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Preferred habitat and the term structure of interest rates in DSGE models

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ABSTRACT
The aim of the present study is to use an alternative approach to derive the term structure of interest rates in DSGE models, which is based on the theory of preferred habitat. We show that this approach yields a substantial term premium which is time-variant. In particular, by introducing bonds of longer maturity, we avoid the underestimation of the volatility of the output. In addition, by allowing longer-term bonds, we show that output is more responsive to technology shocks than it would otherwise. Therefore, the goal of stabilizing output around the nonstochastic level is more difficult to achieve.

1. Introduction

Central banks generally use the yield curve to predict future interest rates and inflation. However, a problem with these predictions is that one needs to take into account the fact that the term premium varies over time. This problem is generally dealt with by using DSGE models, as they provide a general equilibrium framework that allows to improve our understanding of how fundamentals influence the term premium behavior. DSGE models though, albeit able to provide a good fit for the behavior of macroeconomic variables, are generally unable to generate a sufficiently large and volatile term premium, a failure usually referred to as the "Bond Premium Puzzle". In fact, over the last decade, researchers have spent a great amount of effort trying to overcome this limitation (Rudebusch & Swanson, 2008).

The aim of the present study is to contribute to the debate by using an alternative approach that delivers a large and volatile term premium. We do so by introducing the term structure of interest rates in a somewhat standard DSGE model. In our model, following the Theory of Preferred Habitat (see, for example, Andres, Lopez-Salido, & Nelson, 2004; Vayanos & Vila, 2009; Mokrini, Waeyenberge, Viaene, & Moens, 2012), we assume that the financial market is represented by distinct segments, each segment dealing with a bond of a particular maturity. To say it more precisely, the contribution of this study is to develop, estimate and analyze a DSGE model with a term structure of interest rates that is a way to overcome the bond premium puzzle in a simpler way than the third-order approximation of Taylor or recursive preferences.

The temporal structure theory of interest rates seeks to explain why zero-coupon bonds, with different maturity dates, have different, expected rates. To this end, the

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literature presents four distinct explanations. The segmented markets theory posits that investors are sufficiently risk-averse and choose to act only within their desired range of maturity dates. That is, no rate differential will induce them to operate using other maturities. For example, what determines long-term interest rates is only the demand and supply of long-term funds. On the other hand, the theory of expectations assumes that the investors setting the prices are not concerned with risk. In this case, regardless of their time horizon, they will choose the bond that gives the highest expected return.

A third approach is given by the liquidity premium theory, which assumes that higher expected yields should be offered to investors so that they will invest in a bond with a horizon other than the one they prefer. It is further assumed that there is a scarcity of longer-term investors, such that it is necessary to offer an additional return for long-term bonds in order to stimulate investors to invest in these bonds. Lastly, the preferred-habitat theory is based on the premise that investors who manage to match the profile of their assets with that of their liabilities are in a position of least possible risk.

This study develops a model with the main frictions of a standard DSGE model. Household has two concerns, one of which is intratemporal, to consume goods or have leisure, and one intertemporal, to consume today or save to consume more in the future. This agent may decide to save using short-term and/or long-term bonds. There is an adjustment friction in the portfolio: any time a government decides to increase the supply of a long-term bond, it must offer a term premium to reestablish equilibrium in this market. The production sector is characterized by three firms: producers of finished products, producers of intermediate goods, and producers of capital. The government, as well as issuing bonds of different maturities, taxes households by way of a lump-sum tax. Observing its budget constraints, the sum total of these public funds are used for government consumption. Lastly, we are considering a closed economy without financial institutions – the household directly funds the government by means of the acquisition of bonds.

Our main result is that our model is capable of generating a substantial time-variant term premium. In particular, by introducing bonds of longer maturity, we avoid the underestimation of the volatility of the output. An implication of our results is that monetary policy might be insufficient to stabilize output around its non-stochastic level.

This paper is structured as follows. In the next section, we discuss the preferred habitat and the literature; section 3 presents the structural model of this work; in section 4, the estimation procedures are described; and section 5 discusses the results. We finish with our concluding remarks.

2. Preferred habitat and the literature

The preferred-habitat theory, a proposal initially mooted by Modigliani and Sutch (1966), states that both borrowers and investors prefer to operate with particular maturities (habitat). Once demand and supply per particular maturities do not find equilibrium, some borrowers and investors will be led to exchange them for maturities with opposing disequilibrium, but to this end they will have to be compensated by an adequate risk premium (term premium), the size of which will take into account the degree of risk aversion, in terms of both price and reinvestment.

If this theory is correct, there will be premiums for bonds with maturities for which demand is insufficient. Such premiums are necessary to induce investors to abandon their

preferred habitat. If there is a sufficiently large number of companies issuing long-term debt compared to the number of investors interested in investing in this maturity, a premium will need to be offered for these bonds. The same logic is valid for the short term.

Definition 2.1 (Spot interest rate). These are the expected rates through to the maturity of a bond that provide the investor with a single cash flow.

Definition 2.2 (Theory of expectations). This theory states that the expected rate of a two-period bond, for example, is set in such a way as to render the return of this bond equal to the return of a one-period bond, plus the expected return of a one-period bond purchased at the start of the second period.

Definition 2.3 (Theory of preferred habitat). In order to understand term premium in preferred-habitat theory, consider an example of two periods. Let R_{01} be the spot interest rate in period one and $\bar{R}_{12}$ the expected spot interest rate for period two. Assuming the theory of expectations is valid, the two-period interest rate is given by:

$$R_{02} = R_{01} \times \bar{R}_{12}$$

Suppose there is an excess of short-term investors and, therefore, an additional return is required to induce them to invest in the bond with a term equal to two periods. With P equal to the magnitude of the term premium, then:

$$R_{02} = R_{01} \times \bar{R}_{12} \times P \quad with \quad P > 1$$

In this case, the preferred-habitat theory would result in a series of spot rates that could similarly have been obtained from the liquidity premium theory. On the other hand, if it is necessary to attract investors to the short term, investment in the two-period bond will be less lucrative than the investment in two one-period bonds, i.e.:

$$R_{02} = R_{01} \times \bar{R}_{12} \times P \quad with \quad P < 1$$

Proof of the preferred habitat can be seen in Figure 1. Between January 18 and 3 February 2000, the US government announced the early redemption of bonds maturing in 30 years; this had the effect of reducing the yield of these bonds by 58 basis points, from 6.75% to 6.17%, while the yields of bonds maturing in 5 years and 2 years only fell 9 basis points (Maiti, Sen, Paul, & Acharya, 2007). So, it can be seen that the excess demand for the 30-year bond produced a term premium lower than 1 – the interest rate of the 30-year bond dropped below the interest rates of other maturities – bearing out what was explained in the previous paragraphs.

