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Macroeconomic Implications of Covid-19 Pandemic in Morocco

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ABSTRACT

The aim of this paper is to study the effects of the Covid-19 Pandemic in Morocco and subsequent responses on the economy using in a linear DSGE model. The analysis takes into account internal and external shocks and a high level of unemployment since the pandemic crisis affects a priori some contact-intensive sectors but do widen to other sectors via general equilibrium, inducing a job loss worrying situation and subsequently a great recession. I use DSGE model with an open economy, nominal rigidities in prices and five types of agents (households, producers, retailers, monetary authority and fiscal authority). I calibrated the model using Bayesian techniques and data covering the period 1998Q1 – 2019Q2. Results indicate a lasting effect shock for at least 12 quarters after the impact. Higher public debt is an obvious result of all the shocks except for the consumption tax shock. Results indicates also a significant decline in GDP following external shocks, monetary policy shock, labor tax shock, capital tax shock and technology shock. The consumption tax shock has unlike the others a very small negative impact on GDP followed by an increase in GDP. For the government expenditure and investment shock, GDP eventually decreases after increasing on impact. The inflation shock has a surprisingly a positive impact on GDP followed by a negative one four quarters after the shock.

Keywords: Fiscal policy, monetary policy, unemployment, pandemic.
JEL Codes: E62, E52, J60, I10.

1. Introduction

The disruption in the world's economies caused by the ongoing COVID-19 outbreak has pushed many economists to try to quantify the magnitude of its impact on the economy. However, the consensus is that the pandemic lead to contractions in production, in household spending, in business investment and in international trade due primarily to the health measures undertaken by several countries resulting in the temporary factories shut down, restrictions on travel and mobility and uncertainty in financial markets.

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Indeed, even with nearly similar measures undertaken by governments and monetary authorities around the world, the response is different in terms of size among countries. In Morocco, which is the subject of our study, growth prospects strongly decreases, estimated at -5.8%[3] for 2020, following the measures taken in the fight against the pandemic. In terms of fiscal policy, the covid-19 pandemic should induce adverse effects on the government budget with a significant widening of the budget deficit due to lower tax revenues, estimated at 7.4%[4] (to GDP). As for foreign trade, the unfavorable international economic environment should negatively affect the economy. Exports are expected to decline following the decline in world demand. In such circumstances, how should fiscal and monetary policy react in order to support the sectors affected by the pandemic and to revive the economy? Is the Keynesian fiscal stimulus appropriate in such a situation?

Assessing the impact of the COVID-19 crisis on the economy is fundamental in order to help the government and monetary authorities making right decisions. Therefore, several theoretical and empirical studies appeared following the crisis. Faria-e-Castro (2020)[5] study the effects of the COVID-19 outbreak in the United States using nonlinear DSGE model and analyze different types of fiscal policies assuming a 20% unemployment rate and a pandemic crisis that lasts for three quarters: from 2020Q1 through 2020Q3. The author argues a complete shutdown of the services sector for three full quarters and a GDP contraction of 15% per quarter. Eichenbaum et al. (2020)[6] extend the classic susceptible-infected-recovered (SIR) model proposed by Kermack & McKendrick (1927)[7] to study the equilibrium interaction between economic decisions and epidemic dynamics in the U.S. Their model allows to endogenize the epidemic dynamics and thus to deduce the optimal responses of public policies. They find that a deep recession, intensified by agents' optimal decision to cut back on consumption and hours worked, helps reduce the severity of their epidemic, as measured by total deaths; roughly half a million lives in the U.S. can be saved.

Fornaro & Wolf (2020)[8] use in their analysis a small theoretical model and conclude on possible stagnation of the global economy accompanied by low growth and high unemployment caused by the current pandemic; a situation that requires a monetary stimulus and aggressive fiscal policy interventions. Umba et al. (2020)[9] study the macroeconomic impact of COVID-19 on the economic activity of the DR Congo using an open economy DSGE model and Bayesian approach. They predict a significant decrease in the output gap for 8th quarter after the shock and a downward effect of consumption for more than 10 quarters after the shock. All the aforementioned works reveal that COVID-19 is actually a both supply and demand shock caused by a decrease in employment and in household's consumption. These contractions could have as a result a great economic recession, a deterioration in the government deficit and a widening current account deficit.

In the present work, we try to assess the impacts of the Covid-19 pandemic assuming that it generates several shocks affecting the whole economy. We use, for this purpose, a standard open economy New Keynesian DSGE model with Bayesian techniques adapted to the Moroccan economy. The model integrates monopolistic competition, nominal rigidities in prices and a semi-fixed exchange regime. We consider five types of agents in the model: households; producers; retailers; monetary authority and fiscal authority.

The paper is organized as follows: The next section presents the theoretical model in its original form. Section 3 outlines the methodological approach, data employed, model calibration and prior distributions for Bayesian estimation. Section 4 reports the results of the Bayesian estimation and evaluates the impulse - response functions to Covid19 shocks. We present also sensitivity analysis to gauge the credibility of the estimation. Section 5 concludes the paper and summarizes its main findings.

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[3] According to the Higher Planning Commission of Morocco estimates.

[4] According to the Higher Planning Commission of Morocco estimates.

[5] Faria-e-Castro M., (2020). Fiscal Policy during a Pandemic. Federal Reserve Bank of St. Louis. Working Paper Series No. 2020-006.

[6] Eichenbaum M.S., Rebelo S. and Trabandt M., (2020). The Macroeconomics of Epidemics. National Bureau of Economic Research, NBER Working Paper No. 26882.

7 Kermack W. O. and McKendrick A. G., (1927). A Contribution to the Mathematical Theory of Epidemics. Proceedings of the Royal Society of London, Series A115, No. 772, pp. 700-721.

8 Fornaro L. and Wolf M., (2020). Covid-19 Coronavirus and Macroeconomic Policy. Barcelona Graduate School of Economics, Working Papers No. 1168.

9 Umba G. B., Siasi Y. and Lumbala G., (2020). Leçons Macroéconomiques de la Covid-19: une Analyse pour la RDC. CEPREMAP, Dynare Working Papers No. 64.

The appendix presents the log-linearized form of the model along with figures exhibiting the estimation results.

2. Theoretical Model

The model used in this work is based largely on Bhattarai & Trzeciakiewicz (2017)[10] and Umba et al. (2020). The model consists in capturing the households' behavior, firms, monetary authority and fiscal policy. The rest of the world is also considered; where the prices of exported and imported goods are determined. Firms are divided into producers and retailers. The model allows for unemployment, monopolistic competition and staggered re-optimization in the wholesale market as in Calvo-type staggered price setting. Monetary policy is described by a nominal interest rate Taylor rule that allows some flexibility in the exchange rate, which can be parameterized according to preference.

The Covid-19 shock is integrated in the model through several shocks affecting simultaneously aggregate supply, aggregate demand, fiscal policy and monetary policy. Thus we assumed a productivity shock (ε_t^A), inflation shock (ε_t^π), government expenditure shock ($\varepsilon_t^{G^g}$), government investment shock ($\varepsilon_t^{I^g}$), consumption tax shock ($\varepsilon_t^{\tau^c}$), capital tax shock ($\varepsilon_t^{\tau^k}$), labor tax shock ($\varepsilon_t^{\tau^w}$), monetary policy shock (ε_t^i), exports shock (ε_t^x) and finally imports shock (ε_t^m). These shocks are specified as follows (in log-linearized terms):

$$\tilde{\varepsilon}_t^X = \varphi_X \tilde{\varepsilon}_{t-1}^X + \tilde{\eta}_X \tag{0.1}$$

Where $\tilde{\varepsilon}_t^X = \left\{\tilde{\varepsilon}_t^A; \tilde{\varepsilon}_t^\pi; \tilde{\varepsilon}_t^{G^g}; \tilde{\varepsilon}_t^{I^g}; \tilde{\varepsilon}_t^{\tau^c}; \tilde{\varepsilon}_t^{\tau^k}; \tilde{\varepsilon}_t^{\tau^w}; \tilde{\varepsilon}_t^i; \tilde{\varepsilon}_t^x; \tilde{\varepsilon}_t^m\right\}$.

2.1 Households

The economy is populated by a continuum of identical households that are able to maximize its intertemporal utility by choosing consumption, savings and investment. For saving, the household can choose between two different savings instruments: physical capital and government bonds. With the disposable income after payment of taxes, the household can purchase consumer goods, capital goods, and/or government bonds.

2.1.1 Dynamic optimization problem of households

The utility functional of each household is represented by:

$$U(C_t, L_t) = \frac{{C_t}^{1-\sigma_c}}{1-\sigma_c} - \frac{\varepsilon^L {L_t}^{1+\sigma_l}}{1+\sigma_l} \tag{0.2}$$

Where $\sigma_l \geq 0$ denotes the inverse Frisch elasticity of labor supply L_t, $\sigma_c > 0$ denotes the inverse of the intertemporal elasticity of substitution in consumption C_t and ε^L represents an AR (1) process which reflects a labor supply shock.

Each household maximizes its lifetime utility:

$$\max_{C_t, L_t} E_0 \sum_{t=0}^{\infty} \beta^t\, U\left(\frac{{C_t}^{1-\sigma_c}}{1-\sigma_c} - \frac{{L_t}^{1+\sigma_l}}{1+\sigma_l}\right) \tag{0.3}$$

Where β^t the subjective discount factor satisfies $0 < \beta^t < 1$

Subject to the following budget constraint:

$$\begin{aligned}(1+\tau_t^c)C_T P_T + P_t I_t + \frac{B_{t+1}}{i_t} \\ = (1-\tau_t^w)W_t N_t + \left(1-\tau_t^k\right)\left(r_t^k z_t K_{t-1}\right) - \psi_k(z_t)K_{t-1} + D_t + B_t \\ + TR_t\end{aligned} \tag{0.4}$$

[10] Bhattarai K. and Trzeciakiewicz D., (2017). Macroeconomic Impacts of Fiscal Policy Shocks in the UK: A DSGE Analysis. Economic Modelling, Vol. 61, Issue C, pp. 321-338.

Where τ_t^c denotes the consumption tax rate, τ_t^W the labor tax rate and τ_t^k the capital tax rate. The budget constraint states that the household's total expenditure on consumption C_t, on investment in physical capital I_t and on accumulation of a portfolio of riskless one-period contingent B_t must equal the household's total disposable income.

The total real disposable income of each household consists of the following:

The after tax labor income $(1-\tau_t^W)W_tN_t$, where $W_t$denotes the real wage rate and N_t denotes the level of employment;

The after tax return on capital $(1-\tau_t^k)(r_t^k z_t K_{t-1}) - \psi_k(z_t)K_{t-1}$, where r_t^kdenotes the real rate of return on capital, K_t represents the physical stock of capital, and z_t the capital utilization rate. Setting the level of capital utilization rate requires each household to incur a cost equal to $\psi_k(z_t)K_{t-1}$. Like Smets & Wouters (2002)[11] and Christiano et al. (2005)[12], Bhattarai & Trzeciakiewicz (2017), we assume that $\frac{\psi_k''(z_t)}{\psi_k'(z_t)} = \kappa$. Consequently, only the dynamics of the model depend on the parameter κ. In the steady state, the capital utilization cost is equal to zero when the capital utilization is equal to 1 $(\psi_k\,(1) = 0)$;

The income from dividends D_t;

B_t denotes bonds issued by the government and i_t the nominal interest rate on a one-period bond;

TR_t indicates the flat-rate government transfers.

Physical capital accumulates in accordance with the following:

$$K_t = (1-\delta_k)K_{t-1} + F_t(I_t, I_{t-1}) \tag{0.5}$$

Where $F_t(I_t, I_{t-1}) = I_t\left[1 - S\left(\frac{\varepsilon_t^{inv} I_t}{I_{t-1}}\right)\right]$ indicates the investment function adjustment cost. ε_t^{inv} denotes the investment function shock, which follows an AR (1) process : $\varepsilon_t^{inv} = \rho_{inv}\varepsilon_{t-1}^{inv} + \eta_t^{inv}$with $\eta_t^{inv} \sim N\left(0, \sigma_{\eta^i}^2\right)$. As in Christiano et al. (2005), Smets and Wouters (2002) and others, the derivative of the function $S(.)$ equals zero in steady state so that the adjustment costs will only depend on the second-order derivative $S''(.) = \Upsilon > 0$.

2.1.2 Unemployment

The labor supply is separated in the model so that a fraction represents the unemployment rate:

$$\tilde{L}_t = (1-\varphi)\tilde{N}_t + \varphi\tilde{U}_t \tag{0.6}$$

Where φ is the separation rate, N_t indicates the level of employment and U_t denotes the level of unemployment.

Based on Alichi (2015)[13] and on the Okun rule, unemployment depends on its past value and on the output, and can be subject to shocks ε_t^U:

$$\tilde{U}_t = \omega_U\tilde{U}_{t-1} + \omega_Y\tilde{Y}_{t-1} + \tilde{\varepsilon}_t^U \tag{0.7}$$

2.1.3 First order conditions of households

To solve the problem of the household, a Lagrangian function is used:

[11] Smets F. and Wouters R., (2002). An Estimated Stochastic Dynamic General Equilibrium Model of the Euro Area. International Seminar of Macroeconomics, European Central Bank, ECB Working Paper Series No. 171.

[12] Christiano L. J., Eichenbaum M. and Evans C. L., (2005). Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy. University of Chicago Press, Journal of Political Economy, Vol. 113, No. 1, pp. 1-45.

[13] Alichi A., (2015). A New Methodology for Estimating the Output Gap in the United States. International Monetary Fund, IMF Working Papers No. 15/144.

$$\mathcal{L} = E_t \sum_{t=0}^{\infty} \beta^t \left\{ \left[\frac{C_t^{1-\sigma_c}}{1-\sigma_c} - \frac{\varepsilon^L L_t^{1+\sigma_l}}{1+\sigma_l} \right] - \lambda_t \left[(1+\tau_t^c) C_t P_t + \frac{B_{t+1}}{i_t} - (1-\tau_t^w) W_t N_t - (1-\tau_t^k)(r_t^k z_t K_{t-1}) + \psi_k(z_t) K_{t-1} - D_t - B_t - TR_t \right] - \lambda_t P_t^k \left[K_t - (1-\delta_k) K_{t-1} - I_t \left[1 - S\left(\frac{\varepsilon_t^{inv} I_t}{I_{t-1}} \right) \right] \right] \right\} \tag{0.8}$$

Where P_t^k is the shadow price of capital and λ_t denotes the marginal utility of income.
The first order conditions associated with the choices of C_t, N_t, B_t, K_t, I_t and z_t are respectively:

$$\frac{\partial \mathcal{L}}{\partial C_t} = \beta^t C_t^{-\sigma_c} - \lambda_t P_t (1+\tau_t^c) = 0 \tag{0.9}$$

$$\frac{\partial \mathcal{L}}{\partial N_t} = -\beta^t \varepsilon^L L_t^{\sigma_l} + \lambda_t (1-\tau_t^w) W_t = 0 \tag{0.10}$$

$$\frac{\partial \mathcal{L}}{\partial B_{t+1}} = -\frac{\lambda_t}{i_t} + \beta^t E_t \lambda_{t+1} = 0 \tag{0.11}$$

$$\frac{\partial \mathcal{L}}{\partial K_t} = -P_t^k + \beta^t E_t \frac{\lambda_{t+1}}{\lambda_t} \left[P_{t+1}^k (1-\delta_k) + (1-\tau_t^k) r_{t+1}^k z_{t+1} - \psi(z_{t+1}) \right] = 0 \tag{0.12}$$

$$P_t^k S' \left(\frac{\varepsilon_t^{inv} I_t}{I_{t-1}} \right) \frac{\varepsilon_t^{inv} I_t}{I_{t-1}} + \beta^t E_t P_{t+1}^k \frac{\lambda_{t+1}}{\lambda_t} S' \left(\frac{\varepsilon_{t+1}^{inv} I_{t+1}}{I_t} \right) \left(\frac{\varepsilon_{t+1}^{inv} I_{t+1}}{I_t} \right) \left(\frac{I_{t+1}}{I_t} \right) = 1 \tag{0.13}$$

$$(1-\tau_t^k) r_t^k = \psi_k'(z_t) \tag{0.14}$$

From equation (2.9),

$$\lambda_t = \beta^t \frac{C_t^{-\sigma_c}}{P_t (1+\tau_t^c)} \tag{0.15}$$

Substituting the equation (2.15) into (2.10), it results in the equation of labor supply:

$$\frac{W_t}{P_t} = \frac{\varepsilon^L L_t^{\sigma_l} C_t^{\sigma_c} (1+\tau_t^c)}{1-\tau_t^w} \tag{0.16}$$

