibility index suggested by de Mendonça (2007), the CBB's credibility fell from 0.41 in January 2011 to 0.19 in May 2016, on a scale ranging from 0 (no credibility) to 1 (full credibility).

In this broader context, the first research step was to estimate a simple forward-looking monetary policy reaction function for the Meirelles era (2003.01 to 2010.12) and record its estimated parameters. We then calculated the policy rate (known as the Selic rate) which would be confirmed in the Tombini era should these parameters remain unchanged. In the estimated policy rule (using monthly data and the Ordinary Least Square method), the basic interest rate is a function of a constant, its lagged value in two periods, the actual output gap and the difference between expected inflation and its target. The estimated parameters were [0.79; 0.92; 0.14 and 0.67], respectively, all of which are statistically significant at 5%. Figure 1 shows the evolution of both the simulated (red line) and actual (blue line) policy rates during the Tombini years.

Figure 1: Actual versus simulated policy rates: Tombini Era

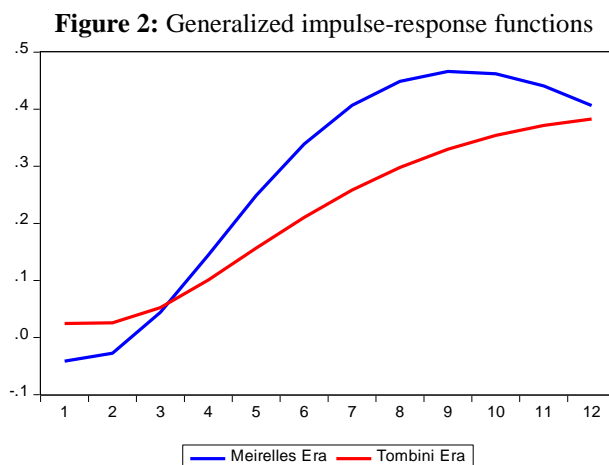


We note that the actual policy rate remained below the simulated rate over nearly the entire period, although the policy rate observed at the end of the Tombini era was just over 3% higher than that observed at the beginning. The permanent difference between these two rates is an indication that the monetary policy changed post-2011, at least

compared to the monetary policy rule over the previous period, and that adverse supply shocks were not taken into account in either period³.

In fact, when the actual real interest rate was compared to the time-varying long term equilibrium interest rate⁴, calculated using the Hodrik-Prescott (HP) filter, we noted that from the first half of 2012 to the third quarter of 2013 monetary policy remained expansionist: the actual interest rate was lower than one which, theoretically, could maintain the output gap at zero and inflation at its target level. Not coincidentally, official data demonstrates that the expected inflation over these seven quarters ranged from 5.33% to 5.96%, at a time when the inflation target was 4.5%. On the other hand, when we compared the expected market inflation twelve months ahead with the ex-post accumulated inflation rate twelve months later, we saw that, over the entire Tombini era, the forecast error (expected inflation minus ex-post inflation) remained negative, while in the Meirelles era this forecast error oscillated between negative and positive values. This suggests that the dynamic behavior of expected inflation was more favorable to the central bank under the Tombini chairmanship.

Remaining with our preliminary analysis, we estimated Vector Autoregression (VAR) models with variables: interest rate, output gap and the gap between expected inflation and its target. Following estimations and analysis of the main diagnostic tests, the impulse-response functions were computed for two distinct subsamples: one for the Meirelles and another for the Tombini era. The generalized impulse-response functions of the two VAR models, both with two lags, are shown in Figure 2. These are the interest rate responses over twelve periods due to shocks of one standard deviation (0.92% in the annualized rate) in the gap between expected inflation and its target.



We note that the interest rate response is only significant at a 95% confidence interval following the fourth period (in the case of the Meirelles era) and the sixth period (in the

³ In terms of the inflation of monitored prices, we observe that variation in these prices, which are not sensitive to interest rate movement, only surpassed the accumulated annual inflation mark of 6% in two periods. The first was in the Meirelles era, from the first half of 2003 to the third quarter of 2006, and the second was in the Tombini era, from the first quarter of 2015 to the second quarter of 2016.