One of the first studies aiming to study bond prices is that of Backus, Gregory, and Zin (1989) which examined risk premium using the asset pricing model based on consumption in an endowment economy. The authors discovered that representative agent models with additively separable preferences do not explain the sign nor the magnitude of risk premiums nor can they explain the variability of these variables. On the other hand, the success of several studies in solving the equity premium puzzle of Mehra and Prescott (1985) was quite encouraging: Campbell and Cochrane (1999), using long-memory habit formation; Epstein
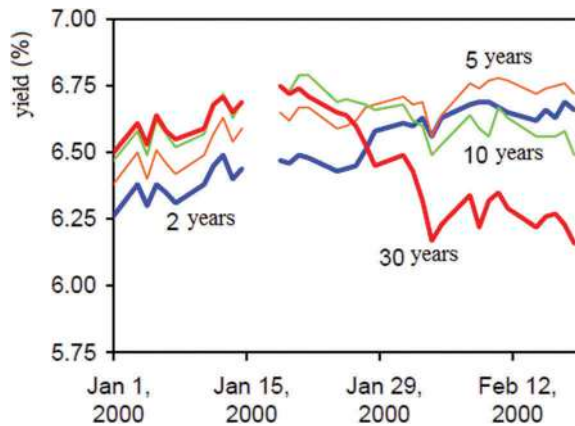
Figure 1. Interest rate curve for bonds with maturities of 2, 5, 10 and 30 years, for the period between January and February 2000. Source: Amended from GarRut07.

and Zin (1989), by means of recursive preferences; and Constantinides and Duffie (1996) and Alvarez and Jermann (2001), using heterogeneous agents.

Though using an endowment economy might solve the bond premium puzzle, its outcome would still be unsatisfactory given the lack of structural relationships between the macroeconomic variables that hinder the study of many questions of interest in macroeconomics. One alternative proposal was to use a stochastic discount factor based on a standard DSGE model, assuming that the term premium would be constant over time (Bekaert, Cho, & Moreno, 2010; Doh, 2006; Hördahl, Tristani, & Vestin, 2008; Wu, 2006). However, as the objective is the variability, as well as the level of the term premium, the solution to this proposal would demand higher-order approximations or a non-linear solution method, as in Rudebusch and Swanson (2008) and Gallmeyer, Hollifield, and Zin (2005). However, the results of these studies do not make it clear if the size and volatility of the bond premiums can be replicated in DSGE models without distorting the macroeconomic fit.

The objective of Rudebusch and Swanson (2008) was to show that the term premium for long-term bonds in DSGE models used in macroeconomics is far lower and more stable in respect of the data. Initially, the authors estimate a base model using third-order approximation by means of the algorithm of Swanson, Anderson, and Levin (2006). Then the authors incorporate into the model long-memory habit formation following Campbell and Cochrane (1999) and labor market frictions. However, the results show that the bond premium puzzle remains in the DSGE models, even when these models are extended. In other words, these models are still far from equalizing the level and variability of the term premium and the yield curve slope.

Van Binsbergen, Fernández-Villaverde, Koijen, and Rubio-Ramírez (2012) use recursive preferences of the Epstein and Zin type in a production economy with endogenous capital and labor supply through the maximum-likelihood estimation of the model, using a particle filter. The model is estimated considering five different bond maturities. The results show a high coefficient of relative risk aversion and a substantial capital adjustment cost. However, the model only reproduces the average interest rate slope and substantially underestimates the volatility of bond yields. On the plus side, the model is capable of reproducing the pattern of autocorrelation of consumption

growth, the 1-year bond return, and inflation. For a better understanding of these frailties and identification of the parameters, the model is estimated once again, firstly ignoring the inflation rate. The new estimation results in an average interest rate curve slope comparable with the one observed. The model also reproduces the volatility of bond yields. However, this success is explained by the fact that the estimated volatility of inflation is very high. Next, the model was estimated just using bond yields. The results improve marginally on prior results, but do not adjust the volatility of the growth in product and consumption.

Developing a DSGE model capable of generating a time-variant term premium with a lower resolution cost than the traditional alternatives was the main objective of Mokrini et al. (2012). In this way, these authors propose a DSGE model with a financial market segmented by bonds of different maturities and a portfolio adjustment cost other than zero in the long term. The initial results of this model, calibrated for the US, are that it succeeded in replicating the main facts stylized for the American interest rate curve, without adversely affecting the model's macroeconomic dynamics.

Andres et al. (2004) use a dynamic model that allows explicit imperfect substitutability between different financial assets. This picks up on the idea of Tobin69 that a growth in the supply of a bond affects not only the return but also the bond's term premium when compared to alternative assets. The results of these authors suggest that central bank operations exert a modest influence over the relative prices of an alternative bond, and exerts an extra effect on the long-term yield separate from the effect of expected aggregate demand through the short-term interest rate.

The intention of the study by Vayanos and Vila (2009) was to model a term structure of interest rates resulting from the interaction between investors with preferences for specific maturities and risk-averse arbitrageurs. Due to the latter group of agents being risk-averse, shocks in demand for bonds affect the term structure. The authors show that the preferred-habitat view of the term structure generates a rich set of implications for a bond's term premium, for the effects of demand shocks and short-term expectations, and for the transmission of monetary policy.

Chen, Cúrdia, and Ferrero (2012) use a term-structure DSGE model following the assumption of the preferred habitat to analyze the FED's large-scale asset purchase program (LSAPII). The authors find that such effects are moderate in relation to macroeconomic variables, suggesting that such a program has increased GDP growth by less than half a percentage point, although the effect at the level is persistent in relation to inflation, the marginal contribution is very small. A key reason for these results to be small is due to the small degree of the financial market segment.

3. Model

The model in the present study presents the characteristics of a standard new-Keynesian model. The new feature, following Mokrini et al. (2012)[1] and Andres et al. (2004), has economic motivation with the inclusion of a friction on the family portfolio adjustment, based on the preferred-habitat theory (Vayanos & Vila, 2009). This friction generates a certain degree of rigidity in the timing of the reallocation of the family portfolio,

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[1]It is important to highlight some differences between Mokrini et al. (2012) and this model:

providing demand for bonds of different maturities and making them imperfect substitutes (Tobin, 1969, 1982).

3.1. Households

There exists a continuum of households indexed by $j \in [0, 1]$. This representative household maximizes its intertemporal utility by choosing consumption, savings, and leisure:

$$\max_{C_{j,t}, L_{j,t}, B_{j,t+1}, B_{L,j,t+1}} E_t \sum_{t=0}^{\infty} \beta^t S_t^P \left[\frac{(C_{j,t} - \phi_c C_{j,t-1})^{1-\eta}}{1 - \eta} - S_t^L \frac{L_{j,t}^{1+\omega}}{1 + \omega} \right] \quad (1)$$

subject to the following budget constraint,

$$C_{j,t} P_t + \frac{B_{j,t+1}}{R_t^B} + \frac{B_{L,j,t+1}}{R_{L,t}^B} \left(1 + AC_t^L \right) = W_t L_{j,t} + B_{j,t} + \frac{B_{L,j,t}}{\prod_{i=2}^{N_L} R_{t+i-1}^B} - T_{j,t} P_t \quad (2)$$

where E_t is the expectation operator, β is the intertemporal discount factor, η is the relative risk-aversion parameter, ω is the marginal disutility of labor, ϕ_c is the parameter of consumption habit persistence, C is consumption, P is the general price level, W is wages, L is the number of hours worked, and T is a lump-sum tax. Households allocate their income between two types of zero-coupon bonds, short-term (B) and long-term (B_L), whose yields are expressed by R^B and R_L^B, respectively. Lastly, N_L represents the maturity of the long-term bond.

