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Abstract

This paper develops a DSGE model for a small open oil economy which has two rates at official and free (unofficial) markets for foreign currency. In this model, government has access to foreign currency by supplying oil in international markets. Using the oil revenue, the government provides the Central Bank and essential imported goods with foreign currency at the official rate; Other goods are imported at the unofficial rate. The CB's objective is to minimize the difference between nominal free and official exchange rates. To do so, the CB uses three policy instruments: *i*) either holds foreign currency as financial assets or sells it to the free market at the unofficial rate, *ii*) nominal monetary base growth rate and *iii*) nominal depreciation of official exchange rate. These instruments are applied in this paper in four scenarios of CPI targeting and PPI targeting in both dual and unified exchange rate regimes. Through a welfare analysis, this paper indicates that PPI targeting works better than CPI targeting in this economy. As well, this paper illustrates that PPI targeting under unified system considerably increases welfare. In addition, the interaction between fiscal and monetary policy is assessed. The results show that monetary and exchange rate policies are also more effective when fiscal authority follows a procyclical fiscal rule.

JEL classification: E52, E58, F41.

Keywords: DSGE model, Dual-Exchange Rate System, PPI Inflation Targeting.

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1 Introduction

This paper, using a rich DSGE model, studies monetary and exchange rate policies in developing oil economies which have adopted daul-exchange rate regime (hereafter DODs for such economies[1].). A country has an oil economy if oil revenues finance a significant proportion of the economy. Iran, Saudi Arabia, Venezuela, Sudan, Libya, Kuwait and Iraq are good example for such economies. Among them, Iran, Iraq and Venezuela use dual (or multiple)-exchange rate regime. In practice, mainly banks and large importers benefit from multiple-exchange rates, whereas foreign investors and even the government itself, which is obliged to sell its oil-export revenues at a lower rate, are losers. Multiple-exchange are aimed to positively impact the BOP by making exports more competitive and imports cheaper. However, in the realty, currency remains volatile, initially succeeded by an extreme devaluation and then the expansion of multiple exchange rates and a currency black market. These factors usually assist to long periods of instability in the economy(Hanke and Schuler (2002), Spiegel et al. (2002) and Frankel (2003)). Figure 1 and 2 depict the exchange rate duality for Venezuela and Iran in recent years.

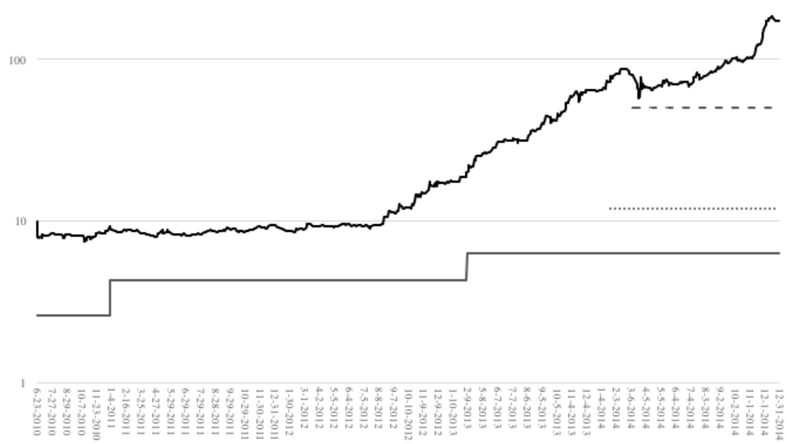

Figure 1: Venezuela: multiple-exchange rate system. Source: Bahar et al.