In log-linearized terms:

$$\widetilde{W}_t = \sigma_l \tilde{L}_t + \sigma_c \tilde{C}_t + \left(\frac{\tau^c}{1+\tau^c} \right) \tilde{\tau}_t^c - \left(\frac{\tau^w}{1+\tau^w} \right) \tilde{\tau}_t^w + \tilde{P}_t + \varepsilon^L \tag{0.17}$$

Substituting equation (2.15) in equation (2.11), we obtain the Euler equation:

$$\frac{\hat{C}_t^{-\sigma_c}}{\hat{C}_{t+1}^{-\sigma_c}} = i_t E_t \left[\frac{P_t}{P_{t+1}} \frac{(1+\tau_t^c)}{(1+\tau_{t+1}^c)} \right] \tag{0.18}$$

With: $\pi_t = \frac{P_t}{P_{t-1}}$, we obtain in log-linearized terms:

$$\tilde{C}_t = E_t \tilde{C}_{T+1} - \frac{1}{\sigma_c} \left[\tilde{\imath}_t - E_t(\tilde{\pi}_{t+1}) + \left(\frac{\tau^c}{1+\tau^c} \right) (\tilde{\tau}_t^c - E_t \tilde{\tau}_{t+1}^c) \right] \tag{0.19}$$

And with: $\pi_t^c = \frac{(1+\tau_t^c) P_t}{(1+\tau_{t-1}^c) P_{t-1}}$ [14], we obtain, in log-linearized terms, the consumer price inflation:

[14] We distinguish between π_t and π_t^c so that the first expression indicates the central bank price (excluding consumption tax) while the second indicates the price paid by households.

$$\tilde{\pi}_t^c = \tilde{\pi}_t + \frac{\tau^c}{1+\tau^c}(\tilde{\tau}_t^c - \tilde{\tau}_{t-1}^c) \tag{0.20}$$

From (2.12), we obtain the capital shadow price equation:

$$P_t^k = \beta^t E_t \frac{\lambda_{t+1}}{\lambda_t}\left[P_{t+1}^k(1-\delta_k) + \left(1-\tau_t^k\right) r_{t+1}^k z_{t+1} - \psi(z_{t+1})\right] = 0 \tag{0.21}$$

The price of capital depends positively on its expected value taking into account the depreciation rate, the expected real rental rate and the expected capital utilization rate.

The Euler equation in log-linearized terms implies:

$$\tilde{\lambda}_t = E_t\tilde{\lambda}_{t+1} + E_t\tilde{r}_t^k \tag{0.22}$$

Where $\tilde{r}_t^k = \tilde{\imath}_t - E_t\tilde{\pi}_{t+1}$

We log-linearize capital equation around steady state:

$$\begin{aligned}\tilde{P}_t^k &= E_t\left(\tilde{\lambda}_{t+1} - \tilde{\lambda}_t\right) \\ &\quad + \frac{1}{1-\delta_k + (1-\tau^k)r^k} E_t\Bigg[(1-\delta_k)\tilde{P}_{t+1}^k \\ &\quad + r^k(1-\tau^k)\left(\tilde{r}_{t+1}^k - \frac{\tau^k}{1-\tau^k}\tilde{\tau}_{t+1}^k\right)\Bigg]\end{aligned} \tag{0.23}$$

Substituting (2.22) into (2.23), we obtain the capital shadow price equation, in log-linearized terms:

$$\begin{aligned}\tilde{P}_t^k &= -(\tilde{\imath}_t - E_t\tilde{\pi}_{t+1}) \\ &\quad + \frac{1}{1-\delta_k + (1-\tau^k)r^k} E_t\Bigg[(1-\delta_k)\tilde{P}_{t+1}^k \\ &\quad + r^k(1-\tau^k)\left(\tilde{r}_{t+1}^k - \frac{\tau^k}{1-\tau^k}\tilde{\tau}_{t+1}^k\right)\Bigg]\end{aligned} \tag{0.24}$$

The price of capital depends negatively on the interest rate, and the capital tax rate.

With $S(1) = 1,\ S'(1) = 0,\ S''(1) = -\xi$ and $\Omega = \frac{1}{\xi}$, we log-linearize investment equation (2.13) and obtain:

$$\tilde{I}_t = \frac{1}{1+\beta}\tilde{I}_{t-1} + \frac{\beta}{1+\beta}E_t\tilde{I}_{t+1} + \frac{\Omega}{1+\beta}\tilde{P}_t^k + \frac{1}{1+\beta}E_t\left(\beta\tilde{\varepsilon}_{t+1}^{inv} - \tilde{\varepsilon}_t^{inv}\right) \tag{0.25}$$

The first-order condition with respect to the capital utilization rate (2.14) indicates that the real rental rate net of capital taxes is equal to the marginal cost of capital utilization.

$$\left(1-\tau_t^k\right)r_t^k = \psi_k'(z_t) \tag{0.26}$$

The equation for capital accumulation:

$$\tilde{K}_t^F = (1-\delta_k)\tilde{K}_{t-1}^F + \delta_k\tilde{I}_{t-1} \tag{0.27}$$

By equalizing the marginal costs of labor and capital, we obtain the following equation:

$$\tilde{L}_t^F = -\tilde{W}_t^F + \left(1+\tilde{\psi}_k\right)\tilde{r}_t^k + \tilde{K}_{t-1}^F \tag{0.28}$$

Where $\tilde{\psi}_k = \frac{\tilde{\psi}_k'(1)}{\tilde{\psi}_k''(1)}$

The capital utilization equation, in log-linearized terms, is as follows:

$$\tilde{z}_t^F = \frac{1}{\tilde{\psi}_k}\left(\tilde{r}_t^k - \frac{\tau^k}{1-\tau^k}\tilde{\tau}_t^k\right) \tag{0.29}$$

2.2 Production / Labor market

The productive sector of the economy is divided into two subsectors: producers of finished goods (retailers); and producers of intermediate goods (wholesales). The producer of the final goods purchases differentiated goods from intermediate producers and aggregates them into one single consumption good (Y_t). The wholesale sector is formed by a great number of firms, each producing a different good $(Y_{j,t})$. These firms have monopoly power over the varieties they produce and set prices in a Calvo (1983)[15] staggered fashion.

2.2.1 Firm producer of the final goods

The finished good is produced by a single firm that operates in perfect competition. The firm aggregates a continuum of intermediate goods into a single finished good according to the Dixit-Stiglitz aggregator (Dixit & Stiglitz, 1977) using the following technology:

$$Y_t = \left[\int_0^1 Y_{j,t}^{\frac{\varphi-1}{\varphi}} dj\right]^{\frac{\varphi}{\varphi-1}} \tag{0.30}$$

Where Y_t denotes aggregate output, $Y_{j,t}$ indicates the intermediate product j and $P_{j,t}$ the corresponding price. $\varphi > 0$ denotes the elasticity of substitution between intermediate goods.

The problem of the retail firm is as follows:

$$\max_{Y_{j,t}} (1-\tau_t^c)P_tY_t - \int_0^1 P_{j,t}Y_{j,t}\, dj \tag{0.31}$$

Where τ_t^c indicates the flat tax rate on finished goods. Retailer optimizes its profits by deciding how much intermediate inputs to purchase based on their price and elasticity of substitution.

Substituting (2.30) into (2.31), we obtain:

$$\max_{Y_{j,t}} (1-\tau_t^c)P_t\left[\int_0^1 Y_{j,t}^{\frac{\varphi-1}{\varphi}} dj\right]^{\frac{\varphi}{\varphi-1}} - \int_0^1 P_{j,t}Y_{j,t}\, dj \tag{0.32}$$

The first order condition for each intermediate good j is:

$$(1-\tau_t^c)P_t\left[\int_0^1 Y_{j,t}^{\frac{\varphi-1}{\varphi}} dj\right]^{\frac{\varphi}{\varphi-1}-1} Y_{j,t}^{\frac{\varphi-1}{\varphi}-1} - P_{j,t} = 0 \tag{0.33}$$

It results in a demand function for intermediate goods:

$$Y_{j,t} = Y_t\left[\frac{(1-\tau_t^c)P_t}{P_{j,t}}\right]^{\varphi} \tag{0.34}$$

Equation (2.34) indicates that the demand for intermediate good j is a decreasing function of its relative price and increasing in relation to the aggregate output of the economy.

The general price level is obtained by substituting equation (2.34) in (2.30):

$$Y_t = \left\{\int_0^1 \left[Y_t\left(\frac{(1-\tau_t^c)P_t}{P_{j,t}}\right)^{\varphi}\right]^{\frac{\varphi-1}{\varphi}} dj\right\}^{\frac{\varphi}{\varphi-1}} \tag{0.35}$$

[15] Calvo G. A., (1983). Staggered Prices in a Utility-maximizing Framework. Journal of Monetary Economics, Vol. 12, Issue 3, pp. 383-398.

The zero profit condition implies that the price index is represented by the following equation:

$$P_t = (1-\tau_t^c)\left(\int_0^1 P_{j,t}{}^{\frac{\varphi-1}{\varphi}} dj\right)^{\frac{\varphi}{\varphi-1}} \quad (0.36)$$

2.2.2 Firm producers of intermediate goods

The intermediate good production sector is formed by a large number of firms, each producing a different good under a monopolistic competitive structure and set prices in a Calvo (1983) staggered fashion. First of all, these firms take as given the prices of production factors: wages (W) and return to capital (R) and determine the quantities of those inputs that will minimize their costs then they determine the optimal price of good j and the quantity that will be produced in accordance with this price.

Drawing on Coenen & Straub (2005), Smets & Wouters (2003), Rabanal (2007) and Bhattarai & Trzeciakiewicz (2017), the production function is:

$$Y_{j,t} = \varepsilon_t^A\left(z_t K_{j,t-1}\right)^{\alpha} N_{j,t}{}^{1-\alpha} K_{t-1}^{g}{}^{\sigma_g} - \varphi_y \quad (0.37)$$

Where φ_y denotes a fixed cost of production, K_t^g denotes public capital, ε_t^A is a productivity shock, α the share of capital in output, and z_t the utilization rate of capital which is common to all firms.

Analogously to private capital, public capital is accumulated according to the following law of motion:

$$K_t^g = \left(1-\delta_g\right)K_{t-1}^g + I_t^g \quad (0.38)$$

In log-linearized terms:

$$K\widetilde{K}_t^g = \left(1-\delta_g\right)K\widetilde{K}_{t-1}^g + I\tilde{I}_t^g \quad (0.39)$$

In steady state:

$$K = \left(1-\delta_g\right)K + I \quad (0.40)$$

From (2.40), we drive the expression:

$$K = \frac{I}{\delta_g} \quad (0.41)$$

Substituting (2.41) into (2.39), we obtain:

$$\widetilde{K}_t^g = \left(1-\delta_g\right)\widetilde{K}_{t-1}^g + \delta_g\tilde{I}_t^g \quad (0.42)$$

The production function, in log-linearized terms is, as follows:

$$\tilde{Y}_{j,t} = \varphi_y\left(\tilde{\varepsilon}_t^A + \alpha\tilde{z}_t + \alpha\widetilde{K}_{j,t-1} + (1-\alpha)\widetilde{N}_{j,t} + \sigma_g\widetilde{K}_{t-1}^g\right) \quad (0.43)$$

Firms rent capital ($K_{j,t-1}$) and labor ($N_{j,t}$), for which they pay respectively a nominal rental rate (r_t^k) and a wage rate (W_t). Monopolistic companies face the following cost-minimization problem:

$$\min_{N_{j,t},K_{j,t}} W_t N_{j,t} + r_t^k z_t K_{j,t-1} \quad (0.44)$$

Using the Lagrangian function to solve the previous problem[16]:

$$\mathcal{L} = W_t N_{j,t} + r_t^k z_t K_{j,t-1} - \mu_t\left(\varepsilon_t^A z_t{}^{\alpha} K_{j,t-1}{}^{\alpha} N_{j,t}{}^{1-\alpha} K_{t-1}^{g}{}^{\sigma_g}\right) \quad (0.45)$$

The first order conditions are:

$$\frac{\partial\mathcal{L}}{\partial N_{j,t}} = W_t - (1-\alpha)\mu_t\, \varepsilon_t^A z_t{}^{\alpha} K_{j,t-1}{}^{\alpha} N_{j,t}{}^{-\alpha} K_{t-1}^{g}{}^{\sigma_g} = 0 \quad (0.46)$$

$$\frac{\partial\mathcal{L}}{\partial K_{j,t-1}} = r_t^k z_t - \alpha\mu_t\varepsilon_t^A z_t{}^{\alpha} K_{j,t-1}{}^{\alpha-1} N_{j,t}{}^{1-\alpha} K_{t-1}^{g}{}^{\sigma_g} = 0 \quad (0.47)$$

[16] The fixed cost share of the output is wasted. The presence of fixed costs ensures that in the steady state, firms' profits are equal to zero, as in Bhattarai & Trzeciakiewicz (2017).

From equations (2.46) and (2.47), we obtain:

$$W_t = \mu_t(1-\alpha)\frac{Y_{j,t}}{N_{j,t}} \tag{0.48}$$

$$r_t^k z_t = \mu_t \alpha \frac{Y_{j,t}}{K_{j,t-1}} \tag{0.49}$$

And from equations (2.48) and (2.49), we obtain (2.50), which implies that the capital to labor ratio across all of the monopolistic producers remains the same.

$$\frac{W_t N_{j,t}}{r_t^k z_t K_{j,t-1}} = \frac{1-\alpha}{\alpha} \tag{0.50}$$

The nominal marginal cost is represented by the following:

$$MC_t = \left(\frac{1}{1-\alpha}\right)^{1-\alpha}\left(\frac{1}{\alpha}\right)^{\alpha}\frac{1}{\varepsilon_t^A}{W_t}^{1-\alpha}{r_t^k}^{\alpha}{K_{t-1}^g}^{-\sigma_g} \tag{0.51}$$

The marginal cost increases as the wage rate and the rate of return on capital increase. However, a positive productivity shock along with an increase in public capital conducts to a decrease in the marginal costs.

Price setting:

The wholesale firm maximizes its profit by choosing the price of its good j,

$$\max_{P_{j,t}} P_{j,t}Y_{j,t} - W_t N_{j,t} + r_t^k z_t K_{j,t-1} \tag{0.52}$$

Substituting (2.34), (2.48) and (2.49) in (2.52), we obtain:

$$\max_{P_{j,t}} P_{j,t}Y_t\left[\frac{(1-\tau_t^c)P_t}{P_{j,t}}\right]^{\varphi} - \mu_t Y_t\left[\frac{(1-\tau_t^c)P_t}{P_{j,t}}\right]^{\varphi} \tag{0.53}$$

We obtain the following first order condition:

$$(1-\varphi)Y_t\left[\frac{(1-\tau_t^c)P_t}{P_{j,t}}\right]^{\varphi} + \varphi\mu_t Y_t\left[\frac{(1-\tau_t^c)P_t}{P_{j,t}}\right]^{\varphi}{P_{j,t}}^{-1} = 0 \tag{0.54}$$

$$\mu_t = \frac{(\varphi-1)}{\varphi}P_{j,t} \tag{0.55}$$

Substituting (2.55) into (2.48) and (2.49), and under the assumption that these firms have the same technology, we get:

$$\frac{W_t}{P_t} = \left(\frac{\varphi-1}{\varphi}\right)(1-\alpha)\frac{Y_t}{N_t} \tag{0.56}$$

$$\frac{r_t^k}{P_t} = \left(\frac{\varphi-1}{\varphi}\right)\alpha\frac{Y_t}{K_{t-1}} \tag{0.57}$$

Intermediate goods producers set prices following the Calvo mechanism (Calvo, 1983). At each period t, a share of these firms $0 < 1-\theta < 1$ are allowed to choose the price of their good for period t, $\hat{P}_{j,t}$. The remaining firms are not able to reoptimize their price and keep the price of the previous period $(P_{j,t} = P_{j,t-1})$[17].

