Revising a medium-sized structural model – Samba

This box presents the changes made to the medium-sized structural model Samba[1], since the release of its last revision.[2] Samba is part of a set of models used in the construction of scenarios and projections underlying the decision-making process of the Monetary Policy Committee (Copom) of the Banco Central do Brasil (BCB).

This box firstly introduces the changes in the model's structure, in the treatment of variables observed and in the estimation process. Throughout the box, some exercises with the new version of the model are presented, mainly aiming at justifying the changes made. We show the Samba impulse response functions, comparing results with the 2015 version, and the historical decomposition of inflation and product based on the structural shocks simulated by the model. In addition, the text justifies the changes made in the observables measuring equations with two exercises: first, with an analysis of the volatility of inflation and product projections; second, by means of a specific example observed in the publication of official information, by calculating the effects on projections of the change in the observation equations.

Changes to the model

The model underwent significant changes, both in the treatment of observed variables and estimated parameters, as well as in its equations. In terms of treatment of observed and estimated variables, the changes were as follows:

1) Components of domestic demand – household consumption, government investment and consumption – are still observed in terms of growth rate. However, instead of subtracting a sample average of the growth of the Gross Domestic Product (GDP) from the observations for the construction of the gap, we subtract a common linear trend, estimated from the GDP series;

2) The treatment applied to the imported goods prices has changed. Previously, the trend was obtained from a linear regression. Now, the Hodrick-Prescott (HP) filter is used. The gap is formed from the difference between the observed series and the trend;

3) The model's parameters were re-estimated with data updated until the third quarter of 2018. It should be noted that the parameter describing the inverse of the Frisch elasticity has now been estimated with a normal *a priori* distribution, with higher average and variance.[3] The result is a final parameter of higher magnitude compared to the initially calibrated value in *Castro et al.* (2011).

1/ See *Castro et al.* (2011).

2/ See box *"Revisão do Modelo Estrutural de Médio Porte – Samba"*, of September 2015.

3/ The higher average *a priori* distribution was calibrated according to the observations in Chetty (2012), which shows evidence of the mismatch between the recent microeconomic estimates of Frisch's elasticity and the results of macroeconomic models. The higher distribution's variance, on the other hand, allows a better adjustment of the model to Brazilian data.

Regarding the model's equations, the changes were as follows:

1) The equation of the inflation target's law of movement was changed to allow an anticipated shock in six quarters, according to the equation below, where $\overline{\Pi}_t^C$ is the inflation target for the period "t" and $\varepsilon_t^{\overline{\Pi}^c}$ are exogenous shocks occurring in "t" that deviate the goal from steady state. Previously, the used shock followed a traditional AR(1) autoregressive process. This new formulation is consistent with the announcement of the target a year and a half before its effectiveness, which is in line with the period of notice observed for most of the period of the inflation targeting regime.

$$\overline{\Pi}_t^C = (\overline{\Pi}^c)^{1-\rho_{\overline{\Pi}^c}} (\overline{\Pi}_{t-1}^C)^{\rho_{\overline{\Pi}^c}} exp\left\{\varepsilon_{t-6}^{\overline{\Pi}^c}\right\}.$$

2) The cost of adjusting imports originally took into account the import-product ratio of the respective sector and now depends only on the quantity imported, as illustrated by the equation below. The previous formulation forced, in the short term, a unitary elasticity between product and imports, which conflicts with the results of empirical studies for Brazil.[4] In the formulation below, subscript "H" refers to the sector of the economy (household consumption, investment, government consumption or exports), $\Gamma_{H,t}^M$ is the cost of adjusting imports of sector "H" in the period "t", $\widetilde{M}_t^H$ is the quantity imported by the "H" sector, Z_t^z is the aggregate productivity of the economy, and $Z_{H,t}^M$ is a shock in the demand for imports.

$$\Gamma_{H,t}^M = \frac{\vartheta_H^M}{2}\left((Z_{H,t}^M)^{-\frac{1}{\vartheta_H^M}} \frac{\widetilde{M}_t^H Z_t^z}{\widetilde{M}_{t-1}^H} - Z^z \right)^2.$$

3) The sector referring to the rest of the world in Samba was restructured, going from individual AR(1) processes to an autoregressive vector (VAR) with five variables and two lags. Its estimation was made using Bayesian methods with shocks identified by the imposition of signal restriction on the impulse response functions. The variables observed in the estimation were: Fed funds rate, global GDP gap (same series used in the semi-structured models[5]), USA consumer price index (CPI), CBOE volatility index (Chicago Board Options Exchange Volatility Index – VIX) and Index of Commodities – Brazil (IC-Br) in dollars. Four shocks are identified in the system: monetary policy, supply, demand and financial shock (in this case, the restriction is to associate increases in VIX to falls in the global product gap).