On the left-hand side of equation (2) the bonds are priced according to the appropriate interest rates. Meanwhile, on the right-hand side, the secondary market for the trading of bonds is incorporated, i.e., bonds with different maturities are priced according to the short-term rate. Thus, in t, a household that purchases a bond with a longer maturity and plans to sell it in the following period will not be certain about its gains, as R_{t+1}^B is not known in t – price risk for this asset[2]

The differentiation in bond maturities is obtained by introducing a portfolio adjustment friction, representing an impediment to households' arbitrage behavior which would tend to equalize bond yields. Following Mokrini et al. (2012), AC^L is a friction in the portfolio adjustment of maturity L whose structure is as follows:

$$AC_t^L = \left[\frac{\vartheta_L}{2} \left(\frac{B_{L,t+1}}{B_{L,t}} \right)^2 \right] Y_t \quad (3)$$

where ϑ_L is the sensitivity of the portfolio adjustment friction of maturity L. As mentioned, the economic motivation related to this friction stems from the preferred-habitat theory. Given this perspective, the transaction cost represents the inertial behavior of the investor positioned at each maturity. In equation (3), an increase in the supply of a bond should be accompanied by an increase in the adjustment cost to maintain equilibrium between the demand and supply for this asset. Moreover, the extent of these adjustment costs is given by the parameter ϑ_L.

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[2]The term structure of interest rates has been developed by Cox, Ingersoll, and Ross (1985a, 1985b) and by LeRoy (1982).

In addition, the model presents two stochastic shocks on the demand side. S^P is the shock of the intertemporal preference, which alters household's consumption and savings choices, with the following law of motion:

$$\log S_t^P = \rho_P \log S_{t-1}^P + \epsilon_{P,t} \tag{4}$$

where $\epsilon_{P,t} \sim N(0, \sigma_P)$. As for the shock with the supply of labor S^L – which affects the household's willingness to supply labor, the following applies:

$$\log S_t^L = \rho_L \log S_{t-1}^L + \epsilon_{L,t} \tag{5}$$

where $\epsilon_{L,t} \sim N(0, \sigma_L)$.

The first-order conditions for the problem of the representative household are:

$$\lambda_{j,t} P_t = S_t^P \left(C_{j,t} - \phi_c C_{j,t-1} \right)^{-\eta} - \phi_c \beta E_t \left[S_{t+1}^P \left(C_{j,t+1} - \phi_c C_{j,t} \right)^{-\eta} \right] \tag{6}$$

$$S_t^P S_t^L L_{j,t}^\omega = \lambda_{j,t} W_t \tag{7}$$

$$\frac{\lambda_{j,t}}{R_t^B} = \beta E_t \lambda_{j,t+1} \tag{8}$$

$$\frac{1}{R_{L,t}^B} \left[1 + \frac{3}{2} \vartheta_L \left(\frac{B_{L,j,t+1}}{B_{L,j,t}} \right)^2 Y_t \right] = E_t \left\{ \Xi_{j,t,t+1} \left[\left(\frac{1}{\prod_{i=2}^{N_L} R_{t+i}^B} \right) + \left(\frac{1}{R_{L,t+1}^B} \right) \vartheta_L \left(\frac{B_{L,j,t+2}}{B_{L,j,t+1}} \right)^3 Y_{t+1} \right] \right\} \tag{9}$$

$$E_t \Xi_{j,t,t+1} = \beta E_t \left(\frac{\lambda_{j,t+1}}{\lambda_{j,t}} \right) \tag{10}$$

where $\Xi_{t,t+1}$ is the related stochastic discount factor.

The combination of equations (6) and (7) represents the supply of labor, and of equations (8) and (9) the Euler equations for the short-term and long-term bonds, respectively. Equation (10) is the definition of the related stochastic discount factor.

Proposition 3.1 (Term premium in the short-term). *The presence of the secondary market in the model is sufficient to generate a term premium in the short-term.*

(11) *Proof.* Combining equations (8) and (10),

$$\frac{1}{R_t^B} = E_t \left(\Xi_{t,t+1} \right)$$

Then, ignoring the portfolio adjustment costs in equation (9),

$$\frac{1}{R_{L,t}^B} = E_t \left(\frac{\Xi_{t,t+1}}{\prod_{i=2}^{N_L} R_{t+i}^B} \right)$$

Knowing that the standard approach to the term structure of interest rates (hypothesis of expectations given by definition 2.2) implies that the interest rate of maturity L is determined by the short-term interest rate in period 1 and by the expected short-term interest rates, $(R_{L,t}^B)^{-1} = (R_t^B)^{-1} \times E_t(\prod_{i=2}^{N_L} R_{t+i}^B)^{-1}$.

Since

$$cov_t\left(\Xi_{t,t+1}, \frac{1}{\prod_{i=2}^{N_L} R_{t+i}^B}\right) = E_t\left(\Xi_{t,t+1} \times \frac{1}{\prod_{i=2}^{N_L} R_{t+i}^B}\right) - E_t\left(\Xi_{t,t+1}\right) \times E_t\left(\frac{1}{\prod_{i=2}^{N_L} R_{t+i}^B}\right)$$

Equation (12) is:

$$\frac{1}{R_{L,t}^B} = E_t\left(\Xi_{t,t+1}\right) \times E_t\left(\frac{1}{\prod_{i=2}^{N_L} R_{t+i}^B}\right) + cov_t\left(\Xi_{t,t+1}, \frac{1}{\prod_{i=2}^{N_L} R_{t+i}^B}\right) \qquad (13)$$

or,

$$\frac{1}{R_{L,t}^B} = \frac{1}{R_t^B} \times E_t\left(\frac{1}{\prod_{i=2}^{N_L} R_{t+i}^B}\right) + cov_t\left(\frac{1}{R_t^B}, \frac{1}{\prod_{i=2}^{N_L} R_{t+i}^B}\right) \qquad (14)$$

Therefore, if $\frac{1}{R_{L,t}^B} = \frac{1}{R_t^B} \times E_t\left(\frac{1}{\prod_{i=2}^{N_L} R_{t+i}^B}\right)$ represents the hypothesis of expectations of the term structure of interest rates, the term premium in the short term is represented by $\left(cov_t\left(\frac{1}{R_t^B}, \frac{1}{\prod_{i=2}^{N_L} R_{t+i}^B}\right)\right)$.