Under the Calvo price setting, $P_{j,t+n} = \hat{P}_{j,t}$with probability $\theta^n$for $n = 0,1,2,....$, the profit maximization problem can be expressed as follows:

$$\max_{\hat{P}_{j,t}} E_t\sum_{n=0}^{\infty}(\beta\theta)^n\left[Y_{t+n}(\hat{P}_t - MC_{t+n}^p)\right] \tag{0.58}$$

[17] When θ is equal to 1, all firms are able to reoptimize their prices, and when θ is equal to 0, none of the firms can reoptimize its price.

Where θ denotes the price stickiness factor, $\hat{P}_t$ the optimal price defined by the firm having the possibility of adjusting the price and $MC_{t+n}^{p} = MC_t P_t$. In perfect competition, firms set their prices at marginal cost. However, the expression $(\hat{P}_t - MC_{t+n}^{p})$ means that the price deviates from nominal marginal cost by an amount equal to the markup $\left(\frac{\theta}{\theta-1}\right)$.

Subject to the following demand function:

$$Y_{t+n} = \left[\frac{(1-\tau_t^c)P_{t+n}}{\hat{P}_t}\right]^{\varphi}\left(C_{t+n} + \int_0^1 C_{t+n}^i \, di\right) \tag{0.59}$$

Substituting (2.59) into (2.58), we obtain:

$$\max_{\ddot{P}_{N,t}^F} E_t \sum_{n=0}^{\infty} (\beta\theta)^n \left\{\left[\frac{\hat{P}_t}{1-\tau_t^c)P_{t+n}}\right]^{-\varphi}\left(C_{t+n} + \int_0^1 C_{t+n}^i \, di\right)(\hat{P}_t - MC_{t+n}^p)\right\} \tag{0.60}$$

The first order condition with respect to $\hat{P}_t$ leads to:

$$\sum_{n=0}^{\infty} (\beta\theta)^n E_t \left\{-\varphi \frac{Y_{t+n}}{\hat{P}_t}(\hat{P}_t - MC_{t+n}^p) + Y_{t+n}\right\} = 0 \tag{0.61}$$

$$\sum_{n=0}^{\infty} (\beta\theta)^n E_t \left\{-\varphi Y_{t+n} + Y_{t+n} + \varphi \frac{Y_{t+n}}{\hat{P}_t} MC_{t+n}^p\right\} = 0 \tag{0.62}$$

$$\sum_{n=0}^{\infty} (\beta\theta)^n E_t \left\{Y_{t+n}\left(\hat{P}_t - \frac{\varphi}{\varphi-1} MC_{t+n}^p\right)\right\} = 0 \tag{0.63}$$

$$\sum_{n=0}^{\infty} (\beta\theta)^n E_t \left\{Y_{t+n}P_{t-1}\left(\frac{\hat{P}_t}{P_{t-1}} - \frac{\varphi}{\varphi-1}\frac{P_{t+n}}{P_{t-1}}\frac{MC_{t+n}^p}{P_{t+n}}\right)\right\} = 0 \tag{0.64}$$

We replace by the following expressions: $MC_{t+n} = \frac{MC_{t+n}^p}{P_{t+n}}$; $\pi_{t-1,t+n} = \frac{P_{t+n}}{P_{t-1}}$, we obtain :

$$\sum_{n=0}^{\infty} (\beta\theta)^n E_t \left\{Y_{t+n}P_{t-1}\left(\frac{\hat{P}_t}{P_{t-1}} - \frac{\varphi}{\varphi-1}\pi_{t-1,t+n} MC_{t+n}\right)\right\} = 0 \tag{0.65}$$

In log linearized terms around steady state, we have $\tilde{\pi}_{t+n} = 1$, thus we get:

$$\hat{\tilde{P}}_t = \tilde{P}_{t-1} + \sum_{n=0}^{\infty} (\beta\theta)^n E_t \tilde{\pi}_{t+n} + (1-\beta\theta)\sum_{n=0}^{\infty} (\beta\theta)^n E_t(\widetilde{MC}_{t+n} - MC) \tag{0.66}$$

Where $MC = \log\ MC = \log\ \frac{\varphi-1}{\varphi}$ denotes the steady state real marginal cost.

The first order standard stochastic equation eliminating the infinite sum is as follows:

$$\hat{\tilde{P}}_t = \tilde{P}_{t-1} + \beta\theta E_t\left[\hat{\tilde{P}}_{t+1} - \tilde{P}_t\right] + \tilde{\pi}_t + (1-\beta\theta)(\widetilde{MC}_{t+1} - MC) \tag{0.67}$$

Under the Calvo price setting defined above, the price index is expressed by:

$$P_t = \left[\theta {P_{t-1}}^{1-\varphi} + (1-\theta){\hat{P}_t}^{1-\varphi}\right]^{\frac{1}{1-\varphi}} \tag{0.68}$$

Log-linearizing (2.68) around the zero inflation steady state, we get:

$$\tilde{\pi}_t = (1-\theta)\left(\hat{\tilde{P}}_t - \tilde{P}_{t-1}\right) \tag{0.69}$$

Substituting (2.69) into (2.67), we obtain:

$$\hat{\tilde{P}}_t - \tilde{P}_{t-1} = \beta\theta E_t\left[\hat{\tilde{P}}_{t+1} - \tilde{P}_t\right] + \tilde{\pi}_t + (1-\beta\theta)(\widetilde{MC}_{t+1} - MC) \tag{0.70}$$

$$\frac{\tilde{\pi}_t}{(1-\theta)} = \beta\theta E_t\left[\frac{\tilde{\pi}_{t+1}}{(1-\theta)}\right] + \tilde{\pi}_t + (1-\beta\theta)\left(\widetilde{MC}_{t+1} - MC\right) \tag{0.71}$$

$$\tilde{\pi}_t = \beta\theta E_t\tilde{\pi}_{t+1} + (1-\theta)\tilde{\pi}_t + (1-\theta)(1-\beta\theta)\left(\widetilde{MC}_{t+1} - MC\right) \tag{0.72}$$

$$\tilde{\pi}_t - (1-\theta)\tilde{\pi}_t = \beta\theta E_t\tilde{\pi}_{t+1} + (1-\theta)(1-\beta\theta)\left(\widetilde{MC}_{t+1} - MC\right) \tag{0.73}$$

$$\theta\tilde{\pi}_t = \beta\theta E_t\tilde{\pi}_{t+1} + (1-\theta)(1-\beta\theta)\left(\widetilde{MC}_{t+1} - MC\right) \tag{0.74}$$

It results in the following New Keynesian Philips Curve:

$$\tilde{\pi}_t = \beta E_t\tilde{\pi}_{t+1} + \frac{(1-\theta)(1-\beta\theta)}{\theta}\left(\widetilde{MC}_{t+1} - MC\right) \tag{0.75}$$

2.3 Fiscal policy

The government collects taxes and issues bonds to finance its spending on goods and services. Tax revenue is formed by taxes levied on household income, capital, and consumption. The government refunds also its last-period debt with interests $\left[\left(\frac{i_{t-1}}{\pi_t}\right)B_{t-1}\right]$. Equation (3.76) presents the government budget constraint:

$$B_t = \left(\frac{i_{t-1}}{\pi_t}\right)B_{t-1} + G_t^g + I_t^g - \left(\tau_t^w W_t N_t + \tau_t^c C_t + \tau_t^k r_t^k z_t K_{t-1}\right) \tag{0.76}$$

Where B_t denotes the government bond issues, i_t the interest rate, G_t^g the total expenditure of government which includes government expenditure on goods and services as well as compensation of public sector employees, I_t^g public investment, τ_t^w the tax rate on labor, τ_t^c the tax rate on consumption and τ_t^k the tax rate on capital.

We broadly follow Leeper et al. (2009)[18] and Bhattarai & Trzeciakiewicz (2017) in specifying fiscal policy instruments rules. Government expenditures and government investment are assumed to respond countercyclically to deviations in GDP and debt from their respective steady states, whereas taxes are assumed to respond procyclically; therefore, fiscal instruments play a role of automatic stabilizers. To account for possible delays in the reaction of fiscal instruments to debt, we consider the respective lagged value. Fiscal instruments rule are defined according to the following rules (in log-linear approximation):

$$\tilde{G}_t^g = -\lambda_{G^g}\tilde{B}_{t-1} - \gamma_{G^g}\tilde{Y}_t + \tilde{\varepsilon}_t^{G^g} \tag{0.77}$$

$$\tilde{I}_t^g = -\lambda_{I^g}\tilde{B}_{t-1} - \gamma_{I^g}\tilde{Y}_t + \tilde{\varepsilon}_t^{I^g} \tag{0.78}$$

$$\tilde{\tau}_t^c = \lambda_{\tau^c}\tilde{B}_{t-1} + \gamma_{\tau^c}\tilde{Y}_t - \tilde{\varepsilon}_t^{\tau^c} \tag{0.79}$$

$$\tilde{\tau}_t^k = \lambda_{\tau^k}\tilde{B}_{t-1} + \gamma_{\tau^k}\tilde{Y}_t - \tilde{\varepsilon}_t^{\tau^k} \tag{0.80}$$

$$\tilde{\tau}_t^w = \lambda_{\tau^w}\tilde{B}_{t-1} + \gamma_{\tau^w}\tilde{Y}_t - \tilde{\varepsilon}_t^{\tau^w} \tag{0.81}$$

Where $\tilde{\varepsilon}_t^{G^g}$, $\tilde{\varepsilon}_t^{I^g}$, $\tilde{\varepsilon}_t^{\tau^c}$, $\tilde{\varepsilon}_t^{\tau^k}$ and $\tilde{\varepsilon}_t^{\tau^w}$ are i.i.d. error terms. λ_{G^g}, λ_{I^g}, λ_{τ^c}, λ_{τ^k} and λ_{τ^w} are debt coefficients. γ_{G^g}, γ_{I^g}, γ_{τ^c}, γ_{τ^k} and γ_{τ^w} are output coefficients. We assume that the i.i.d. error terms in the above fiscal policy rules constitute unexpected changes in the policy and thus fiscal shocks.

2.4 Monetary policy

The monetary authorities in Morocco apply a conventional exchange rate regime. They have always been encouraged by the IMF to make the exchange rate more flexible[19]. The central bank sets prices in dirham on the basis of a basket composed by the euro and the US dollar, at a rate of 60% and

[18] Leeper E. M., Plante M. and Traum N., (2009). Dynamics of Fiscal Financing in the United States. National Bureau of Economic Research, NBER Working Papers No. 15160.

[19] IMF, (2020). Second Review under the Arrangement under the Precautionary and Liquidity Line-Press Release; Staff Report; and Statement by the Executive Director for Morocco. IMF country Report No. 20/14, International Monetary Fund.

40%, respectively. The establishing of floating exchange rate regime was initiated in January 2018; the fluctuation band went from ± 0.3% to ± 2.5% on 01/15/2018 then to ± 5% on 03/09/2020.

In order to reflect more accurately the monetary policy framework described above, we choose a Taylor type rule (1993)[20] that links the nominal interest rate it to its own lag term$(\tilde{\imath}_{t-1})$, to inflation $(\tilde{\pi}_t)$, to output $(\tilde{Y}_t)$ and to nominal exchange rate $(\tilde{S}_t)$. Changes in the nominal exchange rate are included in the monetary policy response function to account for the semi-fixed exchange rate and capital account restrictions, as in Lubik & Schorfheide (2007)[21], Marzo & Lubik (2005)[22], Best (2013)[23] and Del Negro & Schorfheide (2008)[24].

$$\tilde{\imath}_t = \rho_i \tilde{\imath}_{t-1} + (1-\rho_i)\left[\rho_\pi \tilde{\pi}_t + \rho_y\left(\tilde{Y}_t - \tilde{Y}_{t-1}\right) + \psi_s\left(\tilde{S}_t - \tilde{S}_{t-1}\right)\right] + \tilde{\varepsilon}_t^i \quad (0.82)$$

Where ρ_i captures the degree of interest rate smoothing. ρ_π, ρ_y and ψ_s represent the weight on the monetary policy rule of inflation, output and nominal exchange rate respectively. $\tilde{\varepsilon}_t^i$ denotes an i.i.d. normal error term on the interest rate rule; it will also be denoted the monetary policy shock.

If $\psi_s = 1$, the interest rate will respond sharply to nominal exchange rate movements so as to keep it constant. In our semi-fixed, or "target zone" specification, the prior value of ψ_s must be set so that the volatility of the nominal exchange rate in the model matches the fluctuation band determined by the central bank.

To take into account the exchange rate regime adopted, we use the following autoregressive nominal exchange rate process:

$$\tilde{S}_t = \rho_s \tilde{S}_{t-1} + \tilde{\varepsilon}_t^s \quad (0.83)$$

Where $\tilde{\varepsilon}_t^s \sim N(O, \sigma_{x,t})$

2.5 Market clearing condition

To complete the model it is necessary to use the equilibrium conditions in the goods market. Goods market clearing requires that the aggregate supply equals the aggregate public and private demand for consumption and investment goods. In other words, the global output net of capital utilization costs must equal private as well as public consumption and investment. To account for the importance of trade, we introduce the trade balance $(X_t - M_t)$ as an exogenous component. Thus, the equilibrium condition on the goods market is as follows:

$$Y_t - \psi(z_t)K_{t-1} = C_t + I_t + G_t^g + I_t^g + X_t - M_t \quad (0.84)$$

The dynamics of the trade balance are given by the following AR(1) processes, in log linearized terms:

$$\tilde{X}_t = \rho_x \tilde{X}_{t-1} + \tilde{\varepsilon}_t^x \quad (0.85)$$

$$\widetilde{M}_t = \rho_m \widetilde{M}_{t-1} + \tilde{\varepsilon}_t^m \quad (0.86)$$

2.6 World economy

The rest of the world is governed by the following tree log-linearized exogenous equations:

$$\tilde{Y}_t^* = \rho_{y^*} \tilde{Y}_{t-1}^* + \tilde{\varepsilon}_t^{y^*} \quad (0.87)$$

$$\tilde{\pi}_t^* = \rho_{\pi^*} \tilde{\pi}_{t-1}^* + \tilde{\varepsilon}_t^{\pi^*} \quad (0.88)$$

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[20] Taylor J. B., (1993). Discretion versus Policy Rules in Practice. Carnegie-Rochester Conference Series on Public Policy, Elsevier, Vol. 39, Issue 1, pp. 195-214.

[21] Lubik T. and Schorfheide F., (2007). Do Central Banks Respond to Exchange Rate Movements? A Structural Investigation. Journal of Monetary Economics, Vol. 54, Issue 4, pp. 1069-1087.

[22] Marzo M. and Lubik T., (2005). Optimal Monetary Policy in a Two Sector with Different Degree of Price and Wage Stickiness. Society for Computational Economics, Computing in Economics and Finance No. 340.

[23] Best G., (2013). Fear of Floating or Monetary Policy as Usual? A Structural Analysis to Mexico's Monetary Policy. North American Journal of Economics and Finance, Vol. 24, pp. 45-62.

[24] Del Negro M. and Schorfheide F., (2008). Inflation Dynamics in a Small Open-economy Model under Inflation Targeting: Some Evidence from Chile. Federal Reserve Bank of New York, Staff Reports No. 329.

$$\tilde{\imath}_t^* = \rho_{i^*}\tilde{\imath}_{t-1}^* + \tilde{\varepsilon}_t^{i^*} \tag{0.89}$$

Where $\tilde{Y}_t^*$ denotes foreign output, $\tilde{\pi}_t^*$ foreign inflation and $\tilde{\imath}_t^*$ foreign interest rate.