⁴ For the real interest rate we used the pre-DI SWAP rate for 360 days discounted from inflation expectations for the following 12 months. Neither the real interest rate nor the equilibrium real interest rate are reported here, but are available on request.

Tombini one). It is possible to observe that, although the response of the interest rate is positive in the two subsamples, for most of the simulation horizon, the interest rate response of the Meirelles era is higher following the third period. Indeed, the cumulative impact on interest rates in the twelfth period after the expected inflation shock is 3.3% in the first subsample and 2.6% in the second. This suggests that the monetary policy was less reactive to deviations in expected inflation during the Tombini era than in the Meirelles one. These same impulse-response function patterns are observed when the VAR models are estimated with 3 and 4 lags.

In general, the results of the exercises performed in this section suggest, albeit in a preliminary manner, that the parameters of the CBB's reaction function changed under the Alexandre Tombini chairmanship, so that monetary policy became more flexible and potentially destabilizing. One justification for this change in monetary authority behavior is a greater concern with economic growth⁵, which ends up generating more inflation without the guarantee of better dynamism in the real GDP growth rate over the medium term. In fact, the average inflation rate during the Tombini era was 0.5% higher than the same rate during the Meirelles era, which includes the atypical year of 2003. The average real GDP growth rate, on the other hand, was 3.5% lower. However, the causal relationship between the flexibility of monetary policy and the depth and duration of the recession that began in 2014 will not be investigated here.

3. Model specification and database

Based on the contributions of Judd and Rudebusch (1998) and Clarida, Galí and Gertler (1998), the monetary policy reaction function considered in this study has partial adjustment and assumes the following format:

$$i_t = \rho \cdot i_{t-2} + (1 - \rho)[\alpha_1 + \alpha_2(\pi^e - \pi^*) + \alpha_3 h_t + \alpha_4(e_t - \bar{e}_t)] + \varepsilon_t. \quad (1)$$

According to this forward-looking specification of the Taylor rule, in addition to a constant (α_1) and its value lagged in two periods (i_{t-2}), the interest rate in each period of time (i_t) depends on the gap between expected inflation (π^e) and the inflation target (π^*), the output gap (h_t) and the percentage change in the real exchange rate in relation to its long-term trend ($e_t - \bar{e}_t$). It is assumed that the error term (ε_t), which represents random exogenous shocks in the basic interest rate, is i.i.d, and that the parameter measuring the degree of interest rate smoothing (ρ) is in the interval (0,1).

If we define $\beta_1 = (1 - \rho)\alpha_1$; $\beta_2 = (1 - \rho)\alpha_2$; $\beta_3 = (1 - \rho)\alpha_3$; $\beta_4 = (1 - \rho)\alpha_4$,

⁵ While it cannot be categorically stated that the CBB was the target of political interference during the Tombini era, certain statements made by President Dilma Rousseff in South Africa on 03/27/2013 are symptomatic: "I do not agree with anti-inflation policies that look at the issue of economic growth" (...) "we do not think that inflation is out of control. On the contrary, we think it is controlled, and there are changes and conjunctural fluctuations". We note that in March 2013 the inflation accumulated over 12 months exceeded the upper target limit (6.5%), while the expected inflation for the following 12 months was 5.53%, one percentage point above the central inflation target.

the monetary policy reaction function can be rewritten as follows:

$$i_t = \rho.i_{t-2} + \beta_1 + \beta_2(\pi^e - \pi^*) + \beta_3 h_t + \beta_4(e_t - \bar{e}_t) + \varepsilon_t \quad (1')$$