Proposition 3.2 (Term premium in the long-term). *The existence of a portfolio adjustment cost is sufficient for the presence of the long-term term premium.*

Proof. Using the steady state combination of equations (8) and (9), we arrive at:

$$R_{L,ss}^B = R_{ss}^B N_L\left[1 + \left(\frac{3}{2} - \beta\right)\vartheta_L Y_{ss}\right]$$

Therefore, if $R_{L,ss}^B = R_{ss}^B N_L$ represents the hypothesis of expectations, then $\left[1 + \left(\frac{3}{2} - \beta\right)\vartheta_L Y_{ss}\right]$ represents the long-term term premium.

3.2. Firms

3.2.1. Firms producing finished goods (retail)

From an aggregated perspective, the monopolistic competition involves, among other things, facing the fact that consumers purchase a large variety of goods, but for the purpose of modeling, it is assumed that they buy just one specific good (aggregated). This good is sold by firms in a structure of perfect competition.

With the aim of producing this aggregated good, the retail firm must buy a large quantity of intermediate goods. These are the inputs used in the production process. Accordingly, the assembly firm has to solve the following problem:

$$\max_{Y_{j,t}} P_t Y_t - \int_0^1 P_{j,t} Y_{j,t} dj \qquad (15)$$

subject to the following technology expressed by the Dixit-Stiglitz aggregator (Dixit & Stiglitz, 1977),

$$Y_t = \left(\int_0^1 Y_{j,t}^{\frac{\varphi-1}{\varphi}} dj \right)^{\frac{\varphi}{\varphi-1}} \tag{16}$$

where Y_t is the product of the retailers in periods t, and $Y_{j,t}$ para $j \in [0,1]$ is the wholesale good j. And $\varphi > 1$ is the elasticity of substitution between the intermediate goods.

Solving the previous problem, we arrive at the demand for product $Y_{j,t}$:

$$Y_{j,t} = Y_t \left(\frac{P_t}{P_{j,t}} \right)^{\varphi} \tag{17}$$

Substituting equation (13) in equation (12), we arrive at the general price level:

$$P_t = \left(\int_0^1 P_{j,t}^{1-\varphi} dj \right)^{\frac{1}{1-\varphi}} \tag{18}$$

3.2.2. Firms producing intermediate goods

The problem of firms producing intermediate goods is divided into two stages: in the first stage, it chooses the quantity of inputs used in the production process; in the second, it defines the price of its good.

3.2.2.1. Decision on the quantity of inputs in the production process. In this stage, the firm must choose the quantity of labor and capital with the aim of minimizing costs:

$$\min_{L_{j,t}, K_{j,t}} W_t L_{j,t} + R_t U_t K_{j,t} \tag{19}$$

subject to the following technology:

$$Y_{j,t} = A_t \left(U_t K_{j,t} \right)^{\alpha} L_{j,t}^{1-\alpha} \tag{20}$$

where α is the share of capital in the production process, U is the level of installed capacity, K is the capital stock level, with return R and A is the technological level which observes the law of motion:

$$\log A_t = \rho_A \log A_{t-1} + \epsilon_{A,t} \tag{21}$$

where $\epsilon_{A,t} \sim N(0, \sigma_A)$.

The first-order conditions for the problem of the intermediate goods producer are:

$$L_{j,t} = MC_{j,t}(1-\alpha) \frac{Y_{j,t}}{W_t} \tag{22}$$

$$U_t K_{j,t} = MC_{j,t} \alpha \frac{Y_{j,t}}{R_t} \tag{23}$$

the marginal cost being: (MC):

$$MC_{j,t} = \frac{1}{A_t} \left(\frac{R_t}{\alpha} \right)^{\alpha} \left(\frac{W_t}{1-\alpha} \right)^{1-\alpha} \tag{24}$$

3.2.2.2. *Pricing a la calvo.*
The firm producing intermediate goods must decide the price of its product according to a rule of Calvo (Calvo, 1983). There is a probability θ that the firms will maintain the level of prices of the prior period and the probability $(1 - \theta)$ of setting an optimal price for its good, $P_{j,t}^*$. As the price is defined in t, there is the probability θ of it remaining fixed at t + 1, a probability θ^2 of it remaining fixed at t + 2, and so on and so forth. Therefore, this firm must consider these probabilities when defining the price in t. Thus, the problem of the firm which adjusts the price of its good in t is:

$$\max_{P_{j,t}^*} E_t \sum_{i=0}^{\infty} (\beta\theta)^i \left(P_{j,t}^* Y_{j,t+i} - Y_{j,t+i} MC_{j,t+i} \right) \tag{25}$$

subject to equation (17), and θ is the rigidity factor in the readjustment of prices.

The first-order condition for this problem is:

$$P_{j,t}^* = \left(\frac{\varphi}{\varphi - 1} \right) E_t \sum_{i=0}^{\infty} (\beta\theta)^i MC_{j,t+i} \tag{26}$$

Combining the pricing rule in equation (18) with the assumption that all firms in conditions define the price in a similar fashion, we arrive at the general price level:

$$P_t = \left[\theta P_{t-1}^{1-\varphi} + (1-\theta) P_t^{*1-\varphi} \right]^{\frac{1}{1-\varphi}} \tag{27}$$

3.2.3. *Firms producing capital goods*
The accumulation of capital is the responsibility of one single firm, which transforms a basket of investment goods (I) into capital (K). This firm defines the investment quantity to be transformed into capital maximizing the profit earned by transferring capital to the firms producing intermediate goods, subject to a cost of investment and non-maximum utilization of the capital. Therefore, this firm has to solve the following problem:

$$\max_{U_t, K_{t+1}, I_t} E_t \sum_{t=0}^{\infty} \Xi_{0,t} \left\{ R_t U_t K_t - P_t K_t \left[\psi_1 (U_t - 1) + \frac{\psi_2}{2} (U_t - 1)^2 \right] - P_t I_t \right\} \tag{28}$$

subject to the law of motion of capital,

$$K_{t+1} = (1-\delta)K_t + I_t \left[1 - \frac{\chi}{2} \left(\frac{I_t}{S_t^I I_{t-1}} - 1 \right)^2 \right] \tag{29}$$

where I is the investment, ψ_1 and $\psi_2 > 0$ are sensitivity parameters for the use of installed capacity, χ is the sensitivity parameter for investment growth, and S_t^I is the productivity of the investment whose law of motion is:

$$\log S_t^I = \rho_I \log S_{t-1}^I + \epsilon_{I,t} \tag{30}$$

where $\epsilon_{I,t} \sim N(0, \sigma^I)$.

The first-order conditions for the previous problem are:

$$\frac{R_t}{P_t} = \psi_1 + \psi_2(U_t - 1) \tag{31}$$

$$Q_t = E_t \Xi_{t,t+1} \left\{ Q_{t+1}(1-\delta) + R_{t+1}U_{t+1} - P_{t+1}\left[\psi_1(U_{t+1}-1) + \frac{\psi_2}{2}(U_{t+1}-1)^2\right] \right\} \tag{32}$$

$$P_t - Q_t\left[1 - \frac{\chi}{2}\left(\frac{I_t}{S_t^I I_{t-1}} - 1\right)^2 - \chi\left(\frac{I_t}{S_t^I I_{t-1}}\right)\left(\frac{I_t}{S_t^I I_{t-1}} - 1\right)\right]$$
$$= \chi E_t \left[\left(\frac{\Xi_{t,t+1}Q_{t+1}}{S_{t+1}^I}\right)\left(\frac{I_{t+1}}{I_t}\right)^2\left(\frac{I_{t+1}}{S_{t+1}^I I_t} - 1\right)\right] \tag{33}$$

where Q is known as Tobin's Q and represents the Lagrange multiplier for the evolution of capital.