3. Data and methodology

The log-linearized model is estimated with Bayesian Maximum Likelihood using data for Morocco. Following Smets & Wouters (2002), Bayesian Maximum Likelihood has become the standard method for estimating DSGE models, Rudolf & Zurlinden (2014)[25]. The Bayesian approach requires choosing prior distributions of the parameters. These priors represent prior information obtained from earlier studies at both the micro and macro level. The priors are updated with observed data using Bayesian inference method. The resulting posterior distributions are then used to compute the parameter estimates. In the following, we describe the adopted approach and outline the data and the prior distributions used in its implementation. We present estimation results in next section.

3.1 Methodology

We solve the model using log-linearization technique around the deterministic steady state. Stacking all the endogenous variables of the model in the vector X_t and using the accentuation ~ above each variable to denote log deviations from the steady state (i.e. $\tilde{X}_t \equiv \log X_t - \log X$)

We can write the model as:

$$\alpha E_t(\tilde{X}_{t+1}) = \beta \tilde{X}_t + \theta Z_t \tag{0.1}$$

Where Z_t represent the exogenous variables matrice (i.e., the shocks). α, β and θ depend on the structural coefficients in the model and on the steady state values of X_t.

To estimate the log-linearized model with Bayesian methods, we use twelve Moroccan data series for the period from 1998Q1 to 2019Q2. The estimation of DSGE models with Bayesian methods is described in a series of papers by Frank Schorfheide and various co-authors. In the following, we give a brief outline based on An & Schorfheide (2007), Schorfheide & al. (2010) and Herbst & Schorfheide (2015)[26]:

Let $P(\vartheta|A)$ be the prior distribution of the parameter vector $\vartheta \in \Theta$ for the model A and let $L(Y^T|\vartheta, A)$ be the likelihood function for the observed data $Y^T = \{y_t\}_{t=1}^T = y_t, \ldots, y_T$. The likelihood is computed starting from the log-linear state-space representation of the model by means of the Kalman filter and the prediction error decomposition. The posterior distribution of the parameter vector ϑ is then obtained combining the likelihood function $L(Y^T|\vartheta, A)$ with the prior distribution of ϑ, the posterior distribution is:

$$P(\vartheta|Y^T) = \frac{L(Y^T|\vartheta, A)P(\vartheta|A)}{L(Y^T)} \tag{0.2}$$

Where $L(Y^T) = \int L(Y^T|\vartheta, A)P\big((\vartheta|A)\big)d\vartheta$.

The computation of the integral at the denominator becomes rapidly an impossible task as the number of parameters increases (we have 49 parameters to estimate). In order to obtain numerically a sequence from this unknown posterior distribution $P(\vartheta|Y^T)$, we use the random-walk Metropolis-Hastings algorithm.

We use the MATLAB preprocessor Dynare (see Adjemian et al., 2011)[27] to solve and subsequently estimate the model using Bayesian techniques. Chris Sims' optimization routine CSMINWEL is used to obtain an initial estimate of the posterior mode, based on prior distributions and observable time series for endogenous model variables. To approximate the distribution of the parameters, we employ Markov-Chain-Monte-Carlo (MCMC) or more specifically the random-walk Metropolis-Hastings algorithm with

[25] Rudolf B. and Zurlinden M., (2014). A Compact Open Economy DSGE Model for Switzerland. Swiss National Bank, Economic Studies No. 2014-08.

[26] Herbst E. and Schorfheide F., (2015). Bayesian Estimation of DSGE Models. Economics Books, Princeton University Press.

[27] Adjemian S., Bastani H., Karamé F., Juillard M., Maih J., Mihoubi F., Perendia G., Pfeifer J., Ratto M. and Villemot S., (2011). Dynare: Reference Manual Version 4. CEPREMAP, Dynare Working Papers No. 1.

five chains, each including 500000 parameter vector draws, to generate draws from the posterior distribution. The posterior moments are computed from the posterior draws.

3.2 Data

For the Bayesian estimate, we use quarterly data ranging between 1998Q1 and 2019Q2 and twelve time series: Moroccan GDP Y, final household consumption expenditure C, nominal exchange rate S, domestic inflation rate π, Moroccan money market rate i, public investment I^g, government spending G^g, exports X, imports M, Euro zone GDP Y^*, Euro zone inflation rate π^* and Euro zone[28] money market rate i^*. Appendix C presents a historical visual presentation of these variables.

Since the model is in log-deviations from the steady state, all variables are in the form of fluctuations around their dynamic trends. The cyclical time-series decomposition method is applied to the logarithm of each variable to isolate the trend using the Hodrick-Prescott filter, except for the nominal exchange rate, the domestic inflation rate, the rate the Moroccan money market, the Euro zone inflation rate and the Euro zone money market rate, because applying the filter on these rates could hide relevant information.

Data on Moroccan nominal GDP and final household consumption are taken from the Higher Planning Commission in Morocco. Data on the nominal exchange rate, the domestic CPI (2010 = 100), the GDP deflator (2010 = 100), the seasonally adjusted GDP deflator for the Euro zone (2010 = 100), the nominal exports, the nominal imports, the Moroccan money market rate, the Euro zone money market rate, the seasonally adjusted nominal GDP of the Euro zone are taken from the IMF (International Financial Statistics). Data on the Euro zone CPI (2015 = 100) are taken from the Federal Reserve Bank of Saint-Louis. Data on public investment and government spending are taken from the Moroccan Ministry of Economy and Finance. Nominal data are transformed into real data using the GDP deflator. For the price variables (the domestic CPI and the Euro zone CPI), we take the log-differences first and we calculate their respective inflation rates.

3.3 Model calibration and prior distributions

We use three calibration approaches to parameterize the model. The first approach concerns the parameters that can be considered as very strict priors (as described in Leeper et al. (2009)). These parameters were kept fixed given that there is a large economic literature bringing out the value of these parameters based on objective and scientific evidence, or calibrated from data using OLS estimator applied to the parameters of exogenous AR stochastic processes. The second approach concerns the steady state parameters calibrated using averages from data describing the structure of Moroccan economy. The third group of parameters is estimated using Bayesian estimation approach after we specify the prior distributions based on the existing literature.

Table 1 lists the strict parameters:

Table 1.

Strict parameters

Parameter	Description	Symbol	Value
beta	discount parameter	β	0,990
alpha	share of capital in production	α	0,300
sigma_g	elasticity of output to public capital	σ_g	0,010
delta_k	depreciation rate of private capital	δ_k	0,025
delta_g	depreciation rate of public capital	δ_g	0,015
phi	share of unemployment	φ	0,1480
rho_s	nominal exchange rate persistence	ρ_s	0,9743
rho_y_star	foreign output persistence	ρ_{y^*}	0,9847
rho_pi_star	foreign inflation persistence	ρ_{π^*}	0,9394
rho_i_star	foreign interest rate persistence	ρ_{i^*}	0,9936
rho_x	exports persistence	ρ_x	0,9732

[28] The euro zone is the major trading partner for Morocco.

rho_m	imports persistence	ρ_m	0,9705

The discount factor β is calibrated to 0,990, which implies an annual steady state real interest rate of 4%. The share of capital in the production function is calibrated to 0,300, which implies a steady-state share of labor income in total output of 70%. The elasticity of output to public capital is set to 0,010. The depreciation rate of private capital is set to 0,025, which implies an annual depreciation of 10%. The depreciation of public capital is set to 0,015, which implies an annual depreciation of public capital of 6%. These values are practically standard in the DSGE literature (as in Smets & Wouters (2002), Harrison & Oomen (2010), Bhattarai & Trzeciakiewicz (2017) and in many others ...). The share of unemployment is set to 0,148 based on the 2021 exploratory economic budget published by the Higher Planning Commission in Morocco, which forecasts an unemployment rate of 14.8% in 2020 due to the Covid19 pandemic health crisis.

The autoregressive processes of nominal exchange rate, foreign output, foreign inflation, foreign interest rate, exports and imports are estimated using the OLS method on quarterly data for Morocco ranging between 1998Q1 and 2019Q2. Foreign output approached by Euro zone GDP, foreign inflation approached by Euro zone inflation rate and foreign interest rate approached by Euro zone money market rate. All data series are logarithmically transformed.

Table 2 shows the steady state parameters:

Table 2.

Steady state parameters

Parameter	Description	Symbol	Value
Tau_cSS	consumption tax	τ^c	0,20
Tau_kSS	capital tax	τ^k	0,31
Tau_wSS	labor tax	τ^w	0,30
G_gYSS	government spending/GDP ratio	G^g/Y	0,9692
I_gYSS	government investment/GDP ratio	I^g/Y	0,3155
B_YSS	public debt/GDP ratio	B/Y	0,5904
X_YSS	exports/GDP ratio	CFX/Y	0,1978
M_YSS	imports/GDP ratio	CFI/Y	0,3600

The consumption tax is approached by the normal rate of the value-added tax value. The capital tax is approached by the corporate income tax (CIT) whose annual profit is greater than 1 million DH. In fact, before January 1, 2016, the normal rate of the corporate tax was set to 30%. Starting from 2016, the progressive CIT depending on the net profit was introduced. The labor tax is approached by the income tax for individuals whose annual income is ranging between 60,001 DH and 80,000 DH. Ratios to GDP are calculated based on the average of quarterly data spanning the period 1998Q1-2019Q2. Data are in real terms (2010 base).

Table 3 presents prior distributions:

Table 2.

Priors

Parameter	Description	Symbol	Density	Mean	Std. Dev.
Households parameters					
sigma_C	inverse intertemporal elasticity of substitution between goods	σ_c	Normal	2.00	0.100
sigma_L	inverse elasticity of labor	σ_l	Normal	1.45	0.100
Xi	capital investment adjustment cost	ξ	Normal	4.00	1.500
psi_k	capital utilization adjustment cost	ψ_k	Normal	0.20	0.075
Production / Labor market parameters					
phi_y	fixed cost	φ_y	Normal	1.45	0.250
theta	share of firms changing the price each period	θ	Beta	0.75	0.100
omega_u	unemployment persistence	ω_u	Normal	0.50	0.200
omega_y	unemployment output reaction	ω_y	Normal	0.50	0.200
Fiscal policy parameters					

gamma_gg	government expenditure output reaction	γ_{G^g}	Normal	0.50	0.200
gamma_ig	government investment output reaction	γ_{I^g}	Normal	0.50	0.200
gamma_tc	consumption tax output reaction	γ_{τ^c}	Normal	0.50	0.200
gamma_tk	capital tax output reaction	γ_{τ^k}	Normal	0.50	0.200
gamma_tw	labor tax output reaction	γ_{τ^w}	Normal	0.50	0.200
lambda_gg	government expenditure debt reaction	λ_{G^g}	Gamma	0.50	0.100
lambda_ig	government investment debt reaction	λ_{I^g}	Gamma	0.50	0.100
lambda_tc	consumption tax debt reaction	λ_{τ^c}	Gamma	0.50	0.100
lambda_tk	capital tax debt reaction	λ_{τ^k}	Gamma	0.50	0.100
lambda_tw	labor tax debt reaction	λ_{τ^w}	Gamma	0.50	0.100
Monetary policy parameters					
rho_i	Taylor rule interest rate persistence	ρ_i	Beta	0.80	0.100
rho_pi	Taylor rule inflation	ρ_π	Gamma	1.50	0.500
rho_y	Taylor rule output-gap	ρ_y	Gamma	0.50	0.100
psi_s	Taylor rule nominal exchange rate	ψ_s	Gamma	0.05	0.020

The choice of priors for the Bayesian estimation is based primarily on empirical evidence from previous studies. However, most parameters are non-existent in the literature relating to Morocco, in this case, we take DSGE literature for developing economies or developed economies, when the need arises, as basis to specify priors. For the inverse intertemporal elasticity of substitution between goods, and the inverse elasticity of labor supply, we take the distributions adopted in Algozhina (2016)[29] where the author developed a DSGE model for a developing economy rich in resources and whose calibration is based on Kazakhstan. We choose a normal distribution with a mean of 2.00 and a standard deviation of 0.10 for σ_c, and a normal distribution with a mean of 1.45 and a standard deviation of 0.10 for σ_l.

For parameters relating to investment adjustment cost, capital utilization adjustment cost, fixed costs and the share of firms changing the price each period, we rely on Smets & Wouters (2002) and Drygalla et al. (2017)[30] to define our priors. We adopt a normal distribution with a mean of 4.00 and a standard deviation of 1.50 for ξ, a normal distribution with a mean of 0.20 and a standard deviation of 0.075 for ψ_k, a normal distribution with a mean of 1.45 and a standard deviation of 0.25 for φ_y, and a beta distribution with a mean of 0.75 and a standard deviation of 0.10 for θ.

For unemployment persistence and unemployment output reaction, we choose a normal distribution with a mean of 0.50 and a standard deviation of 0.20. We select also a normal distribution with a mean of 0.50 and a standard deviation of 0.20 for all fiscal policy output response parameters as in Bhattarai & Trzeciakiewicz (2017); this specification allow for the negative estimate for parameters, Leeper (2009). For all fiscal policy debt response parameters, We choose a gamma distribution with a mean of 0.50 and a standard deviation of 0.10 and thus allows only for positive estimates as in Forni et al. (2007)[31].

Regarding monetary policy rule, we select a beta distribution with a mean of 0.80 and a standard deviation of 0.10 for the degree of interest rate persistence as in Smets & Wouters (2002), and for the Taylor rule coefficient on inflation and output, we select a gamma distribution with means, respectively, at 1.50 and 0.50, and standard deviations, respectively, at 0.50 and 0.10 as in Galí et al. (2005)[32]. Finally, for the Taylor rule nominal exchange rate, we define a gamma distribution with mean of 0.05 and a standard deviation of 0.02; so that the prior value matches the fluctuation band determined by the central bank. Lubik & Schorfheide (2007) choose for this prior value a gamma distribution with mean of 0.25 and a standard deviation of 0.10. Their value is specified in order to match the exchange rate volatility in the data during a target-zone period in Sweden.

[29] Algozhina A., (2016). Monetary Policy Rule, Exchange Rate Regime, and Fiscal Policy Cyclicality in a Developing Oil Economy. CEPREMAP, Dynare Working Papers No. 49.
[30] Drygalla A. (2017). Monetary Policy in an Oil-dependent Economy in the Presence of Multiple Shocks. Halle Institute for Economic Research, IWH Discussion Papers No. 14.
[31] Forni L., Monteforte L. and Sessa L., (2007). The General Equilibrium Effects of Fiscal Policy: Estimates for the Euro Area. Banca d'Italia, Economic Research and International Relations Area, Temi di discussion, Working papers No. 652.
[32] Galí J., López-Salido D. and Vallés J., (2005). Understanding the Effects of Government Spending on Consumption. National Bureau of Economic Research, NBER Working Papers No. 11578.

4. Results and discussion

4.1 Posterior estimates

The estimation results are reported in table 4. It reports the posterior means along with their 90% Bayesian probability interval based on the posterior probability densities. Figures in Appendix B provide a visual presentation of the estimation results by plotting together the prior distributions (grey line), the posterior distributions (black line) and the posterior modes (dashed green line). In general, posterior distributions are slightly different from their prior distributions. We conclude that the prior values of the parameters were initially well specified. In cases where the posterior distribution is tighter than the prior distribution, the sample data is very informative. However, when the prior and posterior distributions are identical, data does not present important information. Appendix D shows graphs of the smoothed shocks obtained further to Bayesian estimation.