DOD economies usually share common characteristics such as high degree of fiscal dominance, different channels of influencing oil price shocks on economic growth, the effects of oil price shocks on exchange rate regime, inefficient public investment financed by oil windfall (Berg et al. (2013)) and hybrid monetary policy of inflation targeting and managed exchange rate regime (Benes et al. (2015)). Many studies e.g. Alba et al. (2013), Allegret and Benkhodja (2015), Benkhodja (2014), Dagher et al. (2012), Pieschacón (2012), Sanchez (2011) and Algozhina (2016) analyze policies in developing economies ignoring the oil duality featured by a

[1] Dual (or even multiple) exchange rates are usually a reaction to persistent trade deficits and foreign exchange shortages. The objective is provide foreign exchange for essential goods or to control inflation by lowering import prices. Examples include Germany in 30's, China in the 80's and early 90's, Argentina in 2001, Burma prior to 2012, and Sudan, Venezuela and Iran today. For the long list please see AREAER (2018)

modern oil sector e.g. forward and backward linkages with the rest of the economy and the lack of central bank independence. Indeed, these features limit the use of conventional DSGE models for policy making in DODs. As reported by Allegret and Benkhodja (2015), output growth in small oil exporting countries is heavily dependent upon petrodollars, making them particularly vulnerable to external shocks. In fact, changes in oil price can influence economic growth through both production and consumption channels. In addition, oil-exporting countries experience higher business cycle volatility than other emerging and developing economies (Fund (2012) and Chafik (2019)). This is reflected in the Dutch Disease literature that oil discoveries and oil price increases result in higher government spending, an increase in the relative price of non-tradable goods and loss of competitiveness in the non-oil tradable sector (Benkhodja (2014) and Pieschacón (2012)).

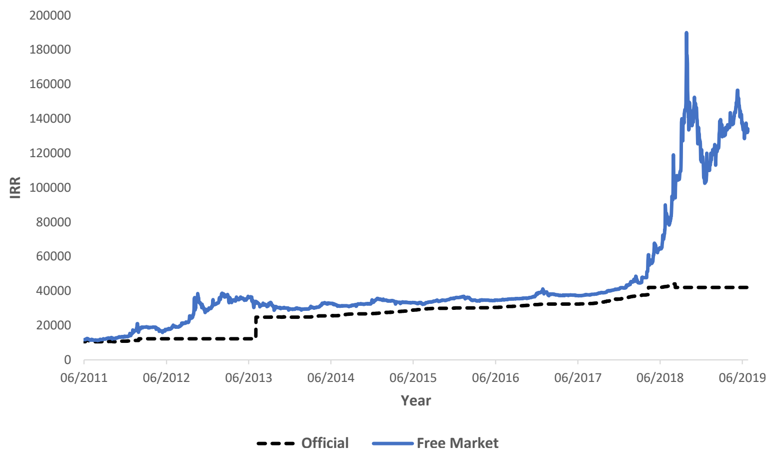

Figure 2: Iran's dual-exchange rate. Source: IMF data

Another property of DODs that is absent in conventional DSGE models (Felices and Tuesta (2013)) is that the exchange rate is highly affected by oil price shocks. In other words, in an oil developing country, real exchange rate behavior is mostly determined by real oil revenues. When there are high oil revenues and thus massive foreign reserves, the central bank is able to overvalue the national currency. Although the real exchange rate is also affected by other factors, oil revenue fluctuations, either caused by changes in oil production levels or oil prices, are the main factor in real exchange rate variations[2] (Tavakolian and Ebrahimi (2012) and Chafik (2019)). Real exchange rate and real oil revenue trends suggest that the real exchange rate is inversely related to real oil revenues in such economies. In fact, when real oil revenues are rising, real exchange rate is decreasing and vice-versa (Tavakolian and Ebrahimi (2012)).

This paper aims to shed lights on the neglected part of the literature of DODs by answering the following key questions: i) how does dual-exchange rate regime result in welfare loss? ii) what are the optimal monetary and fiscal policies under duality of exchange rate? iii) can the

[2]and deviation of nominal exchange rate from Purchasing Power Parity (PPP) trend

results found by Frankel (2011) or Algozhina (2016) be affected by dual-exchange rate regime? To answer these questions, we build a two-block model of an open oil exporting economy. This paper contribute to the literature by building a new model compatible with the reality of developing oil exporting countries with multiple-exchange rate regime. Without loss of generality, in this paper we only apply a dual-exchange regime[3] In our model, whenever a great shock hits the BOP, the Central Bank (hereafter CB), accepts to have at least two exchange rates. The first rate (official rate) belongs to an official market. Government uses this rate to sell a share of its oil revenue directly to the CB and the rest to import consumption goods. The second rate (free rate) belongs to the free market in which the main supplier is the CB. It is also assumed that there are non-oil exports which are another supplier of the free market. Then, the CB starts minimizing the difference between two rates by using its instruments: supplying more in the free market, changing official exchange rate depreciation and changing growth rate of nominal money (Algozhina (2016) and Escude (2012))[4].