4) Originally, only the equations of observation of GDP and the National Extended Consumer Price Index (IPCA) presented exogenous shocks in their formulation (called "errors of observation or measurement" in the literature). This methodology was extended to nominal wages, household consumption, gross fixed capital formation, government consumption, exports and imports. These shocks follow a moving average process MA(1), as described in the equation below for a generic variable "X". For estimation purposes, the volatility of the shocks was restricted to a ceiling of 75% of the observed volatility of each series.

$$\Delta X_t^{obs} = log\, X_t - log\, X_{t-1} + \varepsilon_t + \theta\varepsilon_{t-1}.$$

5) The indexation of administered prices inflation was based on accumulated inflation in the previous four quarters and is now based only on the immediately previous quarter.

6) The indexation of the nominal wage variation was based on the variation of the immediately preceding quarter and is now based on the average variation of the previous four quarters.

7) Mark-ups shocks of market prices, administered prices, wages and exports prices were previously treated as AR(1) processes and now follow the ARMA(1.1) model, in line with the specification in Smets and Wouters

4/ Minella and Souza Sobrinho (2013) estimate short-term income elasticity of 1.98 in a semi-structural model. Morais and Portugal (2005) and Gouvêa and Schettini (2015), both with Markov-Switching models, find a short-term income elasticity significantly larger than one.

5/ See, for example, the box "Small-scale model of disaggregated prices – 2018", published in the June 2018 Inflation Report.

(2007). The equations that characterize mark-ups shocks are described below, where the superscripts "p" and "w" refer to mark-ups of prices and wages:

$$log\,\widehat{Z}_t^{p,w} = \rho\,log\,\widehat{Z}_{t-1}^{p,w} + \epsilon_t - \delta\epsilon_{t-1}$$

8) The process that characterizes the monetary policy shock, which was previously defined as white noise, is now described as an MA(1).

Model properties

In this section, two topics are explored: (i) Samba's impulse response functions compared to the 2015 version of the model, and (ii) the historical decomposition of inflation and product according to the structural shocks of the model.

The first exercise considers a monetary policy shock equivalent to 1 percentage point (p.p.) in annualized terms, with the interest rate path following a Taylor rule in the following periods. Figures 1 and 2 show the four-month accumulated inflation and product trajectories, simulated from the median of the estimated parameters (solid line), as well as confidence intervals for them based on the uncertainty regarding the estimated values for the parameters of the model.[6] The new Samba estimation suggests a greater impact of monetary policy on activity and prices. Regarding especially prices, it is also noted that the maximum effect of monetary policy is reached four quarters after the shock, against an effect of five to six quarters estimated in the previous version of the model.

Figure 1 – Inflation response to monetary policy shocks
4-quarter accumulated IPCA (p.p.)

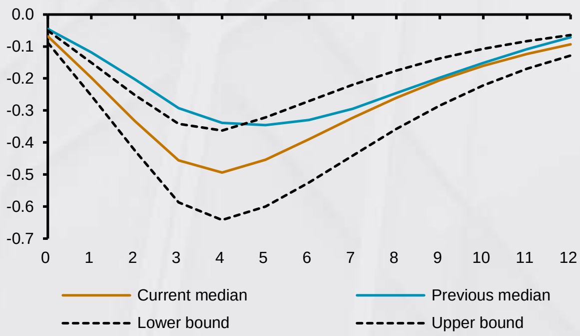
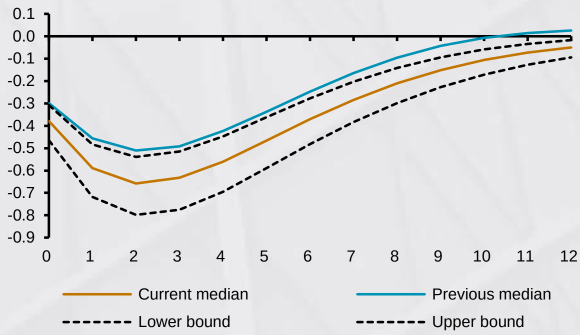


Figure 2 – Economic activity response to monetary policy shocks
Product gap (%)



The second exercise considers a shock of 1 percentage point (p.p.) in the real exchange rate in the first period, with the other variables following the endogenous responses of the model. Figures 3 and 4 show, respectively, the trajectories of accumulated inflation in four quarters and the product in this scenario. The new estimates suggest an increase in the pass-through of the exchange rate to prices, in addition to characterizing a slight expansion in the economy over a one-year horizon. In both the old and the current versions, over a long-term horizon, unexpected depreciations in the real exchange rate generate a reduction in the level of activity, due to the increase in marginal costs of production of companies, where the imported intermediate good is an important component of their structure.