β_i , $i = 1, \dots, 4$ are the short term parameters and α_i , $i = 1, \dots, 4$ are the long term ones. It is expected that all the estimated parameters will present a positive signal, since it is assumed that the monetary authority demonstrates countercyclical behavior and that real exchange rate devaluations are accommodated through monetary policy. In particular, it is expected that the parameter $\alpha_2 = \beta_2 / (1 - \rho)$ will be greater than one. Given an increase in expected inflation, for instance, the central bank should increase the nominal interest rate more than proportionately above the increase in expected inflation, so that the real interest rate will also be affected in the same direction⁶. When discussing this, Clarida, Galí and Gertler (2000, p. 152) show that $\alpha_2 = \beta_2 / (1 - \rho) > 1$ and $\alpha_3 = \beta_3 / (1 - \rho) > 0$ are necessary conditions for the forward-looking monetary policy rule to be stabilizing. These authors point out that, should these conditions not be confirmed, the monetary policy rule is likely to be destabilizing.

In line with the literature, the lagged interest rate was considered in the monetary policy rule, in order to capture the stylized fact of the central bank's smooth adjustments to the interest rate⁷. However, unlike the literature consulted for Brazil, the second lag of interest rate was considered, rather than the first. We proceeded thus because, after 2006, the CBB's Monetary Policy Committee held its meetings to set the interest rate target every 45 days.

In order to include the exchange rate shock within the model, some authors, such as Ball (1998), Hausmann, Ugo and Ernesto (2001), Taylor (2002) and Calvo and Reinhart (2002), argue that in small open economies with a floating exchange rate regime and subject to external shocks, as is the case of Brazil, exchange rate dynamics should be carefully monitored. In this case, the monetary authority tends to react to these exchange rate movements with changes to the nominal interest rate or with international reserves⁸. In addition, works that estimate versions of the monetary reaction function for

⁶ This condition is similar to the well-know "Taylor principle": the proposition that monetary authorities can stabilize the economy by raising their basic interest rate more than one-for-one in response to higher inflation. Note that in the context of a simple New Keynesian model, if the condition described above is not verified, higher expected inflation causes a reduction of the ex-ante real interest rate, which stimulates demand and generates higher inflation. In this case, the macroeconomic equilibrium becomes indeterminate and the monetary policy rule does not prevent fluctuations due to self-fulfilling expectations. Clarida, Gali, and Gertler (2000), for example, argued that the failure of Federal Reserve policy to satisfy this condition may have been the reason for the macroeconomic instability in the US in the 1960s and 1970s.

⁷ For a more in-depth discussion of this topic, see Goodhart (1997) and English, Nelson and Sack (2003).

⁸ One the one hand, Minella et al (2003, p. 25) included exchange rates in their monetary policy rule and pointed out that "the central bank may react to exchange rate movements to curb the resulting inflationary pressures and to reduce the financial impact on dollar denominated assets and liabilities in the balance sheet of firms". On the other hand, Taylor (2000) argues that the monetary policy rule in which the central bank reacts directly to movements in the exchange rate (in addition to inflation and output) does not work as well in terms of stabilizing inflation and economic activity when compared to a simple rule in

the Brazilian economy generally include exchange rate shocks (real or nominal) in some specifications. In this research, we used monthly data for the period from 2003.01 to 2016.12.

In the light of these considerations, we now move to a description of the variables used in our empirical analysis. The interest rate (the policy rate) is the nominal Selic rate accumulated in annual terms and was obtained from the CBB website. This rate is controlled by the CBB and is the main instrument of monetary policy in Brazil. Expected inflation over the next twelve months is measured by the median of market expectation for the accumulated variation in the consumer price index (IPCA), the official price index for Brazil's inflation targeting system. This series was obtained from a survey undertaken by the CBB from a sample of 100 financial market participants and is available in its "Focus Bulletin".

The inflation target is the central target for IPCA variation over the current and following years, defined by the Brazilian National Monetary Council (CMN). The expression proposed by Minella et al (2003) was used to calculate the gap between expected inflation and its target level in the years in which the current year's inflation target differed from the subsequent year's one⁹.