Table 4.
Posterior estimates

Parameter	Description	Prior distribution			Posterior distribution		
		Density	Mean	Std. Dev.[33]	Mean	90% HPD interval	
	Households parameters						
σ_c	inverse intertemporal elasticity of substitution between goods	Normal	2.00	0.100	2.0655	2.0431	2.0843
σ_l	inverse elasticity of labor	Normal	1.45	0.100	1.6589	1.6333	1.6789
ξ	capital investment adjustment cost	Normal	4.00	1.500	4.1740	4.1583	4.1914
ψ_k	capital utilization adjustment cost	Normal	0.20	0.075	0.4540	0.4310	0.4835
	Production / Labor market parameters						
φ_y	fixed cost	Normal	1.45	0.250	1.4750	1.4672	1.4824
θ	share of firms changing the price each period	Beta	0.75	0.100	0.3445	0.3089	0.3724
ω_u	unemployment persistence	Normal	0.50	0.200	0.4547	0.4390	0.4706
ω_y	unemployment output reaction	Normal	0.50	0.200	0.4214	0.4105	0.4363
	Fiscal policy parameters						
γ_{G^g}	government expenditure output reaction	Normal	0.50	0.200	0.4392	0.4274	0.4544
γ_{I^g}	government investment output reaction	Normal	0.50	0.200	0.4114	0.3986	0.4243
γ_{τ^c}	consumption tax output reaction	Normal	0.50	0.200	0.4206	0.4015	0.4409
γ_{τ^k}	capital tax output reaction	Normal	0.50	0.200	0.5088	0.4963	0.5174
γ_{τ^w}	labor tax output reaction	Normal	0.50	0.200	0.6139	0.5960	0.6300
λ_{G^g}	government expenditure debt reaction	Gamma	0.50	0.100	0.7030	0.6834	0.7220
λ_{I^g}	government investment debt reaction	Gamma	0.50	0.100	0.6471	0.6286	0.6629
λ_{τ^c}	consumption tax debt reaction	Gamma	0.50	0.100	0.5049	0.4907	0.5215
λ_{τ^k}	capital tax debt reaction	Gamma	0.50	0.100	0.3660	0.3588	0.3755
λ_{τ^w}	labor tax debt reaction	Gamma	0.50	0.100	0.3070	0.2856	0.3312
	Monetary policy parameters						
ρ_i	Taylor rule interest rate persistence	Beta	0.80	0.100	0.7672	0.7584	0.7781
ρ_π	Taylor rule inflation	Gamma	1.50	0.500	1.4313	1.4225	1.4434

[33] For the inverted Gamma distributions, the degrees of freedom are indicated.

ρ_y	Taylor rule output-gap	Gamma	0.50	0.100	0.5126	0.4926	0.5266
ψ_s	Taylor rule nominal exchange rate	Gamma	0.05	0.020	0.1337	0.1190	0.1469
	Persistence shocks AR (1) parameters						
φ_{inv}	AR(1) investment shock	Beta	0.800	0.100	0.8835	0.8673	0.9018
φ_a	AR(1) technology shock	Beta	0.800	0.100	0.8222	0.8057	0.8354
φ_π	AR(1) inflation shock	Beta	0.800	0.100	0.9993	0.9988	0.9998
φ_{G^g}	AR(1) government expenditure shock	Beta	0.800	0.100	0.8943	0.8876	0.9032
φ_{I^g}	AR(1) government investment shock	Beta	0.800	0.100	0.8887	0.8800	0.8963
φ_{τ^c}	AR(1) consumption tax shock	Beta	0.800	0.100	0.6858	0.6682	0.7097
φ_{τ^k}	AR(1) capital tax shock	Beta	0.800	0.100	0.8571	0.8393	0.8792
φ_{τ^w}	AR(1) labor tax shock	Beta	0.800	0.100	0.9979	0.9964	0.9992
φ_s	AR(1) nominal interet rate shock	Beta	0.800	0.100	0.9949	0.9903	0.9992
φ_{y^*}	AR(1) foreign output shock	Beta	0.800	0.100	0.9992	0.9987	0.9998
φ_{π^*}	AR(1) foreign inflation shock	Beta	0.800	0.100	0.8082	0.7940	0.8260
φ_{i^*}	AR(1) foreign interet rate shock	Beta	0.800	0.100	0.7695	0.7543	0.7771
φ_u	AR(1) unemployment shock	Beta	0.800	0.100	0.7793	0.7716	0.7889
φ_l	AR(1) labor supply shock	Beta	0.800	0.100	0.8376	0.8247	0.8489
	Standard deviations of shocks						
σ_{inv}	investment shock std. dev.	Inv. Gamma	0.010	2	0.2677	0.2579	0.2827
σ_a	technology shock std. dev.	Inv. Gamma	0.010	2	0.2853	0.2740	0.2951
σ_π	inflation shock std. dev.	Inv. Gamma	0.010	2	0.2337	0.2161	0.2483
σ_{G^g}	government expenditure shock std. dev.	Inv. Gamma	0.010	2	0.0042	0.0023	0.0060
σ_{I^g}	government investment shock std. dev.	Inv. Gamma	0.010	2	0.0227	0.0196	0.0258
σ_{τ^c}	consumption tax shock std. dev.	Inv. Gamma	0.010	2	0.0925	0.0753	0.1089
σ_{τ^k}	capital tax shock std. dev.	Inv. Gamma	0.010	2	0.0055	0.0026	0.0078
σ_{τ^w}	labor tax shock std. dev.	Inv. Gamma	0.010	2	0.5300	0.5040	0.5561
σ_s	nominal interet rate shock std. dev.	Inv. Gamma	0.010	2	0.0091	0.0081	0.0103
σ_{y^*}	foreign output shock std. dev.	Inv. Gamma	0.010	2	0.0012	0.0012	0.0012
σ_{π^*}	foreign inflation shock std. dev.	Inv. Gamma	0.010	2	0.0469	0.0374	0.0558
σ_{i^*}	foreign interet rate shock std. dev.	Inv. Gamma	0.010	2	0.2477	0.2310	0.2595
σ_i	monetary policy shock std. dev.	Inv. Gamma	0.010	2	0.0045	0.0024	0.0071
σ_x	exports shock std. dev.	Inv. Gamma	0.010	2	0.0465	0.0344	0.0546
σ_m	imports shock std. dev.	Inv. Gamma	0.010	2	0.2322	0.2232	0.2398
σ_u	unemployment shock std. dev.	Inv. Gamma	0.010	2	0.2925	0.2827	0.3025

σ_l	labor supply shock std. dev.	Inv. Gamma	0.010	2	0.2822	0.2727	0.2934

The posterior mean of the inverse intertemporal elasticity of substitution between goods and the inverse elasticity of labor supply is practically identical to our prior identification with σ_c= 2.07 and σ_l=1.66 respectively. These values are very close to the values of σ_c= 2.97 and σ_l=1.57 obtained by Ait Lahcen (2014)[34], in which the author develops a DSGE model with informality for Morocco, and a little higher to the values of σ_c= 1.61 and σ_l=1.26 obtained by Smets & Wouters (2002).

The investment adjustment cost parameter ξ = 4.17 can be defined as the inverse elasticity of investment with respect to an increase in the installed capital[35]. Its estimate suggests that a 1% increase in the price of capital is followed by a 1/ξ(1-β) = 24% increase in investment. Smets & Wouters (2002) estimate this elasticity at 16 % for the euro area, whereas Christiano et al. (2005) estimate it at 38 % for the USA and Bhattarai & Trzeciakiewicz (2017) estimate it at 20% for the United Kingdom.

The capital utilization adjustment parameter ψ_k = 0.45 can be interpreted as the inverse elasticity of utilization with respect to the rental rate of capital net of capital taxes. Our result is higher than the value of 0.18 obtained by Smets & Wouters (2002) and the value of 0.11 in Forni et al. (2007) for the euro area. However, it is lower than the value of 0.77 obtained by Edge et al. (2003)[36] for the USA.

The fixed cost parameter estimate φ_y= 1,47 is very close to the value of 1.50 obtained by Smets & Wouters (2002) and also by Bhattarai & Trzeciakiewicz (2017) or the value of 1.45 in Drygalla (2017) for the Russian economy but higher than 0.46 in Christiano et al. (2005) for the USA. It is a little lower than 1.61 in Drygalla et al. (2017) for Germany.

The hybrid New-Keynesian Philips curve parameter θ = 0.34 is very close to 0.59 in Bhattarai & Trzeciakiewicz (2014) and lower than 0.91 in Smets & Wouters (2002) or 0.90 in Algozhina (2016). Our finding allows to conclude that prices change roughly every 1.5 quarters[37].

The unemployment persistence parameter is ω_u= 0.45 and the unemployment output reaction is ω_y= 0.42, which implies that unemployment plays an important role in controlling GDP.

Next, we discuss fiscal policy parameters. One can notice that all instruments react strongly to cyclical variations in production and should be considered to stimulate economic activity in a context of fiscal stimulus or to slow down production during economic overheating situation. Given the results, all fiscal instruments should also be considered also in the controlling for debt, especially government expenditure and investment which indicate the highest values. Indeed, government investment and government expenditure imply countercyclical responses to movements in debt and GDP, whereas taxes respond to them procyclically, according to the initial modeling. Note that response of labor tax and capital tax to debt register lower values compared to other instruments.

Regarding monetary policy parameters, estimates are very close to priors: persistence parameter takes the value of ρ_i= 0.77 which implies that the optimal weight associated with the AR (1) term of the interest rate exhibits considerable inertia; response to inflation takes the value of ρ_π=1.43; response to output takes the value of ρ_y= 0.51; and estimate of response to nominal exchange rate is set at ψ_(s)= 0.13. These estimates indicate that the monetary authority give priority to inflation targeting to the detriment of output or exchange rate targeting; this result is in line with the finding of Ait Lahcen (2014). Estimates allow concluding also that the exchange rate flexibility fluctuation band should not exceed ±13%.

4.2 Impulse - responses to various Covid19 shocks

This section presents impulse - response functions resulting from a temporary one standard deviation shock. On each graph presenting the impulse - response, the vertical axis denotes the percentage deviation from the steady state and the horizontal axis indicates time in quarters. We examine through impulse – response functions the dynamic effects of domestic and external shocks on

[34] Ait Lahcen M., (2014). DSGE Models for Developing Economies: an Application to Morocco. Munich Personal RePEc Archive, University of Lausanne, MPRA Paper No. 63404.

[35] Disregarding investment shocks, the investment equation takes the following form: $\tilde{I}_t = \tilde{I}_{t-1} - \frac{1}{\xi}\sum_{i=0}^{\infty}\beta^i \tilde{P}_{t+i}^k$.

[36] Edge R. M., Laubach T. and Williams J. C., (2003). The Responses of Wages and Prices to Technology Shocks. Federal Reserve Bank of San Francisco, Working Papers in Applied Economic Theory No. 21.

[37] Duration is given by $\frac{1}{1-\theta_t}$.

fiscal policy, monetary policy, inflation, output, employment and other variables over three years (12 quarters).

4.2.1 Impulse response to technology shock

The impulse-response functions resulting from a positive technology shock (ε_t^A) are shown in figure 1. Following the shock, output decreases along with the decrease in firm's marginal costs. Unemployment decreases but employment decreases doubly, which explains the decline in GDP even in a context of an increase in productivity. Inflation declines, because real marginal costs respond negatively to the technology shock. The increase in wages causes an increase in consumption. With downward pressure on inflation and the output turning negative, interest rates are lowered by the central bank. As regards fiscal policy, labor and capital tax revenues drop as a result of the shock, worsening public debt.

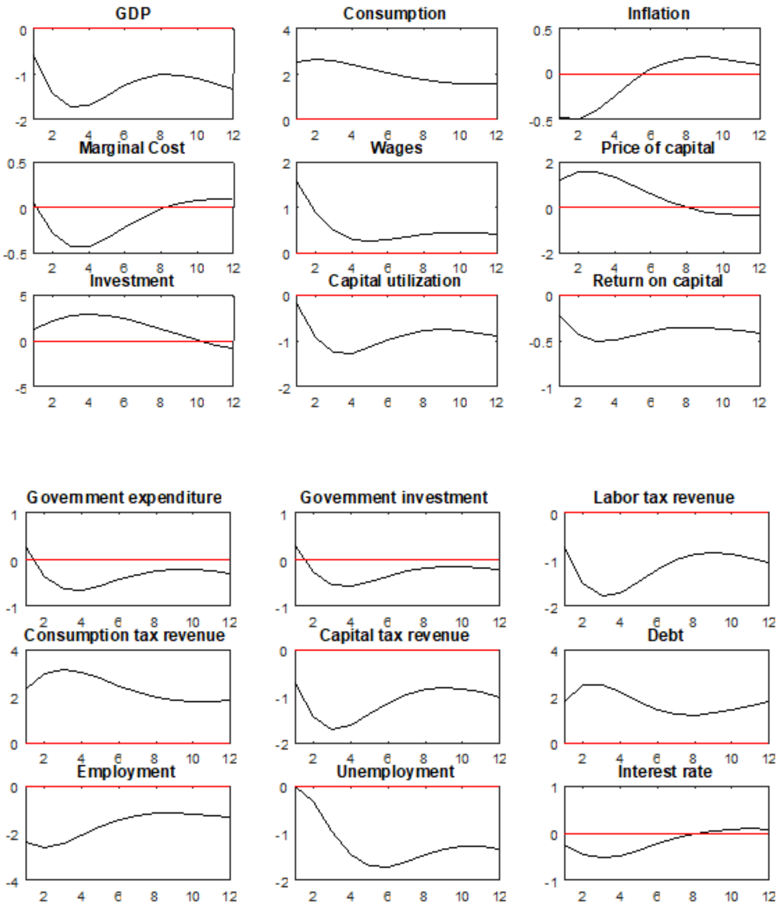


Figure 1. Impulse Response Functions to One Standard Deviation Technology Shock.

4.2.2 Impulse response to inflation shock

The effect of a one positive standard deviation inflation shock (ε_t^π) is reported in figure 2. As a consequence of the shock, output increases in the first two quarters then decreases substantially in the following quarters. This evolution is explained by employment, which records the same tendency. The decrease in wages causes a significant decrease in consumption along with the decrease in firm's marginal costs and the decrease in investment, which worsens over time following the decrease in price of capital, capital utilization and return on capital. Both higher inflation and output, in the first quarters, oblige the central bank to increase the interest rate that leads to a decrease in the price of capital and subsequently investment. The decrease in interest rate two years after the shock will have an opposite effect on the price of capital and therefore on investment. A negative impact on fiscal policy is noticed two quarters following the shock; public debt increases due to the decline in tax revenues.

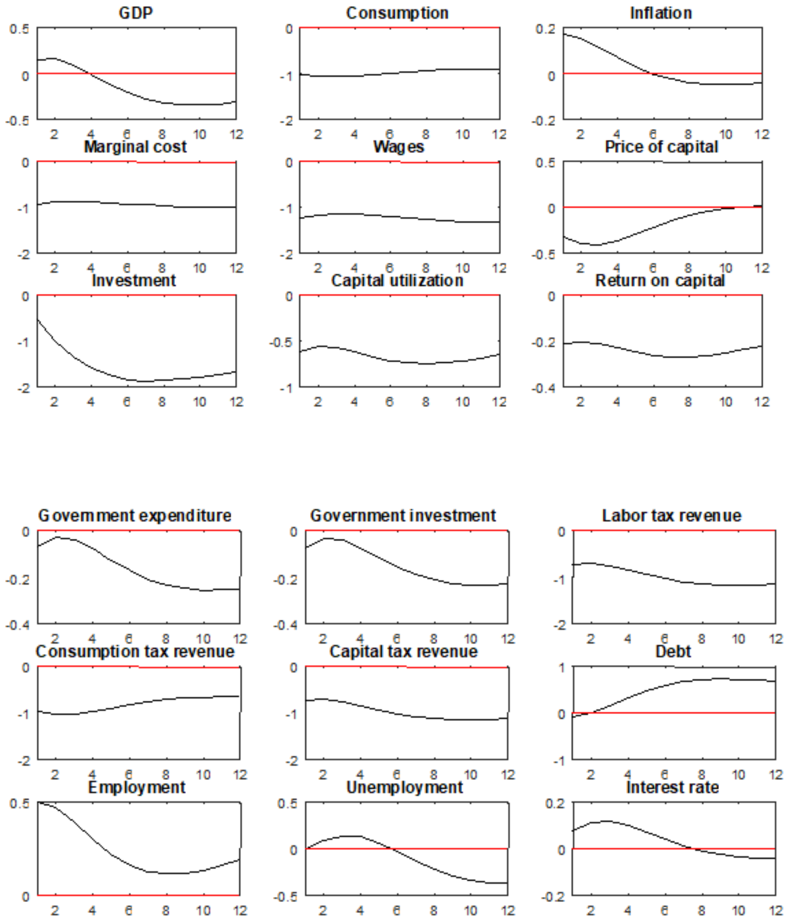
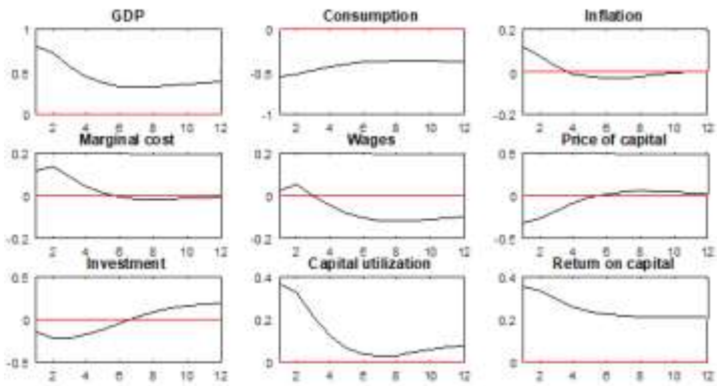


Figure 2. Impulse Response Functions to One Standard Deviation Inflation Shock.