The historical decomposition of shocks seeks to interpret the behavior of deviations of a variable in relation to its long-term value in terms of the shocks of the model. The figures below show historical breakdowns for the period between the first quarter of 2014 and the fourth quarter of 2021 (up to where the inflation target is defined by the National Monetary Council – CMN), starting the projection horizon in 2019. The

6/ The 68% confidence intervals were calculated using simulations from the *a posteriori* distribution of the estimated parameters.

Figure 3 – Economic activity response to effective exchange rate shocks
4-quarter accumulated IPCA (p.p.)

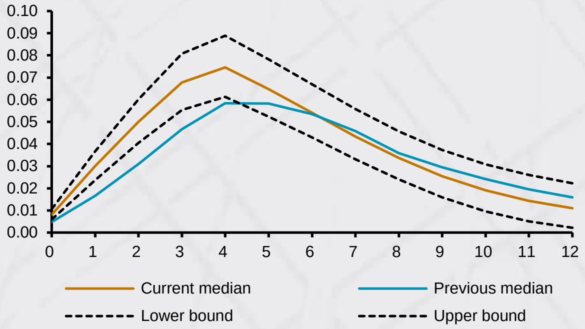
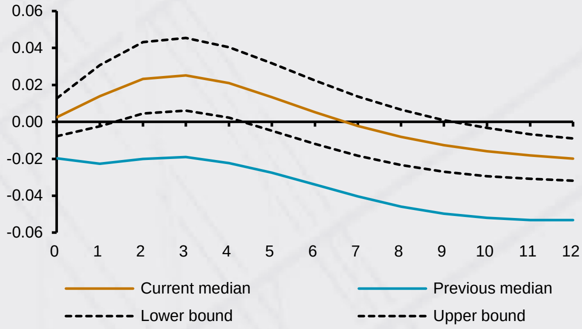


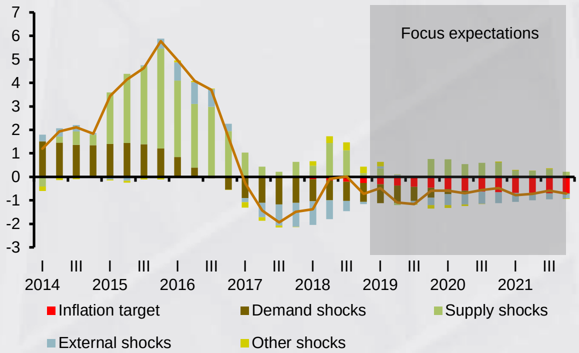
Figure 4 – Economic activity response to effective exchange rate shocks
Product gap (%)



expectations of the Focus survey for IPCA, the Selic rate target, exchange rate and GDP growth rate[7] were used as constraints on the model until the end of 2021, with the objective of extracting consistent shocks with the scenario expected by market analysts. The decomposition of inflation, shown in Figure 5, highlights the recent negative effects of demand shocks, contributing to the variable being below its long-term equilibrium value. This occurs in spite of supply-side negative surprises, mostly observed around mid-2018.

It is also noteworthy the role of the definitions of the last two years on the inflation target. By hypothesis, the historical decomposition of inflation is carried out around a value of 4.5%, corresponding to the most frequent inflation target since the implementation of the regime. The presence of inflation expectations anchored on the targets established for the period between 2019 and 2021 – hence below 4.5% – allows the construction of an estimate of the impacts caused by the announcements of new targets. The new structure of the model, with anticipated shocks about the change on the inflation target, also characterizes contemporary effects of events that will still occur in the future. Thus, the setting, in 2017, of lower targets for 2019 and 2020, compared to the levels established for 2018, displayed disinflationary effects and reduction of the nominal interest rate already in 2018. This effect has been potentiated for longer horizons, with the announcement in 2018 of the target for 2021 at an even lower level. Regarding specifically nominal interest rates between 2019 and 2021, it is estimated that the average performance of surprises with reductions in the risk target announced in 2018 and 2019 is a decrease of 0.4 p.p. in annualized terms.