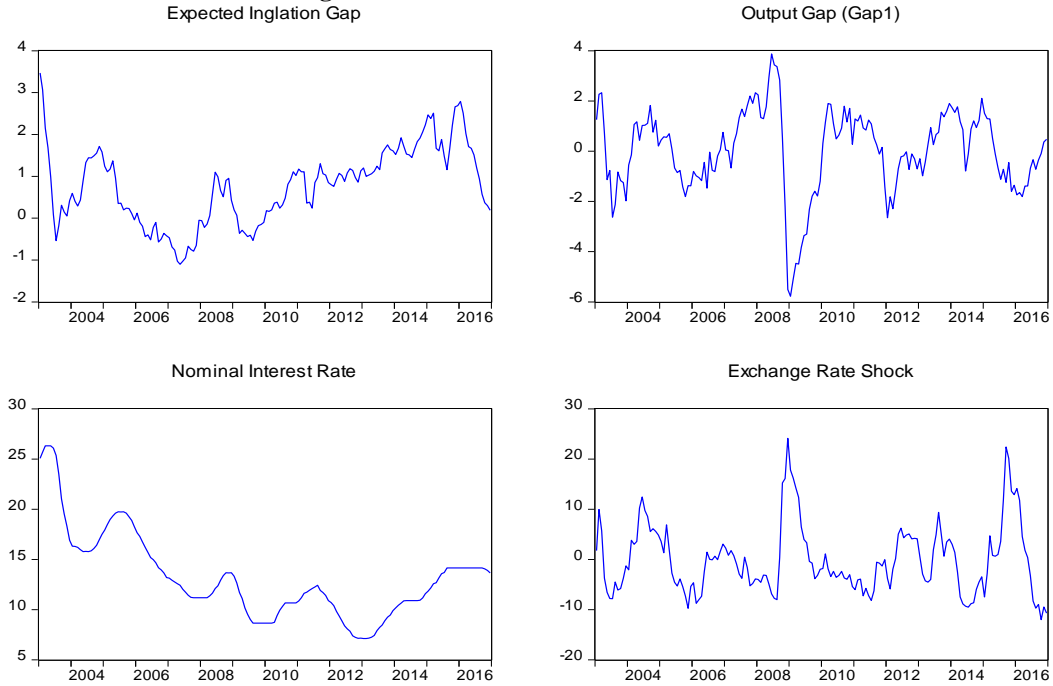
We considered four alternative output gap measures: i) Gap1: the percentage variation in the seasonally adjusted economic activity index, called the IBC-Br (extracted from the CBB website), around its potential level, calculated using the HP filter ($\lambda=14.400$); ii) Gap2: the regression residuals between the IBC-Br and the combination of one linear and one quadratic trend; iii) Gap3: the percentage variation of seasonally adjusted industrial production, extracted from the Brazilian Institute of Geography and Statistics (IBGE) around its long-run trend (using the HP filter) and iv) Gap4: variation in the level of industry capacity utilization (obtained from the Ipeadata website), around its long-run trend (using the HP filter). For its part, the exchange rate shock is the percentage change in the real effective exchange rate (obtained from the CBB website) in relation to its long-run trend (calculated using the HP filter).

The standard model is the one that considers the first output gap proxy. Figure 3 contains the variables used in this specification:

which the central bank only reacts indirectly to exchange rate shocks. The author also points out that, in the case of developed economies, if the central bank reacts strongly to movements in the exchange rate, the product performance tends to deteriorate, which was why he decided not to insert the exchange rate in the rule suggested in his seminal 1993 work.

⁹ The expression used was the following weighted average: $\left(\frac{12-t}{12}\right)(\pi^e - \pi_{year_1}^*) + \frac{t}{12}(\pi^e - \pi_{year_2}^*)$. Note that when the inflation target of one year is identical to the inflation target of the next year, this expression can be simplified as the simple difference between expected inflation and its target.