4.2.3 Impulse response to government expenditure shock

Impulse responses implied by government expenditure shock ($\varepsilon_t^{(G^g)}$) are presented in figure 3. The shock results in a persistent decrease in the household's demand for goods, due to the raise of prices especially in the first year after the shock, which results in higher capital utilization, higher return on capital, and a small increase in employment, which puts upward pressure on wages and subsequently on marginal costs . This effect is reversed in the following quarters. GDP eventually decreases after increasing on impact. The rise in inflation and output pushes the central Bank to raise interest rate. As inflation and GDP decline, so does the interest rate. Public debt increases progressively due to the rise in government expenditure and the drop in consumption tax revenues.



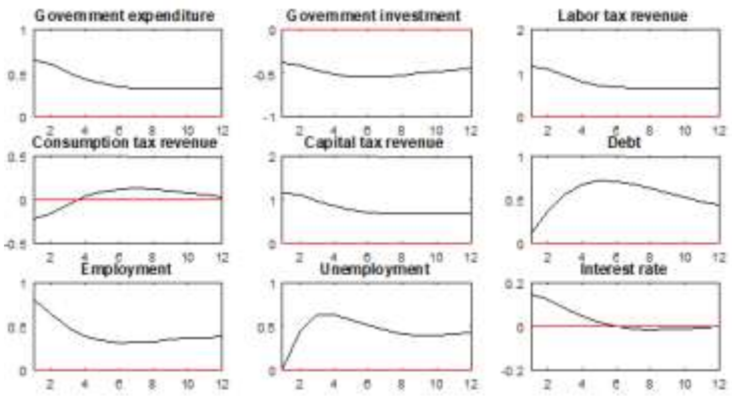


Figure 3. Impulse Response Functions to One Standard Deviation Government Expenditure Shock.

4.2.4 Impulse response to government investment shock

The dynamics implied by the government investment shock ($\varepsilon_t^{I^g}$) are presented in figure 4. When compared with the dynamics implied by the government expenditure shock, one can see almost the same impact. The main difference between the two effects is that the government investment shock leads to a stronger impact.

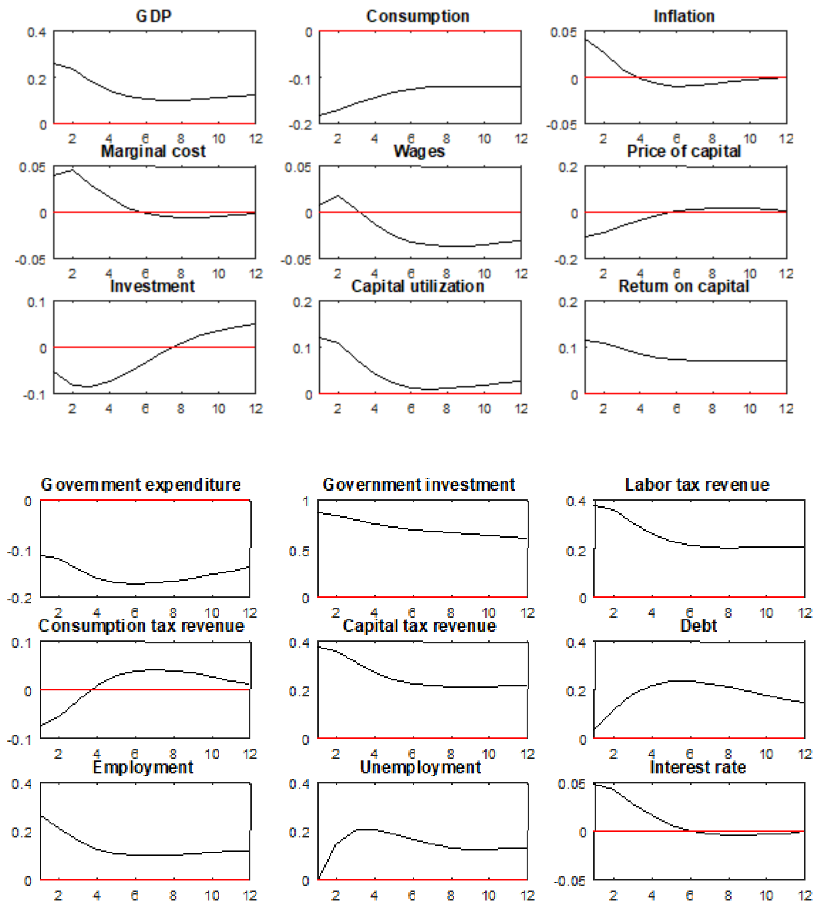


Figure 4. Impulse Response Functions to One Standard Deviation Government Investment Shock.

4.2.5 Impulse response to consumption tax shock

Impulse responses implied by a negative consumption tax shock ($\varepsilon_t^{(\tau^c)}$) are presented in figure 5. A decrease in the consumption tax rate results in a slight decrease in prices lasting for about five months. Consequently, the consumption of households increases slightly along with the GDP but only two quarters after the shock. Higher demand for goods, implied by the consumption tax cut, results in a small decrease in unemployment. The latter begins to raise four quarters after the shock. As the unemployment increases, consumption and marginal costs decline. Lower capital utilization, lower returns on capital, lower investment and lower wages prevent output from rising properly. The monetary authority reacts to the decline in inflation and the drop in output by lowering interest rates. As soon as inflation and GDP start rising, the monetary authority raises slowly the interest rate to contain the inflationary pressures.

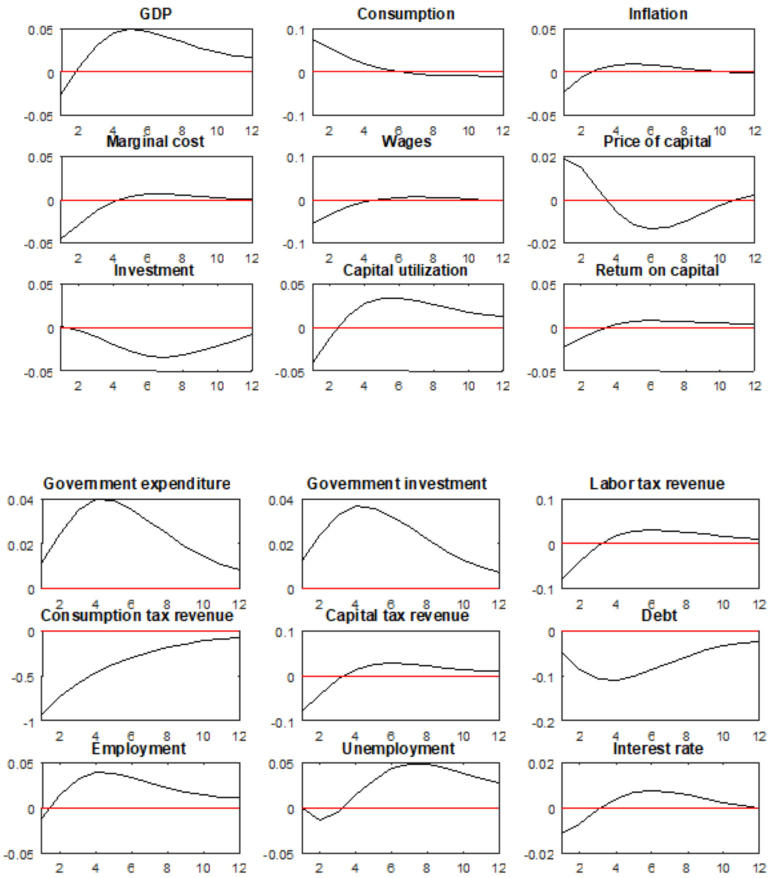


Figure 5. Impulse Response Functions to One Standard Deviation Consumption Tax Shock.

4.2.6 Impulse response to capital tax shock

The impulse responses of the capital tax shock ($\varepsilon_t^{(\tau^k)}$), (figure 6) can be compared to those implied by the consumption tax shock. A priori, one can notice a completely different reaction of the economy as a whole resulting in a significant decline of GDP. Public debt records also a considerable increase at the opposite of the consumption tax shock. Theory suggests that when capital tax rate decreases, investment raise immediately, see Leeper et al. (2010)[38] and Bhattarai & Trzeciakiewicz (2017). This positive impact can be observed after the shock. One can notice also the reallocation of production inputs from labor to capital, which results in higher capital utilization and lower employment. The marginal cost increases as wages and consumption rises. The drop in inflation and GDP oblige the

[38] Leeper, E. M., Walker T. B. and Yang S. C. S., (2010). Government Investment and Fiscal Stimulus. Journal of Monetary Economics, Elsevier, Vol. 57, Issue 8, pp. 1000-1012.

monetary authority to decrease the interest rate. Public debt increases due to the decline in labor and consumption tax revenues.

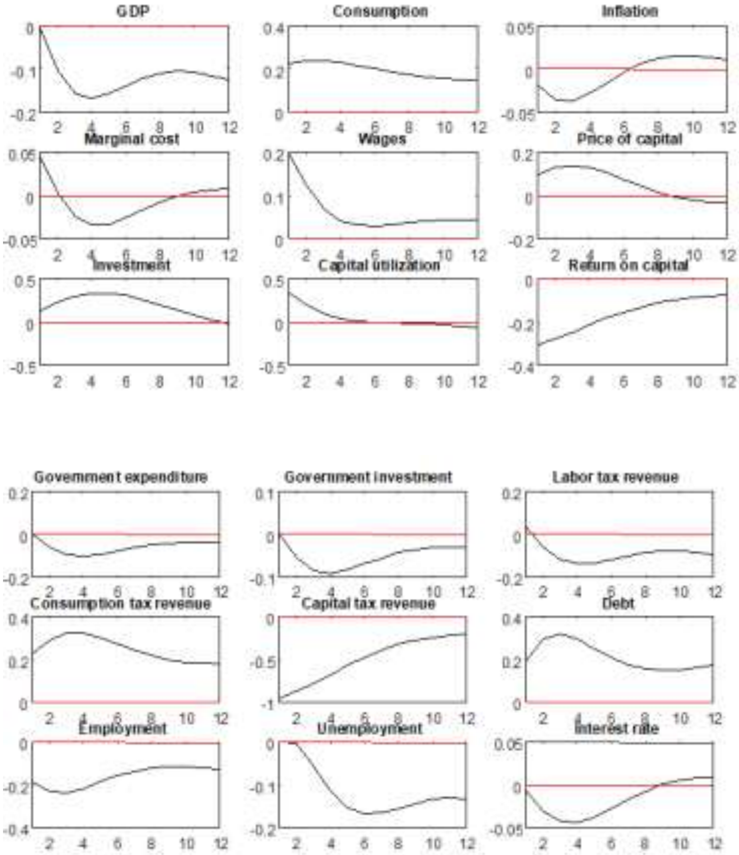
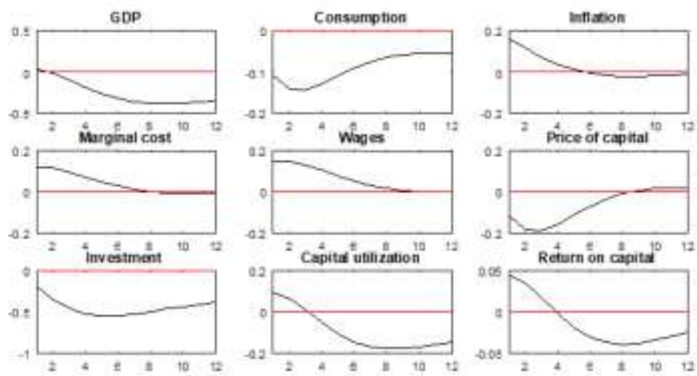


Figure 6. Impulse Response Functions to One Standard Deviation Capital Tax Shock.

4.2.7 Impulse response to labor tax shock

Impulse responses implied by a negative labor tax shock $(\varepsilon_t^{(\tau^w)})$ are presented in figure 7. Following the shock, we should expect a reallocation of production inputs from capital to labor, pushing out employment to increase, capital utilization to decrease and therefore the GDP to rise. Nevertheless, the high level on unemployment, calibrated in the model, prevents this positive externality from recurring in the economy. One can notice also a decrease in consumption even with a rise in wages and marginal costs, which strengthens the hypothesis of a negative wealth effect prevailing within households that expect an increase in distortionary taxes and as a result decrease their consumption expenditures. Inflation rises and therefore monetary authority increase the nominal interest rate despite the decrease in GDP, because the central bank places more weight on inflation than on GDP. The increase in interest rate leads to a decrease in the price of capital and subsequently investment. As in capital tax shock, public debt rises as a result of a decrease in labor and consumption tax revenues.



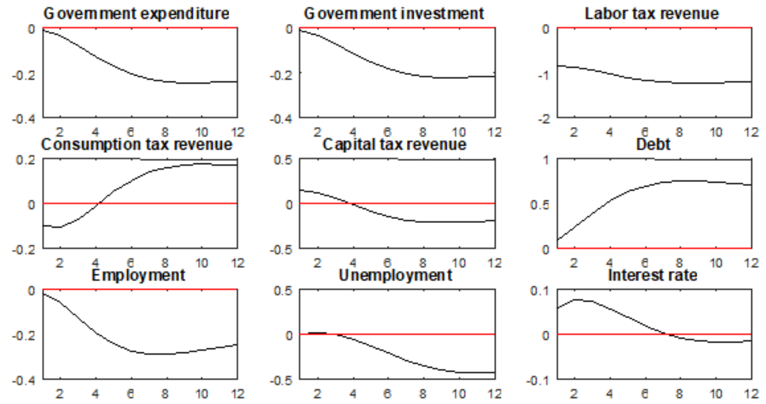


Figure 7. Impulse Response Functions to One Standard Deviation Labor Tax Shock.

4.2.8 Impulse response to monetary policy shock

The dynamics resulting from a positive interest rate shock (ε_t^i) are presented in figure 8. Tightening monetary conditions is, as expected, putting downward pressure on inflation, output and investment. One can notice also a decrease in employment, price of capital, return on capital and thus capital utilization. The fall in prices along with the increase in wages attracts households' demand, which explains the surge in consumption and marginal costs. Public debt raises following the shock due to the decrease in labor and capital tax revenues.