Figure 5 – IPCA historical breakdown
4-quarter variation (%)

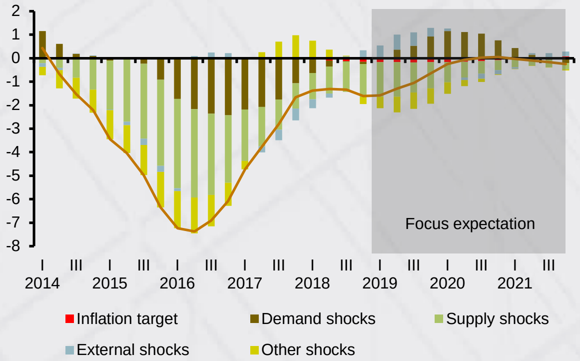


In the historical decomposition of GDP shown in Figure 6 along with the projections presented in the Focus Report for 2019 onwards, external shocks, first, and demand, later, contribute to the economy showing a gradual recovery trajectory. An important sequence of supply shocks, especially those defined as related to productivity, represent a persistent force in reducing the potential growth of the Brazilian economy.[8] The Figure also shows negligible effects of changes in inflation targeting on the GDP growth rate.

7/ Focus projections medians on March 15th 2019.

8/ It should be noted that the productivity shocks cited already appeared in the historical GDP decomposition presented in the previous box, containing an update of the Samba model and published in the September 2015 Inflation Report.

Figure 6 – GDP historical breakdown
4-quarter variation (%)



Changes in observation equations

The introduction of shocks exogenous to the model in the observation equations aims to capture possible high frequency fluctuations in the construction of series that do not reflect, precisely, the moment of the economic cycle.[9] Such fluctuations, when not properly dealt with in the model, could have two undesirable effects: i) implausible economic fluctuations resulting from a possible interpretation by the model that they are structural shocks; and, ii) unnecessary amplification of the volatility of the model projections. In the first case, the literature already recognizes the need to include exogenous shocks in nominal wage observation equations, since their absence results in significant fluctuations in wage markups and an impact on the economic cycle that is much more than reasonable.[10] This section of the box brings two exercises to better characterize the second effect.

In the first exercise, projections are made with the information set of recent Copom meetings, using the re-estimated model. The comparison of the volatility of the projections for inflation and product in relation to the volatility of the projections actually presented at Copom meetings is an approximate measure of the reduction in the variability of the projections obtained with the new specification.[11] The calculations suggest that projection volatility is reduced by almost half over a three year horizon. The same reduction is observed in the projections for inflation two years ahead. In turn, the reduction in volatility for GDP projections is around 30%. Regarding short-term projections, the reduction in volatility for GDP projections reaches 20%, while the volatility of inflation projections presents a slight increase, mainly due to other changes in the model of greater importance to this dimension, such as lower indexation of administered prices.

In a second exercise, it is used a real case of distortion in the model projections resulting from a purely accounting and temporary effect in the National Accounts statistics. In an official note dated November 30th 2018, the Brazilian Institute of Geography and Statistics (IBGE) points out that the accounting of gross fixed capital formation was affected in the third quarter of 2018 "due to the incorporation of goods destined for the oil and gas industry, resulting from changes in the Special Customs Regime of Export and Import of Goods destined to the Activities of Research and Mining of Reserves of Oil and of Natural Gas (Repetro)"[12] That is, machinery and equipment that were already in operation had their property transferred from subsidiaries abroad to companies headquartered in Brazil, positively impacting the investment account in the third quarter of 2018, despite no investments had been effectively made.[13]

9/ Technically, these shocks are known in literature as "measurement errors" or "observation errors". Please note that these are technical terms which do not reflect any evaluation of the quality of the statistics in question.

10/ See, for example, Justiniano, Primiceri and Tambalotti (2011) and Galí, Smets and Wouters (2012).

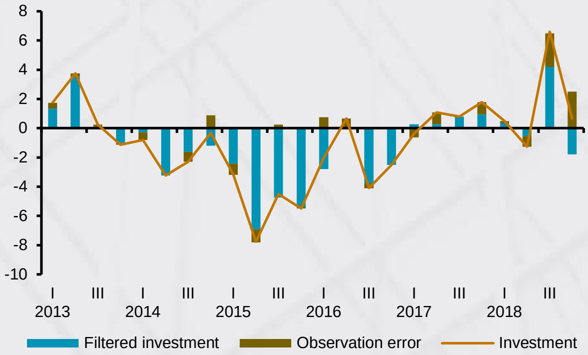
11/ As it should be emphasized, this measure is only approximate, since the replications of previous meetings consider all the structural changes listed at the beginning of this box, and not just the inclusion of exogenous shocks in observation equations.