Figure 3: Series used in the standard model



Following the majority of the empirical literature, the forward-looking monetary policy reaction function was estimated by the Generalized Moment Method (GMM). One of the justifications for using this, rather than the traditional Ordinary Least Squares (OLS), method is that the GMM corrects occasional endogeneity problems, thus avoiding inconsistency in estimated parameters. The expected inflation variable, for example, is probably endogenous, as Clarida, Galí and Gertler (1998, 2000) and Gonçalves and Fenolio (2007) have argued. We note that the instruments used in each estimation must be uncorrelated with the error term. Since the lagged explanatory variables possess this property, they are immediate instruments. Following this principle, the interest rate lagged in two periods was used as its own instrument, while the instruments for the other explanatory variables were their values lagged in one period. In addition, following the suggestion of Gonçalves and Fenolio (2007), we used, in our vector of instruments, the first difference of the Pre-DI SWAP rate for 30 days (this was obtained from the CBB website) and discounted from the country-risk, as measured by the EMBI+ Brazil (Emerging Markets Bond Index Plus) index of JP Morgan Bank.

4. Results

Before estimating the parameters of the monetary policy rule, we tried to ascertain whether the time series used in this study were stationary. This procedure was adopted in order to avoid obtaining spurious results. The question is whether the interest rate and the gap between expected inflation and its target level were stationary, since we know that, by definition, the other series are $I(0)$. The Augmented Dickey-Fuller (ADF) and the Phillips-Perron (PP) tests were used in the specification with no constant and no

trend. The null hypothesis for these two tests is that the series has a unit root against the alternative of stationarity. The statistics for these tests are shown in Table 1.

Table 1

Variable	ADF	PP
i_t	-1.84 ^{***} (4)	-1.73 [*] (9)
$\pi^e - \pi^*$	-2.90 ^{***} (1)	-3.08 ^{***} (6)

Note: ^{***} denotes significance at 1%, ^{**} at 5%, ^{*} at 10%.

As can be seen, it is possible to reject the unit root null hypothesis for the two series at the usual levels of significance. Thus, since uncertainty about the stationarity of the variables has been reduced, the empirical analysis that follows will consider these variables in level, alongside the output gap and the exchange rate shock measures.

The main results of the econometric estimations are presented in Table 2. All the estimates are consistent with the presence of heteroskedasticity and serial autocorrelation in the residuals. We chose White as the estimation weighting matrix in order to calculate the standard errors.

Table 2: Monetary policy reaction function

Dependent variable: Interest rate

Parameters	GMM	GMM	GMM	GMM
β_1	-0.06 (0.22)	-0.10 (0.25)	-0.05 (0.23)	0.25 (0.26)
ρ	0.97 ^{***} (0.01)	0.97 ^{***} (0.02)	0.97 ^{***} (0.02)	0.94 ^{***} (0.02)
β_2	0.36 ^{***} (0.03)	0.39 ^{***} (0.04)	0.32 ^{***} (0.05)	0.47 ^{***} (0.06)
β_4	0.02 ^{**} (0.008)	0.03 ^{***} (0.01)	0.02 ^{**} (0.01)	-0.01 (0.01)
$\beta_{3,Gap1}$	0.29 ^{***} (0.03)			
$\beta_{3,Gap2}$				0.01 (0.01)
$\beta_{3,Gap3}$		0.16 ^{***} (0.02)		
$\beta_{3,Gap4}$			0.48 ^{***} (0.06)	
OBS	166	166	166	166
R ²	0.97	0.97	0.97	0.96
Kleibergen-Paap rk LM statistic	62.2 ^{***}	50.4 ^{***}	48.2 ^{***}	49.2 ^{***}
Hansen J (p-value)	0.31	0.21	0.26	0.78

Note: ^{***} denotes significance at 1%, ^{**} at 5%, ^{*} at 10%. Standard deviations are in brackets.

First, it should be noted that in all the estimated models the short term coefficients of the output gap and the difference between expected inflation and the inflation target were positive, as expected in a central bank that follows an inflation targeting regime. However, the output gap coefficient calculated from the combination of trends was not significant. Note that the numerical difference between the estimated parameters depends on the proxy used for the output gap variable. The smallest short term coefficient for the expected inflation variable was 0.32, while the highest was 0.47. On

the other hand, the statistically significant short term coefficients for output gap ranged from 0.16 to 0.48.