3.3. Government

In this model, the government is represented by two authorities: fiscal and monetary.

3.3.1. Fiscal authority

In order to fund its costs, the fiscal authority taxes households by using a lump-sum tax and issues debt of two different maturities: short-term and long-term. To this end, it must observe the following intertemporal budget constraint:

$$\frac{B_{t+1}}{R_t^B} - B_t + \frac{B_{L,t+1}}{R_{L,t}^B} - \frac{B_{L,t}}{\prod_{i=2}^{N_L} R_{t+i-1}^B} = G_t P_t - T_t P_t \tag{34}$$

The government possesses a fiscal policy tool on the expense side: G_t, and one on the revenue side: T_t. Always observing a rule of public debt stability:

$$\frac{Z_t}{Z_{ss}} = \left(\frac{Z_{t-1}}{Z_{ss}}\right)^{\gamma_Z}\left[\left(\frac{B_t/Y_{t-1}P_{t-1}}{B_{ss}/Y_{ss}P_{ss}}\right)\left(\frac{B_{L,t}/Y_{t-1}P_{t-1}}{B_{L,ss}/Y_{ss}P_{ss}}\right)\right]^{(1-\gamma_Z)\phi_Z} S_t^Z \tag{35}$$

where $Z = \{G_t P_t, T_t P_t\}$. And with a fiscal shock (S^Z) represented by:

$$\log S_t^Z = \rho_Z \log S_{t-1}^Z + \epsilon_{Z,t} \tag{36}$$

where $\epsilon_{Z,t} \sim N(0, \sigma^Z)$.

In addition, there is also the shock with the supply of long-term public debt:

$$\log B_{L,t} = \rho_{BL} \log B_{L,t-1} + \epsilon_{BL,t} \tag{37}$$

where $\epsilon_{BL,t} \sim N(0, \sigma^{BL})$.

3.3.2. Monetary authority

Monetary authority possesses a dual objective: level of product and price stability. Thus, the following Taylor rule is used:

$$\frac{R_t^B}{R_{ss}^B} = \left(\frac{R_{t-1}^B}{R_{ss}^B}\right)^{\gamma_R} \left[\left(\frac{Y_t}{Y_{ss}}\right)^{\gamma_Y} \left(\frac{\Pi_t}{\Pi_{ss}}\right)^{\gamma_\pi}\right]^{1-\gamma_R} S_t^m \tag{38}$$

where γ_Y and γ_π are the sensitivities of the basic interest rate in relation to the product and the inflation rate, respectively, and γ_R is the smoothing parameter. S_t^m is the monetary shock, represented by:

$$\log S_t^m = \rho_m \log S_{t-1}^m + \epsilon_{m,t} \tag{39}$$

where $\epsilon_{m,t} \sim N(0, \sigma^m)$.

And gross rate of inflation:

$$\Pi_t = \frac{P_t}{P_{t-1}} \tag{40}$$

3.4. Condition of equilibrium in the goods market

Now that each agent's behavior has been described, the interaction between them must be studied in order to determine macroeconomic equilibrium. Households decide how much to consume, how much to invest and how much labor to supply, with the aim of maximizing utility, taking prices as given. On the other hand, firms decide how much to produce using available technology and choosing the factors of production (capital and labor) and the prices of their goods.

Therefore, the model's equilibrium consists of the following blocks:

(1) a price system, W, R, R^B, R_L^B, π, MC, λ, Ξ, Q, U and P;
(2) an endowment of values for goods, inputs and stocks Y, C, I, G, L, K, T, B and B_L; and
(3) a production-possibility frontier described by the following equilibrium condition of the goods market (aggregate supply = aggregate demand).

$$Y_t = C_t + I_t + G_t \tag{41}$$

In short, the equilibrium is governed by 27 variables (the variables described in the blocks above plus the shocks: S^P, S^L, S^I, A, S^G, S^T, S^m) and by 27 equations (4, 5, 6, 7, 8, 9, 10, 20, 21, (22–23), 24, (26–27), 29, 30, 31, 32, 33, 34, 35(G), 35(T), 36(G), 36(T), 37, 38, 39, 40, 41)[3]

4. Estimation of the structural model

This section presents the procedures for data treatment and estimation of the structural model.

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[3]The combination of equations (22) and (23) results in the tradeoff of inputs; the combination of equations (26) and (27) results in New-Keynesian Phillips Curve; and equations (35) and (36) are used for the two fiscal policy instruments (G, T).

4.1. Data treatment

This model was estimated using quarterly data between 2000 Q1 and 2018 Q4. Five observable variables were used, as described in Table 1. To prepare the data for estimation, it was necessary to apply logarithmic or logarithmic differences in order to remove the trend.

4.2. Calibrated parameters, prior and posterior

The calibration of the parameters follows two approaches. Some parameters that are not directly related to the main object of this study were calibrated while the parameters that are relevant to the analysis of the propagation of shocks are estimated using a Bayesian methodology. In the first approach, it was decided to use the parameter values of other relevant articles in the DSGE literature. Table 2 summarizes the calibration of these parameters.

Given the prior distributions of the parameters, the model was estimated using a Markov chain process by means of the Metropolis-Hastings algorithm with 100,000 iterations and 10 parallel chains[4] The results of the Bayesian estimation are presented in Table 3 and in Figure 2[5]

The graphs in Figure 2 are particularly relevant insofar as they present the main results of this estimation, serving as a tool for detecting problems with the results. In the first place, the prior and posterior distributions should not be excessively different from one another. Secondly, the posterior distribution should be close to the normal distribution or at least not be of a form which is clearly different from normal. Thirdly, the mode

Table 1. Observable variables in the model for the USA. Source: Own elaboration.