12/ https://agenciadenoticias.ibge.gov.br/agencia-sala-de-imprensa/2013-agencia-de-noticias/releases/23251-pib-cresce-0-8-e-chega-a-r-1-716-trilhao-no-3-tri-de-2018.

13/ http://agenciabrasil.ebc.com.br/economia/noticia/2018-11/indicador-de-investimentos-tem-crescimento-de-96-no-3o-trimestre.

By modifying the structure of the observation equations of the model, one may simulate[14] the trajectory of gross fixed capital formation (GFCF) consistent with the other information included, filtering from the data the exogenous effect of the "shock" associated with the Repetro. Figure 7 shows the GFCF until the end of 2018 according to the IBGE data (solid line), the contribution of the effects of the exogenous shocks (darker bars) and the part "explained" by the model (blue bars) . As can be seen, in the third quarter of 2018, there was a significant increase in the contribution of observation errors in the model.

Figure 7 – Investment
Quarter on quarter variation (%)

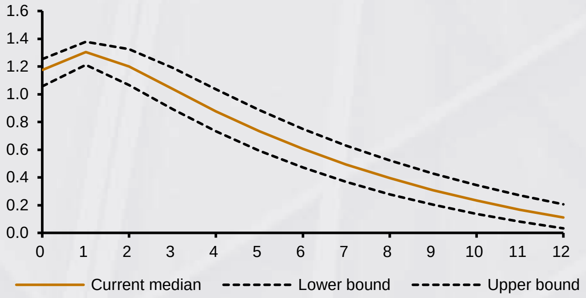


This exercise considers a counterfactual scenario where the effect of exogenous shocks is treated by the Samba model as an effective increase in gross fixed capital formation. For this purpose, the exercise assumes that all investment variation resulting from the exogenous shock would be transformed, in the model, into an investment-specific technological shock[15], in case no change is made to the observation equation. With this approach, the possible consequences on the projections of investment, product and prices are simulated. This procedure is equivalent to calculating the impulse response functions of the investment shock for an initial variation equal to the simulated value of the exogenous shock.

As Figures 8 and 9 show, the effects on investment and product projections are quantitatively relevant, with significant effects up to 12 quarters after the shock occurs. The effects on prices are of small magnitude, as can be seen in Figure 10, but statistically significant over a horizon of up to two years.

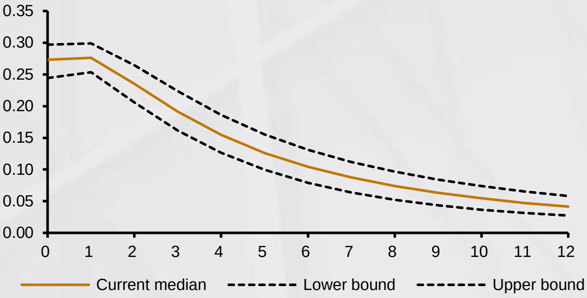
In summary, in order to maintain the level of transparency that characterizes monetary policy actions, this box updates information on the BCB Samba model. The changes implemented seek to improve the predictive and analytical capacity of the model in all its dimensions, not restricting it to an instrument of inflation

Figure 8 – Investment response to investment shock*
Investment gap (%)



* In the magnitude of the observation error of the 2018Q3.

Figure 9 – Economic activity response to investment shock*
Product gap (%)

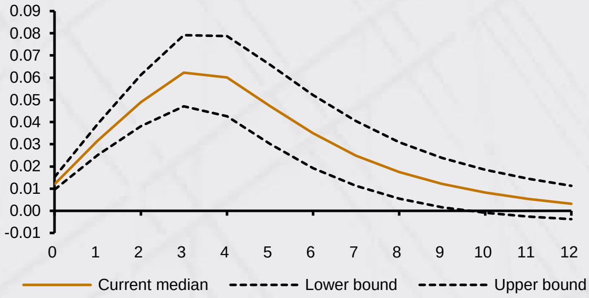


* In the magnitude of the observation error of the 2018Q3.

14/ According to the IBGE, in comparison with the same period of 2017, GFCF grew by 7.8%, including the information on Repetro. Excluding this factor, GFCF growth would be 2.7%, on the same basis of comparison. These estimates could be incorporated into the exercise shown here. However, we prefer to show here the model's ability to detect this type of high-frequency variation in data.

15/ In the terminology of model in *Castro et al.* (2011), the exogenous shock is simulated as a variation in shock Z_t^I.

Figure 10 – Inflation response to investment shock*
4-quarter accumulated IPCA (p.p.)



* In the magnitude of the observation error of the 2018Q3.

projection. This model is part of the set used by Copom in its decision-making process, and is constantly being reviewed and improved.

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