Taking the standard model into account, the long term expected inflation gap coefficient was $0.36/(1-0.97)=12$, while that for the output gap was $0.29/(1-0.97) =9.7$. We also noted that in all other estimates the long term expected inflation gap coefficients were higher than the unit, and the output gap (in three of the four specifications) was positive¹⁰. In this case, one could say that the CBB's behavior was compatible with macroeconomic equilibrium during the 2003-2016 period: the CBB reaction function appeared to be stabilizing.

Second, in the three estimated models, the interest rate coefficient due to real exchange rate shocks was positive and statistically different from zero. In the specification in which this parameter was not statistically significant, the sign opposite to that expected was found. In the standard model, the long term parameter of the exchange rate shock was smaller than the unit [$0.02/(1-0.97)=0.7$], probably because movements in the exchange rate should also affect expected inflation, which is one variable considered in the model. These results, the small coefficient and significance, were not substantially different when the real exchange rate shock was replaced by the nominal rate shock in our estimates (results not reported).

Third, the interest rate smoothing coefficient was statistically significant and high, floating from 0.94 to 0.97. This result is not surprising, however, since previous studies which estimated the CBB reaction function using the interest rate level as a dependent variable [for example Minella et al. (2003), Gonçalves and Fenolio (2007), Sánchez-Fung (2011) and Medeiros, Portugal and Aragón (2016)] also found high coefficients for the autoregressive term.

It is important to note that when the model is over-identified it is necessary to test whether or not the number of instruments over the number of endogenous variables was expendable. To this end, we performed the Hansen J test, and the null hypothesis of this test is that all instruments were valid. As can be seen in Table 2, we should not reject the null hypothesis. On the other hand, two more tests are used in the literature in order to check whether or not instruments are weak: the Cragg-Donald test and the Kleibergen-Paap test¹¹. Statistics from these tests suggested that the instruments we used were not weak.

In a second step, in order to ascertain whether the behavior of the Brazilian monetary authority changed during the Alexandre Tombini administration, a multiplicative dummy variable was added to the model to interact with the variables output gap and

¹⁰ In a non-linear specification for the monetary policy rule, examining an open economy and a structural break in October 2002, Medeiros, Portugal and Aragón (2016) estimated that the long term parameters of the gap between expected inflation and its target was 8.2, while the output gap was 2.9.

¹¹ In the presence of heteroskedasticity and autocorrelation of residues, the Cragg-Donald statistic is no longer valid. The Kleibergen-Paap test was therefore used as an alternative.

the gap between expected inflation and its target level. The new monetary policy rule specification assumed the following format:

$$i_t = \rho i_{t-2} + (1 - \rho)[\alpha_1 + \alpha_2(\pi^e - \pi^*) + \alpha_3 h_t + \alpha_4(e_t - \bar{e}_t) + \alpha_5 d_1(\pi^e - \pi^*) + \alpha_6 d_1 h_t] + \varepsilon_t \quad (2)$$

in which $\beta_5 = (1 - \rho)\alpha_5$; $\beta_6 = (1 - \rho)\alpha_6$. This new specification can be written as follows:

$$i_t = \rho i_{t-2} + \beta_1 + \beta_2(\pi^e - \pi^*) + \beta_3 h_t + \beta_4(e_t - \bar{e}_t) + \beta_5 d_1(\pi^e - \pi^*) + \beta_6 d_1 h_t + \varepsilon_t. \quad (2')$$

The dummy variable d_1 assumed the value 1 for the period from January 2011 to May 2016 (Tombini chairmanship), and zero for the other periods (Meirelles and Goldfajn chairmanships). If both coefficients that interact with the dummy variable were statistically significant, we could conclude that the reaction function of the CBB altered during the Alexandre Tombini chairmanship. If these coefficients were positive (negative), we could state that the CBB became more rigorous (flexible) in anchoring expectations and stabilizing economic activity. Using this specification, we can also test whether the monetary policy became destabilizing. The main results of this new specification, following model (2'), are summarized in Table 3.