Variable	Series	Source
Y	Real Gross Domestic Product,	Federal Reserve
	Percent Change for Quarter One Year Ago, Seasonally Adjusted	Bank of St. Louis
C	Real Personal Consumption Expenditures	Federal Reserve
	Percent Change for Quarter One Year Ago, Seasonally Adjusted	Bank of St. Louis
I	Real Gross Private Domestic Investment	Federal Reserve
	Percent Change for Quarter One Year Ago, Seasonally Adjusted	Bank of St. Louis
G	Federal total expenditures	Federal Reserve
	Billions of Dollars, Quarterly Seasonally Adjusted	Bank of St. Louis
T	Federal government current tax receipts	Federal Reserve
	Millions of Dollars, Quarterly Seasonally Adjusted	Bank of St. Louis
U	Capacity Utilization: Total Industry	Federal Reserve
	Percent of Capacity, Monthly, Seasonally Adjusted	Bank of St. Louis
L	All Employees: Total Nonfarm Payrolls,	Federal Reserve
	Thousands of Persons, Monthly, Seasonally Adjusted	Bank of St. Louis
π	Consumer Price Index for All Urban Consumers:	Federal Reserve
	All Items, Index 1982–1984 = 100, Monthly, Seasonally Adjusted	Bank of St. Louis
R^B	3-Month Treasury Constant Maturity Rate,	Federal Reserve
	Percent, Monthly, Not Seasonally Adjusted	Bank of St. Louis
R^B_L	10-Year Treasury Constant Maturity Rate,	Federal Reserve
	Percent, Monthly, Not Seasonally Adjusted	Bank of St. Louis

[4]This model was estimated using the Dynare platform.
[5]We are using two auxiliary shocks to help identify the parameters: in the rate of growth of the capital's installed capacity, ϵ_{DU}; and in the markup of firms, ϵ_{markup}.

Table 2. Calibrated parameters. Source: Own elaboration.

Parameters	Value	Source
R_{ss}^B	1.000175	3-Month Treasury Constant Maturity Rate (average 2010–2015)
$R_{L,ss}^B$	1.0061	10-Year Treasury Constant Maturity Rate (average 2010–2015)
ϑ_L	$\left[\frac{1}{Y_{ss}\left(\frac{3}{2}-\beta\right)}\right]\left[\left(\frac{R_{L,ss}^B}{R_{ss}^B}\right)\beta - 1\right]$	predetermined
β	$1/R_{ss}^B$	predetermined
δ	0.025	Del Negro et al., 2013
θ	0.75	Del Negro et al., 2013
φ	7.7	Del Negro et al., 2013
ϕ_c	0.7	Del Negro et al., 2013
α	0.33	Del Negro et al., 2013
η	2.5	Del Negro et al., 2013
ω	2	Del Negro et al., 2013
γ_R	0.5	Del Negro et al., 2013
γ_Y	0.2	Del Negro et al., 2013
γ_π	2	Del Negro et al., 2013
ψ_2	4	determined by author
χ	4	determined by author
ψ_1	$\frac{1}{\beta} - (1 - \delta)$	predetermined
N_L	40	determined by author
Y_{ss}	15,525	Real Gross Domestic Product, Billions of Chained 2009 Dollars (average 2010–2015)
P_{ss}	1	normalized by author
$\frac{T_{ss}}{Y_{ss}}$	0.35	IMF14
$\frac{C_{ss}}{Y_{ss}}$	0.66	Bureau of Economic Analysis
$\frac{I_{ss}}{Y_{ss}}$	0.16	Bureau of Economic Analysis
$\frac{G_{ss}}{Y_{ss}}$	0.18	Bureau of Economic Analysis
$\frac{K_{ss}}{Y_{ss}}$	2.5	Rudebusch & Swanson, 2008

should not be too far from the posterior distribution. Analyzing this figure, in general, the estimates were satisfactory.

5. Analysis of results

Propositions 3.1 and 3.2 demonstrated, in theory, that this model is capable of providing term premiums in both the short and the long term. Another sign that the preferred-habitat hypothesis is achieved by the model is by using impulse-response functions for these two types of interest rates, given the shock of an increase in the stock of long-term bonds (Figure 3). The increased supply of these bonds raises the interest rate for this maturity and reduces the short-term interest rate, behavior which is expected in order to satisfy the preferred-habitat hypothesis. These two facts together corroborate the proofs of the existence of this hypothesis for the term structure of interest rates displayed in Figure 1.

In terms of economic policy, Figure 3 shows that a restructuring in the composition of public debt, replacing short-term bonds with long-term bonds, has a positive result on the GDP. For the government, with the maturity of its longer debt, is able to have fiscal space to increase expenditures and thereby stimulate the economy. Therefore, at certain times, it would be important for the government to improve the market conditions of its bonds.

Table 3. Posterior distribution of the model. Source: Own elaboration.

Parameter	Average prior	Average posterior	90% confidence interval	Prior	SD posterior
Parameters					
$\frac{B_{ss}}{Y_{ss}}$	0.6	0.6024	0.6019 0.6029	gamma	0.01
$\frac{B_{L,ss}}{Y_{ss}}$	3.4	3.4123	3.4113 3.4129	gamma	0.01
γ_G	0.5	0.9894	0.9887 0.9900	unif	0.2829
γ_T	0.5	0.9666	0.9601 0.9735	unif	0.2829
ϕ_G	−0.25	−0.3861	−0.4047 − 0.3552	unif	0.1443
ϕ_T	0.5	0.4304	0.3594 0.4923	unif	0.2887
Autoregressive components					
ρ_P	0.5	0.4425	0.4403 0.4446	beta	0.25
ρ_L	0.5	0.6487	0.6214 0.6801	beta	0.25
ρ_I	0.5	0.3395	0.3064 0.3821	beta	0.25
ρ_A	0.5	0.7009	0.6316 0.7491	beta	0.25
ρ_G	0.5	0.4051	0.3644 0.4378	beta	0.25
ρ_T	0.5	0.4435	0.4009 0.4843	beta	0.25
ρ_m	0.5	0.0783	0.0215 0.1123	beta	0.25
ρ_{BL}	0.5	0.9449	0.9348 0.9549	beta	0.25
Exogenous shocks					
ϵ_P	1.0	6.9888	5.6636 7.8635	invg	Inf
ϵ_L	1.0	0.1355	0.1176 0.1512	invg	Inf
ϵ_I	1.0	0.2657	0.2241 0.2982	invg	Inf
ϵ_A	1.0	0.1208	0.1176 0.1247	invg	Inf
ϵ_G	1.0	0.1268	0.1176 0.1372	invg	Inf
ϵ_T	1.0	0.1305	0.1176 0.1424	invg	Inf
ϵ_m	1.0	0.1207	0.1176 0.1239	invg	Inf
ϵ_{BL}	1.0	0.3314	0.2783 0.4052	invg	Inf
ϵ_{DU}	1.0	0.1213	0.1176 0.1257	invg	Inf
ϵ_{markup}	1.0	0.1574	0.1226 0.1893	invg	Inf

The absence of a local market for bonds and long-term credit is generally a feature of developing countries[6] Let T be the period for which there is a domestic market for debt securities, as determined by jurisdictional uncertainty. For terms above T, this uncertainty causes the market to disappear. This means that for long maturities exceeding T, jurisdictional uncertainty cannot be assessed quantitatively; that is, it cannot be expressed as a spread over the interest rate that prevails in long-term foreign markets and, then the domestic market ceases to exist.

Judicial uncertainty would be what gives substance to the so-called original sin[7] of international finance, as identified by EicHaus99. Jeanne03 argues that original sin is the result of the lack of credibility of domestic monetary policy in a context of fixed exchange rates.