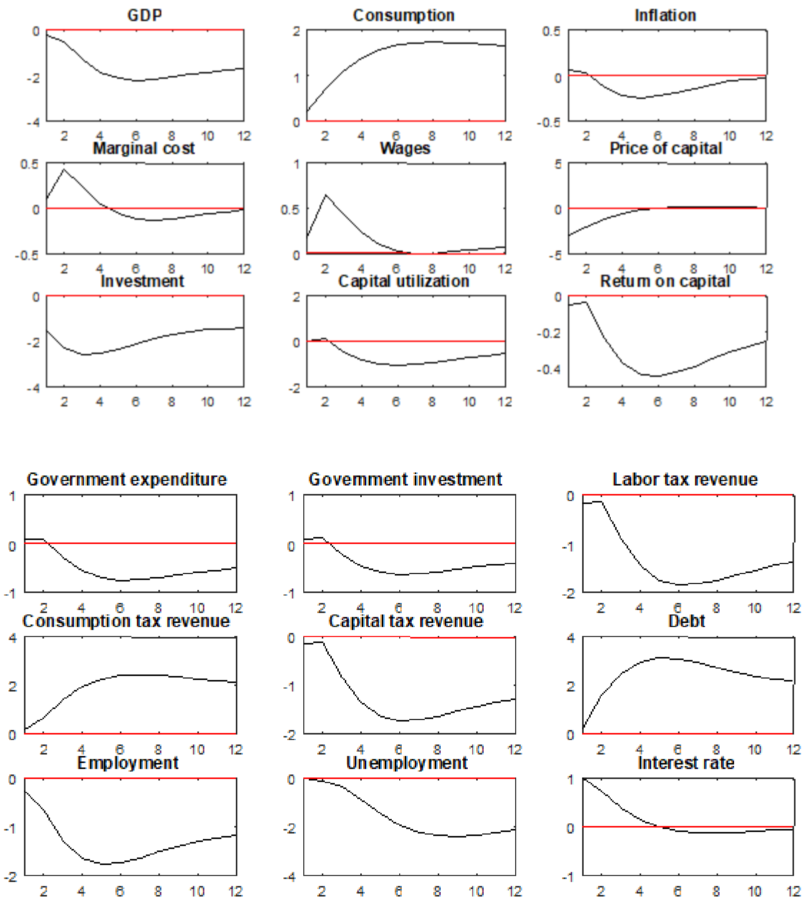


Figure 8. Impulse Response Functions to One Standard Deviation Monetary Policy Shock.

4.2.9 Impulse response to exports shock

The direct implication of a negative exports shock (ε_t^x) (figure 9) is a decrease in output and investment and thus a decrease in employment, in capital utilization, in return on capital and price of capital, which puts upward pressure on inflation. Wages and marginal costs increase on impact before recording a continuous decline. Consumption increases following the increase in wages. Because the monetary authority places more weight on inflation than on GDP, interest rate increases approximately four quarters after the shock before starting to decrease following the decrease in inflation. One can notice a negative impact on fiscal policy illustrated through rising public debt right after the shock; public debt increases due to the decline in labor and capital tax revenues, along with the increase in public expenditure and investment.

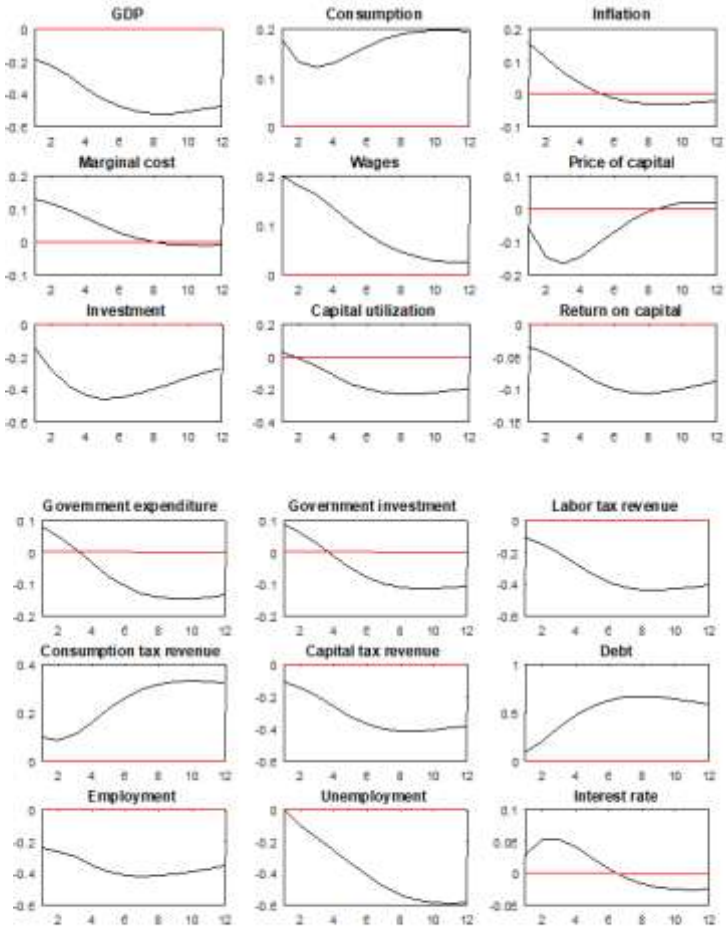
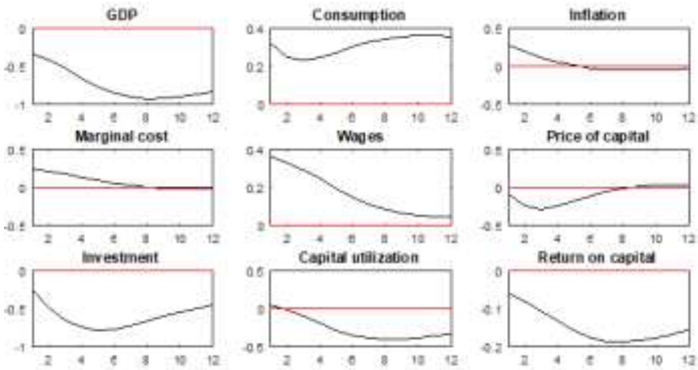


Figure 9. Impulse Response Functions to One Standard Deviation Exports Shock.

4.2.10 Impulse response to imports shock

The impulse responses of imports shock (ε_t^m) (figure 10) can be compared to those implied by the exports shock. A decrease in imports leads to the same impact observed on exports shock. The only difference concerns the intensity of the shock on the macroeconomic variables.



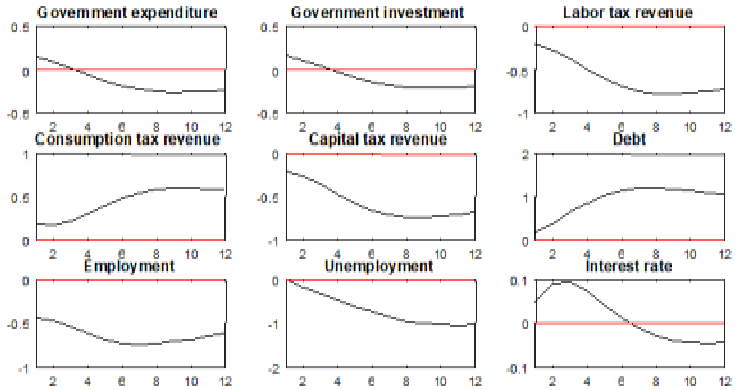


Figure 10. Impulse Response Functions to One Standard Deviation Imports Shock.

4.3 Sensitivity analysis

This section turns to sensitivity analysis. More precisely, we examine to what degree the posteriors (target variables) are affected based on changes in priors (input variables). In our DSGE model, we estimate sensitivity indices that can allow concluding on priors contributing to more uniqueness, stability and determinacy.

The global sensitivity analysis of our model reveals that 32.9% of the prior support gives unique saddle-path solution, 55.9% of the prior support gives explosive dynamics and 11.3% of the prior support gives indeterminacy (see Appendices E, F and G). Table 5 shows results of the Smirnov test for the parameters of interest.

Table 5.
Smirnov statistics

		d-stat	p-value
Smirnov statistics in driving unique solution	ω_u	0.247	0.000
	φ_y	0.139	0.000
	γ_{G^g}	0.134	0.000
	ψ_k	0.124	0.000
	θ	0.102	0.000
Smirnov statistics in driving indeterminacy	ω_u	0.287	0.000
	θ	0.268	0.000
	ψ_k	0.258	0.000
	ξ	0.156	0.000
	φ_y	0.136	0.001
Smirnov statistics in driving instability	ω_u	0.327	0.000
	θ	0.193	0.000
	φ_y	0.172	0.000
	γ_{G^g}	0.154	0.000
	ρ_i	0.087	0.001

5. Conclusion and policy implications

The impact of the COVID-19 pandemic is clear and powerful all around the globe. However, it might be different in terms of size and duration among countries, depending on the ability of economies to withstand and to overcome the shock of the health crisis. In this paper, we try to study the impact of the shock for Morocco. We use for this purpose, a DSGE model with a particular specification. We assume a pandemic crisis that affects aspects of both supply and demand shocks reducing the capacity to produce goods and services due to the strict containment measures adopted by the country leading to the temporary or permanent closure of many firms, and consequently a significant increase in unemployment reducing furthermore consumers' ability or willingness to purchase goods and service.

This situation should induce adverse effects on the state budget in terms of tax revenue. Global activity, strongly disrupted by the upheaval in production, consumption and trade, should negatively affect the trade balance. Thus, we build an open economy DSGE model incorporating unemployment and rigidity in prices. In addition, the model incorporates fiscal and monetary policy with a semi-fixed exchange regime; the monetary policy rule is reacting to fluctuations in inflation, output and exchange rate.

To calibrate and estimate the model, we use Bayesian techniques with Moroccan quarterly data for the period from the first quarter of 1998 to the second quarter of 2019. Parameter estimates indicate that in the controlling for government debt, government expenditure plays the most important role, followed by government investment and consumption tax. The response of labor tax and capital tax to debt register lower values compared to the other instruments. As regards the response the GDP, the labor tax and capital tax plays this time the most important roles. However, all fiscal instruments should be considered to stimulate economic activity in a context of fiscal stimulus; the instruments involving the spending aspect countercyclically and those involving the revenue perspective procyclically. Bayesian estimation results indicate also that the monetary policy gives priority to inflation targeting at the expense of output and exchange rate targeting. Estimates allow also concluding that the exchange rate flexibility fluctuation band must not exceed ±13%.

The dynamics implied by the COVID-19 shock indicate persistent effect for at least 12 quarters and a strong recession related to external shocks, monetary policy shock, labor tax shock, capital tax shock and technology shock. The consumption tax shock has unlike the others a very small negative impact on GDP followed by an increase in GDP. The inflation shock has a surprisingly a positive impact on GDP followed by a negative one four quarters after the shock. For the government expenditure and investment shock, GDP eventually decreases after increasing on impact, but do not drive the economic activity into recession. Therefore, these two fiscal instruments should be considered to stimulate activity during crisis. As regards the effects on fiscal policy, the impulse response functions indicate a negative impact illustrated through rising public debt as a result of all the shocks except for the consumption tax shock. As for inflationary shocks that may occur because of the crisis, monetary policy can obviously be a powerful tool to mitigate them.

Going forward, the model can be enriched through various directions. We can extend the model by adding time-varying wages and price markups and predict their co-movement following demand and supply shocks. We could also consider the Calvo (1983) type staggered behavior on wages. We can also introduce incomplete pass-through of exchange rate to domestic and exports prices considering nominal rigidities in the local currency and real rigidities due to intermediate inputs in production. Incomplete pass-through of marginal cost disturbances to prices can also be considered. It would be also more instructive to consider the model in its nonlinear form for a future research to avoid linear model abstracts; this would allow calibrating the duration of the shocks and studying the effects of different shock sizes or interactions between shocks. Several improvements can be applied to the fiscal and monetary policy depending on the changing needs of policy makers and the evolution of the economic environment.

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Appendices

Appendix A: Log-linearized model equations

Households:

$$\tilde{C}_t = E_t\tilde{C}_{T+1} - \frac{1}{\sigma_c}\left[\tilde{R}_t - E_t(\tilde{\pi}_{t+1}) + \left(\frac{\tau^c}{1+\tau^c}\right)(\tilde{\tau}_t^c - E_t\tilde{\tau}_{t+1}^c)\right] \tag{0.1}$$

$$\widetilde{W}_t = \sigma_l\tilde{L}_t + \sigma_c\tilde{C}_t + \left(\frac{\tau^c}{1+\tau^c}\right)\tilde{\tau}_t^c - \left(\frac{\tau^w}{1+\tau^w}\right)\tilde{\tau}_t^w + \tilde{P}_t \tag{0.2}$$

$$\begin{aligned}\tilde{P}_t^k &= -(\tilde{R}_t - E_t\tilde{\pi}_{t+1}) \\ &\quad + \frac{1}{1-\delta_k+(1-\tau^k)r^k}E_t\Big[(1-\delta_k)\tilde{P}_{t+1}^k \\ &\quad + r^k(1-\tau^k)\left(\tilde{r}_{t+1}^k - \frac{\tau^k}{1-\tau^k}\tilde{\tau}_{t+1}^k\right)\Big]\end{aligned} \tag{0.3}$$

$$\tilde{I}_t = \frac{1}{1+\beta}\tilde{I}_{t-1} + \frac{\beta}{1+\beta}E_t\tilde{I}_{t+1} + \frac{1}{\xi(1+\beta)}\tilde{P}_t^k + \frac{1}{1+\beta}E_t(\beta\tilde{\varepsilon}_{t+1}^{inv} - \tilde{\varepsilon}_t^{inv}) \tag{0.4}$$

$$\tilde{z}_t = \frac{1}{\tilde{\psi}_k}\left(\tilde{r}_t^k - \frac{\tau^k}{1-\tau^k}\tilde{\tau}_t^k\right) \tag{0.5}$$

$$\widetilde{K}_t = (1-\delta_k)\widetilde{K}_{t-1} + \delta_k\tilde{I}_{t-1}$$

$$\tilde{\pi}_t^c = \tilde{\pi}_t + \frac{\tau^c}{1+\tau^c}(\tilde{\tau}_t^c - \tilde{\tau}_{t-1}^c)$$

$$\tilde{P}_t = \tilde{P}_{t-1} + \tilde{\pi}_t$$

Production / Labor market:

$$\tilde{Y}_t = \varphi_y(-\varepsilon_t^A + \propto \tilde{z}_t + \propto \widetilde{K}_{t-1} + (1-\propto)\widetilde{N}_t + \sigma_g\widetilde{K}_{t-1}^g) \tag{0.6}$$

$$\widetilde{N}_t = \tilde{z}_t + \tilde{r}_t^k + \widetilde{K}_{t-1} - \widetilde{W}_t$$

$$\widetilde{MC}_t = -\tilde{\varepsilon}_t^A + (1-\propto)\widetilde{W}_t + \propto \tilde{r}_t^k - \sigma_g\widetilde{K}_{t-1}^g$$

$$\tilde{\pi}_t = \beta E_t\tilde{\pi}_{t+1} + \frac{(1-\theta)(1-\beta\theta)}{\theta}(\widetilde{MC}_t + \tilde{\varepsilon}_t^\pi) \tag{0.7}$$

$$\tilde{L}_t = (1-\varphi)\widetilde{N}_t + \varphi\widetilde{U}_t$$

$$\widetilde{U}_t = \omega_u\widetilde{U}_{t-1} + \omega_y\tilde{Y}_{t-1} + \tilde{\varepsilon}_t^u \tag{0.8}$$