We consider two policy scenarios. In the first scenario the official and free markets have two different rates. In the second scenario, it is assumed that the exchange rates are unified, i.e. official exchange rate is equal to free market exchange rate so both markets are the same. As a result, there is no need for the CB's intervention in free market. Each of these exchange rate regimes are assessed by Consumer Price Index (CPI) targeting and Product Price Index (PPI) targeting monetary policy. Frankel (2011) points out, in emerging commodity exporting countries like countries in Latin America and the Caribbean (LAC), product price (including export commodities and excluding import products) targeting (PPT)can better stabilize domestic economy than consumer price index inflation targeting (CPIT). Algozhina (2016) also considers such monetary policies together with flexible and managed exchange rate regime combined with pro-/countercyclical fiscal policy for Kazakhstan and discusses that the best policy combination is procyclical fiscal and CPI inflation targeting without foreign exchange interventions. Contrary, our paper shows that PPI inflation targeting results in lower loss under both exchange rate regimes.

Since there are two types of exports, oil and non-oil, in the model, we consider a weighted average of domestic goods price inflation and oil price inflation as the inflation target in the last type of monetary policy. This is a standard approach in the literature e.g. see Frankel (2011) and Algozhina (2016). To assess impacts of interactions between monetary and fiscal policy on fluctuations, we apply an improved procyclical fiscal rule à la Algozhina (2016), along with the monetary and exchange rate policies. The results show that procyclical fiscal rule increases welfare regardless of monetary and exchange rate regime combination.

Finally, we use a welfare measure à la De Paoli (2009). This measure is a loss function

[3] For instance in Iran exchange rate regime has been characterized by a system of multiple exchange rates. The number of official exchange rates are varied in response to economic conditions (see Sandararajan et al. (1999) and Tavakolian and Ebrahimi (2012) for detailed review of exchange rate system in Iran).

[4] Algozhina (2016) and Escude (2012) consider nominal interest rate as the policy instrument while we introduce growth rate of nominal money as an instrument which is closer to the reality of oil developing countries.

of variations in inflation, output and real exchange rate. Since we assume dual-exchange rate system as the baseline scenario, the measure of real exchange rate would be a weighted average of real exchange rate based on official and free nominal exchange rates. This property along with the weights of oil and non-oil price inflation in inflation target allows policy makers to find the optimal weights based on loss function value.

The paper is organized as follows. Section 2 outlines a DSGE model that allows for dual-exchange environment in domestic economy. In section 3 I present the Bayesian estimation of the model. The empirical results and interpretation of impulse responses and sensitivity analysis of loss functions are presented in section 4. Finally, section 5 concludes.

2 The Model

2.1 Households

The economy is populated by a continuum of identical households which drive utility from a composite of consumption C_t, public consumption C_{Gt}, real money balances $\frac{M_t}{P_t}$, real amount of holding foreign currency $\frac{S_{St}M_{St}}{P_t}$ and disutility from labor L_t.

Public consumption is considered directly in household utility function because usually in DODs, government consumption through increasing public health, education quality etc affects household's utility. The representative household's preference is described by the following utility function:

$$\begin{aligned} E_0 \sum_{t=0}^{\infty} \beta^t \Big[\frac{(C_t C_{Gt}^{\gamma})^{1-\sigma}}{1-\sigma} + \frac{\kappa_m}{1-b_m} \left(\frac{M_t}{P_t} \right)^{1-b_m} \\ + \frac{\kappa_s}{1-b_s} \left(\frac{S_{St} M_{St}}{P_t} \right)^{1-b_s} - \chi \frac{L_t^{1+\eta}}{1+\eta} \Big] \end{aligned} \tag{2.1}$$