One example of the situation described above would be the case of Brazil which, with the adoption of the floating exchange rate regime in 1999, given the primary surplus sustained in the initial years of this foreign exchange regime, the real exchange rate depreciated to the point where the country began to have high trade balances, significantly reducing the current account deficit. Real interest rates fell but they were significantly higher when compared to the other emerging economies. According to Arida, Bacha, and Lara-Resende (2005), one explanation could be the absence of a local market for long-term credit. The reasons for this condition in Brazil's recent history are punctuated by the loss in the value of long-term financial contracts by virtue of the

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[6]Eichengreen, Hausmann, and Panizza (2003) mention countries such as Chile, Israel, and India that are able to issue domestic long-term debt bonds denominated in domestic currency but not abroad.
[7]The inability to issue long-term foreign debt in national currency.
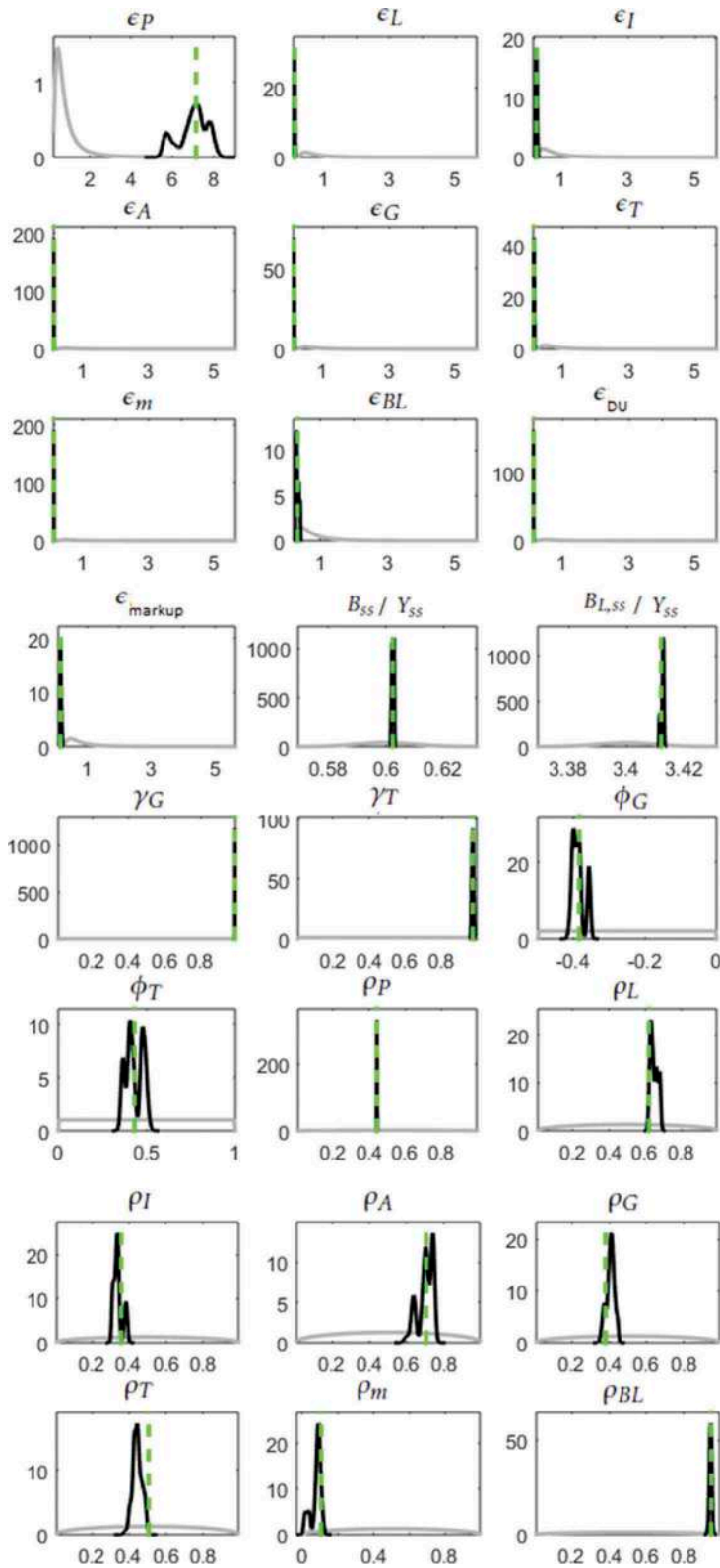
Figure 2. Prior and posterior results for the estimated parameters.
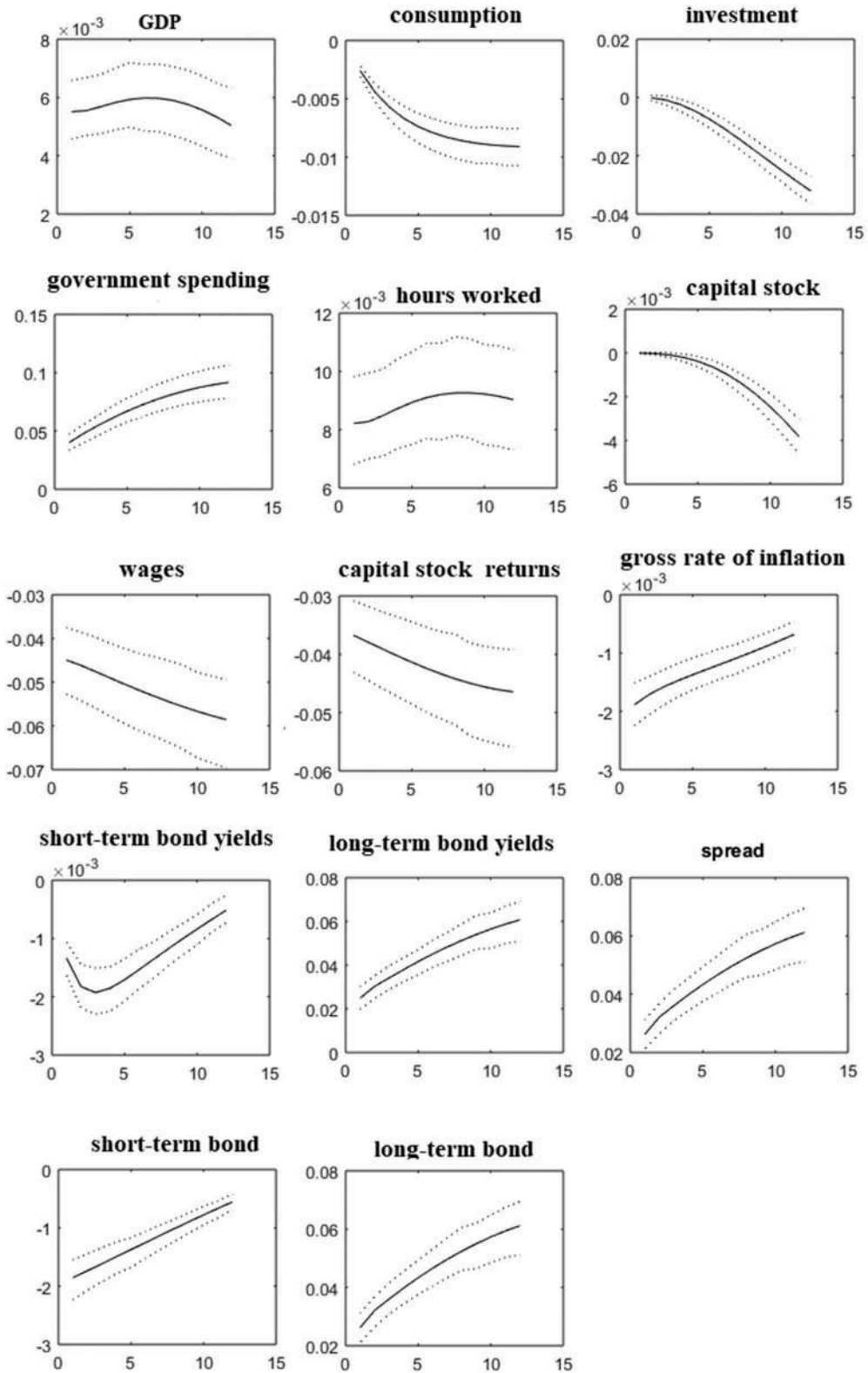Source: Own elaboration.