Fiscal policy:

$$\begin{aligned}\tilde{B}_t\frac{B}{Y} &= R\frac{B}{Y}(\tilde{R}_{t-1} - \tilde{\pi}_t + \tilde{B}_{t-1}) + \frac{G^g}{Y}\tilde{G}_t^g + \frac{I^g}{Y}\tilde{I}_t^g - \tau^w\frac{WN}{Y}(\tilde{\tau}_t^w + \widetilde{W}_t + \widetilde{N}_t) \\ &\quad - \tau^c\frac{C}{Y}(\tilde{\tau}_t^c + \tilde{C}_t) - \tau^k\frac{r^kK^F}{Y}(\tilde{\tau}_t^k + \tilde{r}_t^k + \tilde{z}_t + \widetilde{K}_{t-1})\end{aligned} \tag{0.9}$$

$$\widetilde{K}_t^g = (1-\delta_g)\widetilde{K}_{t-1}^g + \delta_g\tilde{I}_{t-1}^g \tag{0.10}$$

$$\tilde{G}_t^g = -\lambda_{G^g}\tilde{B}_{t-1} - \gamma_{G^g}\tilde{Y}_t + \tilde{\varepsilon}_t^{G^g} \tag{0.11}$$

$$\tilde{I}_t^g = -\lambda_{I^g}\tilde{B}_{t-1} - \gamma_{I^g}\tilde{Y}_t + \tilde{\varepsilon}_t^{I^g} \tag{0.12}$$

$$\tilde{\tau}_t^c = \lambda_{\tau^c}\tilde{B}_{t-1} + \gamma_{\tau^c}\tilde{Y}_t - \tilde{\varepsilon}_t^{\tau^c} \tag{0.13}$$

$$\tilde{\tau}_t^k = \lambda_{\tau^k} \tilde{B}_{t-1} + \gamma_{\tau^k} \tilde{Y}_t - \tilde{\varepsilon}_t^{\tau^k} \quad (0.14)$$

$$\tilde{\tau}_t^w = \lambda_{\tau^w} \tilde{B}_{t-1} + \gamma_{\tau^w} \tilde{Y}_t - \tilde{\varepsilon}_t^{\tau^w} \quad (0.15)$$

$$Inc_t^{\tau^c} = \tilde{C}_t + \tilde{\tau}_t^c \quad (0.16)$$

$$Inc_t^{\tau^k} = \tilde{r}_t^k + \tilde{z}_t^F + \tilde{K}_{t-1}^F + \tilde{\tau}_t^k \quad (0.17)$$

$$Inc_t^{\tau^w} = \tilde{W}_t + \tilde{L}_t + \tilde{\tau}_t^w \quad (0.18)$$

Monetary policy:

$$\tilde{\iota}_t = \rho_i \tilde{\iota}_{t-1} + (1-\rho_i)\left[\rho_\pi \tilde{\pi}_t + \rho_y\left(\tilde{Y}_t - \tilde{Y}_{t-1}\right) + \psi_s\left(\tilde{S}_t - \tilde{S}_{t-1}\right)\right] + \tilde{\varepsilon}_t^i \quad (0.19)$$

$$\tilde{S}_t = \rho_s \tilde{S}_{t-1} + \tilde{\varepsilon}_t^s \quad (0.20)$$

Market clearing condition:

$$\tilde{Y}_t = \frac{C}{Y}\tilde{C}_t + \frac{I}{Y}\tilde{I}_t + \frac{G^g}{Y}\tilde{G}_t^g + \frac{I^g}{Y}\tilde{I}_t^g + \left(1-\tau^k\right)\frac{r^k K}{Y}\tilde{z}_t + \frac{X}{Y}\tilde{X}_t - \frac{M}{Y}\tilde{M}_t \quad (0.21)$$

$$\tilde{X}_t = \rho_x \tilde{X}_{t-1} + \tilde{\varepsilon}_t^x \quad (0.22)$$

$$\tilde{M}_t = \rho_m \tilde{M}_{t-1} + \tilde{\varepsilon}_t^m \quad (0.23)$$

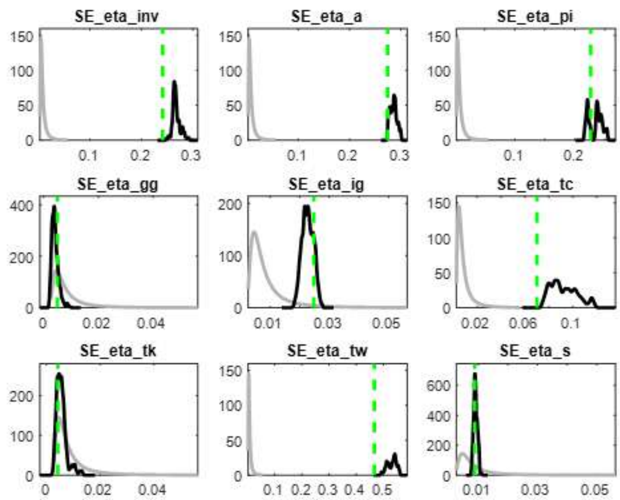
World economy:

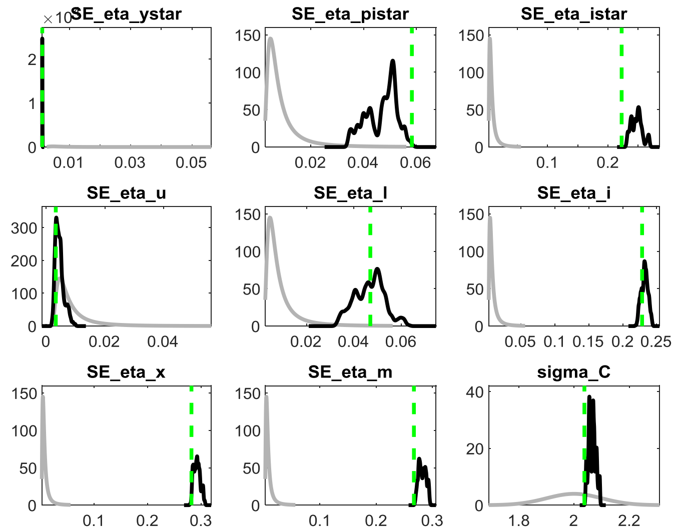
$$\tilde{Y}_t^* = \rho_{y^*} \tilde{Y}_{t-1}^* + \tilde{\varepsilon}_t^{y^*} \quad (0.24)$$

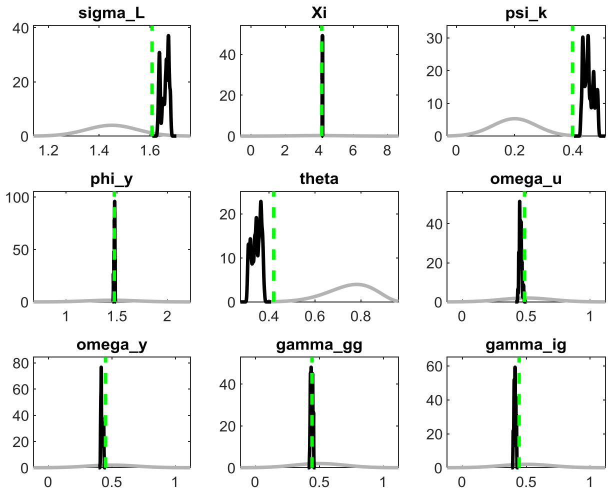
$$\tilde{\pi}_t^* = \rho_{\pi^*} \tilde{\pi}_{t-1}^* + \tilde{\varepsilon}_t^{\pi^*} \quad (0.25)$$

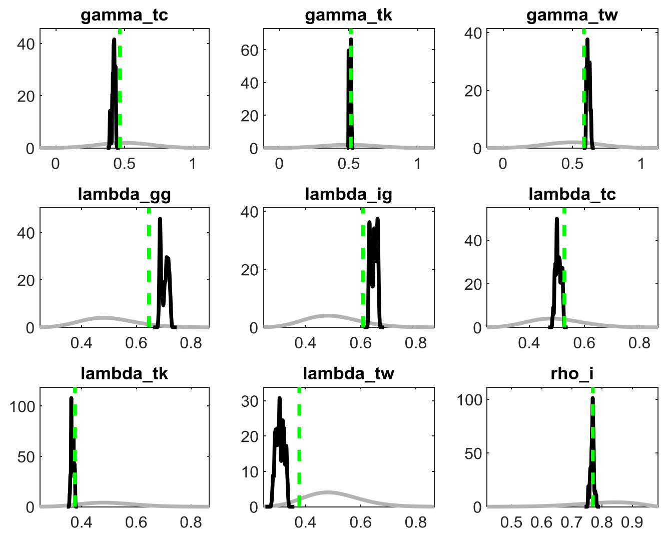
$$\tilde{\iota}_t^* = \rho_{i^*} \tilde{\iota}_{t-1}^* + \tilde{\varepsilon}_t^{i^*} \quad (0.26)$$

Appendix B: Priors and posteriors




SE_eta_ystar
SE_eta_pistar
SE_eta_istar
SE_eta_u
SE_eta_l
SE_eta_i
SE_eta_x
SE_eta_m
sigma_C


sigma_L
Xi
psi_k
phi_y
theta
omega_u
omega_y
gamma_gg
gamma_ig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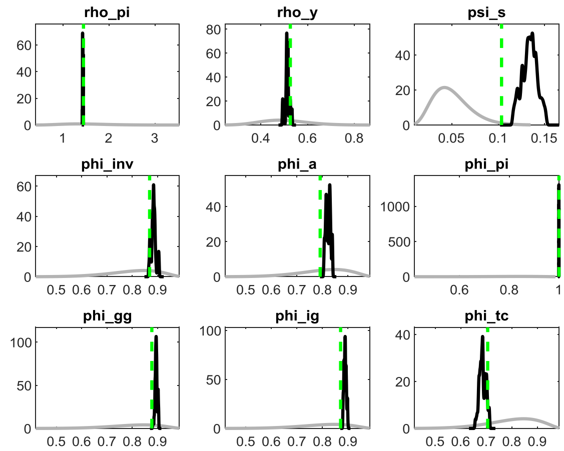
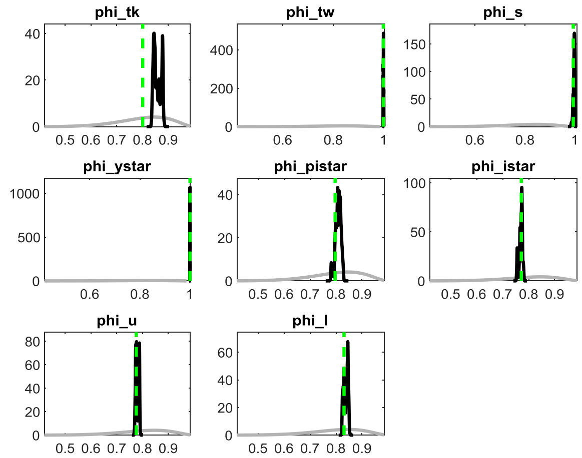
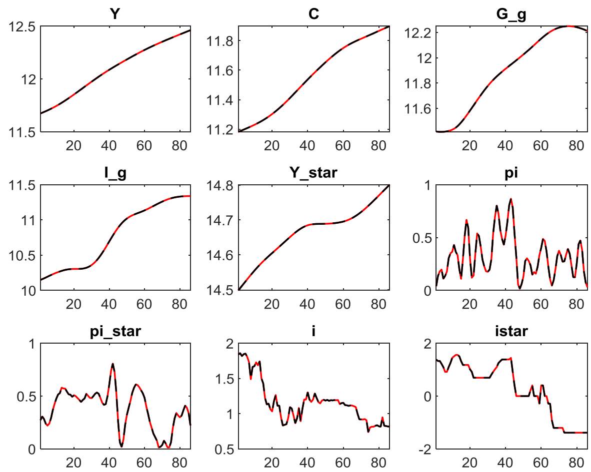
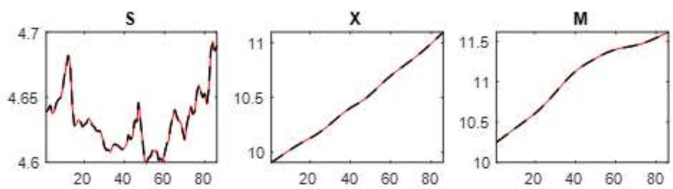
gamma_tk
gamma_tw
lambda_gg
lambda_ig
lambda_tc
lambda_tk
lambda_tw
rho_i



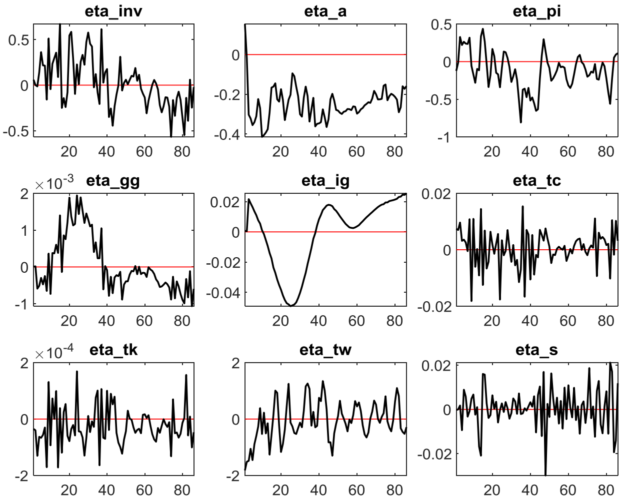


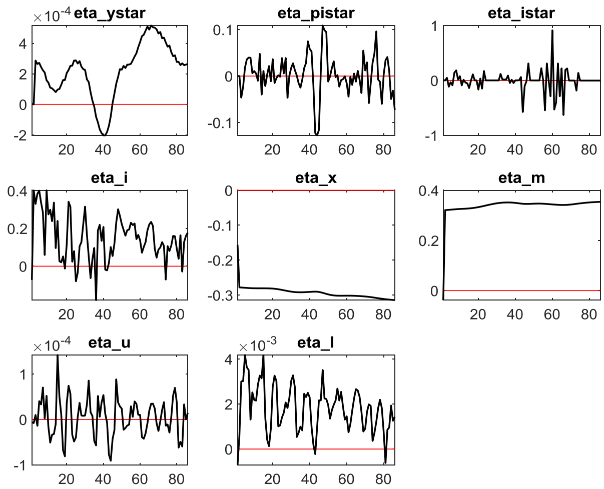
Appendix C: Historical and smoothed variables



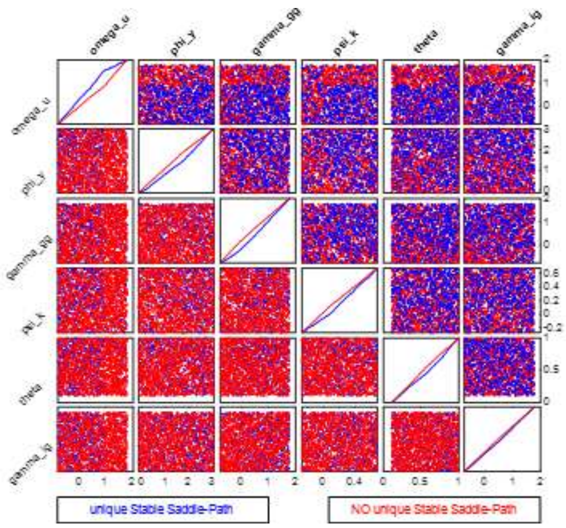


Appendix D: Smoothed shocks

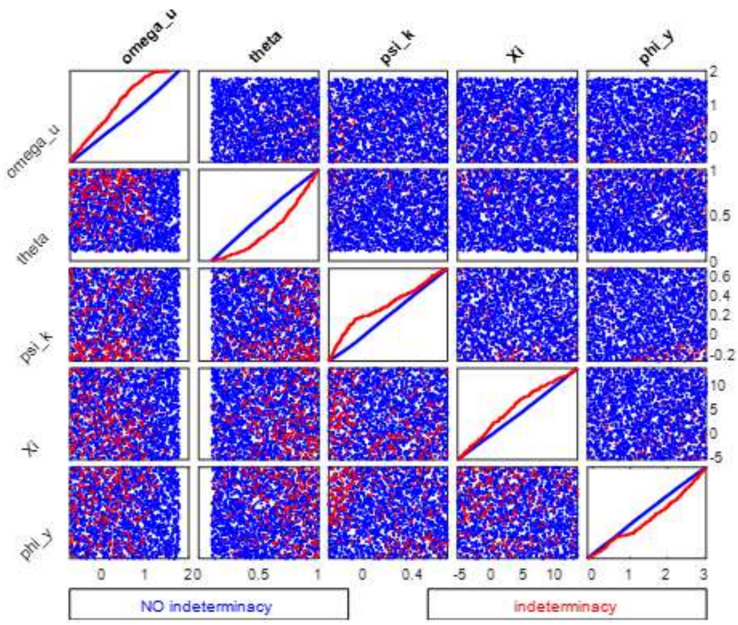




Appendix E: Prior Stability Mapping: Parameter driving non-existence of unique stable solution (Unacceptable)



Appendix F: Prior Stability Mapping: Indeterminacy



Appendix G: Prior Stability Mapping: explosiveness of solution