Table 3: Augmented monetary policy reaction function

Dependent variable: Interest rate				
Parameters	GMM	GMM	GMM	GMM
β_1	0.21 (0.25)	0.19 (0.28)	0.21 (0.25)	0.70 (0.27)
ρ	0.95*** (0.02)	0.95*** (0.02)	0.95*** (0.02)	0.91*** (0.02)
β_2	0.67*** (0.09)	0.69*** (0.11)	0.60*** (0.11)	0.88*** (0.13)
β_4	0.014** (0.007)	0.03*** (0.01)	0.02** (0.01)	-0.01 (0.01)
$\beta_{3,Gap1}$	0.21*** (0.03)			
$\beta_{3,Gap2}$				0.02 (0.02)
$\beta_{3,Gap3}$		0.11*** (0.02)		
$\beta_{3,Gap4}$			0.35*** (0.05)	
$d_1^* \beta_2$	-0.44*** (0.11)	-0.40*** (0.12)	-0.38*** (0.12)	-0.65*** (0.12)
$d_1^* \beta_{3,Gap3}$		0.13*** (0.03)		
$d_1^* \beta_{3,Gap1}$	0.11** (0.05)			
$d_1^* \beta_{3,Gap4}$			0.22 (0.14)	
$d_1^* \beta_{3,Gap2}$				-0.02 (0.02)
OBS	166	166	166	166
R ²	0.97	0.97	0.97	0.97
Kleibergen-Paap rk LM statistic	34.6***	25.8***	18.8***	36.5***
Hansen J (p-value)	0.11	0.36	0.13	0.32

Note: *** denotes significance at 1%, ** at 5%, * at 10%. Standard deviations are in brackets.

The new estimates suggest that during the Alexandre Tombini era the parameter for monetary policy rule which relates to the gap between expected inflation and its target is smaller, since even the coefficient of this variable with no interaction remained positive and significant, while the interaction parameter of this variable with d_t was negative and statistically significant at 1% in all estimates (this interaction parameter ranged from -0.38 to -0.65). On the other hand, the output gap parameter was positive and significant in three of the four specifications, and its interaction with the dummy variable was only positive and significant in two. Note also that, according to the standard model with the dummy variable, the long term parameter related to expected inflation remained greater than unity $(0.67-0.44)/(1-0.95)=4.6$ and the output gap parameter remained positive $(0.21+0.11)/(1-0.95)=6.4$. Even if we consider the other specifications and the real exchange rate shock were replaced by the nominal exchange rate shock, it is not possible to find evidence that the CBB reaction function became destabilizing under Alexandre Tombini's chairmanship. Finally, the exchange rate coefficient was positive and statistically significant in three of the four estimated models (the magnitude of this coefficient did not change substantially).

The results in Table 3, particularly those relating to CBB behavior due to shocks in expected inflation and economic activity, are in line with the empirical evidence found in Curado and Curado (2014) and Barbosa, Camêlo and João (2016). In the former, the authors suggest that the inflation targeting regime became more flexible during the Alexandre Tombini era, while in the latter it was not possible to reject the hypothesis that the CBB changed its reaction function¹² from 2011 to 2015. In addition, as noted by Holland (2005), Soares and Barbosa (2006), Medeiros, Portugal and Aragón (2016) and Barbosa, Camêlo and João (2016), our study demonstrates that the CBB considered exchange shocks in its reaction function.

5. Robustness analysis

In this section we re-estimate alternative specifications for the models presented above, in order to ascertain whether the results described in our standard regression are robust. To this end, we replaced each actual output gap variable with its lagged value. The other model variables remained in their original form. The results are shown in Appendix Table AI, for both the models without the dummy and those where the dummy variable interacts with the output gap and the gap between expected inflation and its target.