Figure 3. Impulse-response functions for a positive shock in long-term government bonds. The values of the graphs represent the log of the difference of the variable in relation to its steady state, $x_t = \log(X_t/X_{ss})$. Source: Own elaboration.

Table 4. Standard deviations of the base and complete models. Source: Own elaboration.

Base model variable	Standard deviation	Complete model variable	Standard deviation
Y	0.0989	Y	0.1196
C	0.1508	C	0.1822
I	0.6023	I	0.7014
G	0.7133	G	1.1443
L	0.2472	L	0.2749
K	0.2603	K	0.2884
W	0.7603	W	0.7253
R	0.6371	R	0.6279
R_B	0.1345	R_B	0.1461
π	0.0794	π	0.0857
T	0.7955	T	1.6180

manipulation of indexation, the change in the monetary standard, freezing of financial assets, legal annulment of adjustment clauses in foreign currency, among other reasons.

Moreover, these authors highlight that:

"A long-term domestic market does not exist because there are no long-term financial savings available under Brazilian jurisdiction. The preferred habitat (Modigliani & Sutch, 1966) of savers is the very short term. It is a distortion resulting not from an inter-temporal consumption allocation decision but rather from the resistance of individuals and firms to make their savings available for the long term under domestic jurisdiction. (Arida et al., 2005, p. 271)".

Table 4 presents the standard deviation values for the base and complete models[8] Note that the complete model is, on average, approximately 20% more volatile than the base model. This higher volatility is also observed in Figure 4, where a positive productivity shock is presented in both models (base and complete), since the effects are underestimated in the base model. For example, the reaction of the GDP to the productivity shock is stronger and more persistent in the complete model than in the base model.

If the complete model is correct, the question that arises is: what would be the consequence of the use of the base model by policymakers? Since productivity shocks are more volatile and persistent, the output is much more volatile when one considers the complete model, implying that monetary policy, by disregarding this greater effect, might have an insufficient reaction to stabilize output around its non-stochastic level.

The variables compared in this table are the differences of the underlying variable with its steady state $X_t = \ln\left(\frac{x_t}{x_{ss}}\right)$.

6. Conclusions

The objective of this work was to present an alternative approach in the implementation of the term structure of interest rates in DSGE models.

Propositions 3.1 and 3.2 demonstrated, in theory, that this model is capable of providing term premiums in both the short and the long term. Another demonstration of this existence is seen in the increased supply of these bonds that raises the interest rate for this maturity and for the short-term interest rate but to a lesser extent.

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[8]The base model differs from the complete model in only one feature, the existence of long-term bonds. In summary, the complete model is that presented in section 3 and the base model is the same model, but only with bonds with one maturity period.
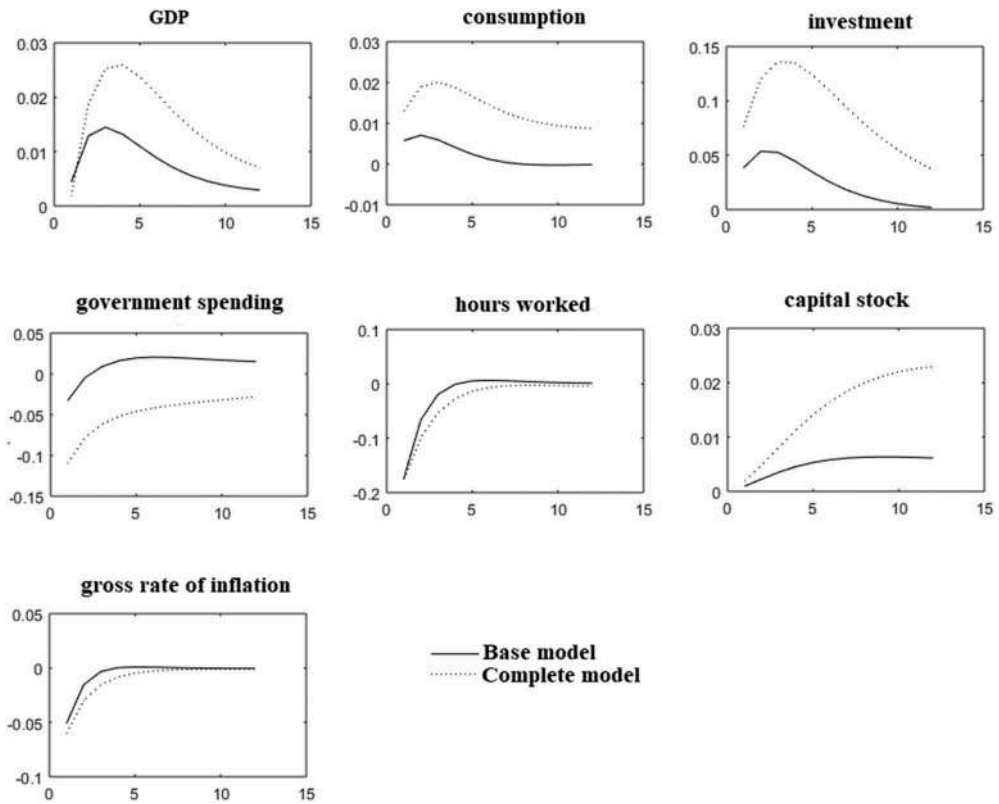
Figure 4. Impulse-response functions of a productivity shock (base and complete models). The values of the graphs represent the log of the difference of the variable in relation to its steady state, $x_t = \log(X_t/X_{ss})$. Source: Own elaboration.

The results show that a recomposition of the public debt, replacing short-term bonds with long-term bonds, positively affects the product. This new structure of the public debt would open space for an expansionary fiscal policy. And, if the complete model is correct, the consequence of the use of the base model by policymakers is that the output gap would be less volatile, implying that monetary policy might have an insufficient reaction to stabilize output around its non-stochastic level.

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No potential conflict of interest was reported by the author.

Notes on contributor

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