As can be seen, the main results that have been previously found were confirmed here, although different output gap measures were inserted into the model with one lag. Once again, the output gap and the exchange rate shock coefficients were not statistically significant for the specifications that considered the Gap2 variable. On the other hand, in all the specifications, during the Tombini era, the expected inflation gap coefficient

¹² According to the authors' calculation, the long term parameter for the inflation gap decreased from 5.2 in the "Lula period" to 0.4 in the "Dilma period", while the output gap increased from 1.7 to 4.0 during the "Dilma period".

was positive, statistically significant, and smaller. Note that this long term coefficient remained higher than the unit in all the estimates, including when we used Gap2. It therefore seems safe to say that CBB behavior was not destabilizing during the recent period.

6. Concluding Remarks

The evidence found in this paper suggests that, between 2003 and 2016, the CBB's reaction function was not destabilizing. On the one hand, we showed that, during the Alexandre Tombini era, the CBB lent less weight to the gap between expected inflation and its target, while, at the same time, the interest rate response due to changes in the output gap was stronger. On the other, no evidence was found to suggest that the monetary policy rule became incompatible with macroeconomic stability in the Tombini era. This is in line with the non-explosive behavior of the inflation rate observed in the post-2011 period. However, changes to the estimated parameters for monetary policy rule in the Brazilian economy may provide an explanation for the above-target inflation rates that were consistently observed in the 2011-2016 period, as well as for the monetary authority's consequent loss of reputation and credibility under Tombini's chairmanship. Finally, the results of this work suggest that the CBB took exchange rate shocks into account in its reaction function.

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Appendix

Table AI: Robustness Analysis

Dependent Variable: Interest Rate								
Parameters	GMM	GMM	GMM	GMM	GMM	GMM	GMM	GMM
β_1	0.12 (0.20)	0.36 (0.23)	0.06 (0.22)	0.30 (0.25)	0.10 (0.22)	0.28 (0.25)	0.27 (0.24)	0.71*** (0.27)
ρ	0.96*** (0.01)	0.94*** (0.02)	0.96*** (0.02)	0.94*** (0.02)	0.96*** (0.01)	0.95*** (0.02)	0.94*** (0.02)	0.91*** (0.02)
β_2	0.30*** (0.04)	0.61*** (0.08)	0.35*** (0.04)	0.63*** (0.01)	0.27*** (0.04)	0.51*** (0.11)	0.45*** (0.06)	0.85*** (0.13)
β_4	0.02** (0.008)	0.02** (0.007)	0.03*** (0.01)	0.03*** (0.01)	0.02*** (0.009)	0.02*** (0.01)	-0.01 (0.01)	-0.008 (0.006)
$\beta_{3,Gap1(t-1)}$	0.30*** (0.03)	0.23*** (0.03)						
$\beta_{3,Gap2(t-1)}$							0.02 (0.014)	0.03 (0.02)
$\beta_{3,Gap3(t-1)}$			0.17*** (0.02)	0.12*** (0.02)				
$\beta_{3,Gap4(t-1)}$					0.54*** (0.06)	0.41*** (0.06)		
$d_1^* \beta_2$		-0.41*** (0.10)		-0.38*** (0.11)			-0.32** (0.12)	-0.64*** (0.12)
$d_1^* \beta_{3,Gap3(t-1)}$				0.11*** (0.03)				
$d_1^* \beta_{3,Gap1(t-1)}$		0.10* (0.05)						
$d_1^* \beta_{3,Gap4(t-1)}$						0.34** (0.16)		
$d_1^* \beta_{3,Gap2(t-1)}$								-0.02 (0.02)
OBS	166	166	166	166	166	166	166	166
R ²	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
Kleibergen-Paap rk LM statistic	56.8	44.3	41.3	37.3	50.2	19.4	46.8	48.6
Hansen J (p-value)	0.64	0.22	0.76	0.53	0.47	0.24	0.76	0.35

Note: *** denotes significance at 1%, ** at 5%, * at 10%. Standard deviations are in brackets.