P_t is price level, M_{St} is nominal amount of foreign currency households hold (in terms of foreign currency) and S_{St} is nominal exchange rate in free market (price of foreign currency in terms of national currency). There are two different markets for foreign currency in this economy. The first one is an official market in which government sells its revenue from oil at rate S_{Ft}. A part of this revenue is sold directly to the CB and the remaining is used up to import essential consumption and investment goods. The second market is a spot market in which the CB is the main supplier. It is assumed that the exchange rate in the official market is lower than that of the free market. Household has only access to foreign currency at rate S_{St} in the free market. $\beta \in (0, 1)$ is the intertemporal preference discount factor, σ, b_m, b_s and η are elasticity of intertemporal substitution of consumption, interest elasticity of real balances, interest elasticity of real foreign currency holding and Frisch labor elasticity, respectively. $\gamma \in (0, 1)$ is the parameter which determines the impact of public consumption on household's preferences. If $\gamma = 0$, then public consumption has no effect on household's utility, while $\gamma = 1$ means that public consumption affects household's utility as well as household consumption. κ_m, κ_s and χ are parameters determining the effects of real balances, real amount of holding foreign currency and disutility from labor, respectively, in utility function. Household maximizes his utility subject to the budget constraint in real term. The budget constraint is:

$$\begin{aligned} C_t + \frac{M_t}{P_t} + I_t + \frac{B_t}{P_t} + \frac{S_{St}M_{St}}{P_t} + T_t = w_t L_t + R_t u_t K_{t-1} \\ -\Psi(u_t)K_{t-1} + \frac{M_{t-1}}{P_t} + D_t + (1+r_{t-1})\frac{B_{t-1}}{P_t} + \frac{S_{St}M_{St-1}}{P_t} + TA_t \end{aligned} \tag{2.2}$$

at t, household receives wage $w_t L_t$, the rent income from the capital stock $R_t u_t K_{t-1} - \Psi(u_t)K_{t-1}$ (where $\Psi(u_t)$ is capital utilization function, satisfying $\Psi(1) = 0$, $\Psi'' \geq 0$ and u_t is capital utilization rate), the principle and interest payment of government bond holding $(1+r_{t-1})\frac{B_{t-1}}{P_t}$, the real balances $\frac{M_{t-1}}{P_t}$, the foreign currency holding $\frac{S_{St}M_{St-1}}{P_t}$, the profits from firms D_t and lump-sum transfer from government TA_t. The household's expenditures at t are consumption C_t, investment I_t, government bond holding $\frac{B_t}{P_t}$, real balances holding $\frac{M_t}{P_t}$, foreign currency holding $\frac{S_{St}M_{St}}{P_t}$ and lump-sum tax payments T_t.

The law of motion for private capital follows:

$$K_t = (1-\delta)K_{t-1} + \left[1 - F\left(\frac{I_t}{I_{t-1}}\right)\right](1-b_I)I_t z_t \tag{2.3}$$

where δ is the depreciation rate of private capital, $F\left(\frac{I_t}{I_{t-1}}\right)$ is the investment adjustment cost and b_I is the fraction of private investment in producing oil reserves. Following Christiano et al. (2005), it is assumed that $F(1) = F'(1) = 0$ and $F''(1) > 0$. z_t is a stationary investment-specific technology shock, given by an AR(1) process

$$\log z_t = \rho_z \log z_{t-1} + \varepsilon_{zt}, \qquad \varepsilon_{zt} \sim i.i.d.N(0, \sigma_z^2) \tag{2.4}$$

Household maximizes his intertemporal utility (2.1) with respect to two constraints (2.2) and (2.3). From the first order conditions and by defining the marginal Tobin's Q as the ratio of the two Lagrangian multipliers, $q_t = \frac{\mu_t}{\lambda_t}$, $m_t = \frac{M_t}{P_t}$ as real money balance, $b_t = \frac{B_t}{P_t}$, as real holding of bonds, $m_{St} = \frac{M_{St}}{P_t^*}$ as real holding of foreign currency, $e_{St} = \frac{S_{St}P_t^*}{P_t}$ as real exchange rate based on free exchange rare and $\pi_t^* = \frac{P_t^*}{P_{t-1}^*}$ as foreign price index inflation, one can get labor supply, demand for real money balances, demand for real amount of foreign currency, conventional consumption Euler equation, an investment Euler equation and capital pricing dynamics as follows:

$$w_t = \frac{\chi L_t^{\eta}}{C_{Gt}^{\gamma}\left(C_t C_{Gt}^{\gamma}\right)^{-\sigma}} \tag{2.5}$$

$$\kappa_m m_t^{-b_m} = \left(\frac{r_t}{1+r_t}\right) C_{Gt}^{\gamma}\left(C_t C_{Gt}^{\gamma}\right)^{-\sigma} \tag{2.6}$$

$$\kappa_s e_{St}^{1-b_s} m_{St}^{-b_s} = \left[e_{St} - E_t\left(\frac{e_{St+1}\pi_{t+1}}{(1+r_t)\pi_{t+1}^{*}}\right)\right] C_{Gt}^{\gamma}\left(C_t C_{Gt}^{\gamma}\right)^{-\sigma} \tag{2.7}$$

$$C_{Gt}^{\gamma}\left(C_t C_{Gt}^{\gamma}\right)^{-\sigma} = \beta E_t \frac{(1+r_t) C_{Gt+1}^{\gamma}\left(C_{t+1} C_{Gt+1}^{\gamma}\right)^{-\sigma}}{\pi_{t+1}} \tag{2.8}$$

$$\begin{aligned} 1 &= (1-b_I) q_t z_t \left[1 - F\left(\frac{I_t}{I_{t-1}}\right) - F'\left(\frac{I_t}{I_{t-1}}\right) . \frac{I_t}{I_{t-1}}\right] \\ &+ (1-b_I) E_t \frac{\pi_{t+1}}{1+r_t} q_{t+1} z_{t+1} F'\left(\frac{I_{t+1}}{I_t}\right) . \left(\frac{I_{t+1}}{I_t}\right)^2 \end{aligned} \tag{2.9}$$

$$q_t = E_t \frac{\pi_{t+1}}{1+r_t}\left[(1-\delta) q_{t+1} + u_{t+1} R_{t+1} - \Psi(u_{t+1})\right] \tag{2.10}$$

2.2 Domestic and Imported Consumption Goods

Aggregate consumption follows a CES index of domestically produced and imported goods according to

$$C_t = \left(a_C^{\frac{1}{\theta_C}} C_{Dt}^{\frac{\theta_C - 1}{\theta_C}} + (1-a_C)^{\frac{1}{\theta_C}} C_{Nt}^{\frac{\theta_C - 1}{\theta_C}}\right)^{\frac{\theta_C}{\theta_C - 1}} \tag{2.11}$$

where C_{Dt} and C_{Nt} denote real consumption of domestic and imported goods respectively. a_C is the share of domestic goods in consumption and θ_C is the elasticity of substitution between domestically produced and imported consumption goods. Total consumption expenditure is

$$P_t C_t = P_{Dt} C_{Dt} + P_{C_N t} C_{Nt} \tag{2.12}$$

where P_{Dt} and $P_{C_N t}$ stand for domestic price index and imported consumption goods price in national currency respectively. Solving (2.11) and (2.12) together for a given C_t gives the consumption price index (for more details about calculations please see Appendix):

$$P_t = \left(a_C P_{Dt}^{1-\theta_C} + (1-a_C)(P_{C_N t})^{1-\theta_C}\right)^{\frac{1}{1-\theta_C}} \tag{2.13}$$

The imported consumption goods follows a CES composite of the goods imported by official exchange rate C_{Nt}^{F} and those imported by free market exchange rate C_{Nt}^{S}:

$$C_{Nt} = \left(a_{C_N}^{\frac{1}{\theta_{C_N}}} (C_{Nt}^{F})^{\frac{\theta_{C_N} - 1}{\theta_{C_N}}} + (1-a_{C_N})^{\frac{1}{\theta_{C_N}}} (C_{Nt}^{S})^{\frac{\theta_{C_N} - 1}{\theta_{C_N}}}\right)^{\frac{\theta_{C_N}}{\theta_{C_N} - 1}} \tag{2.14}$$

where a_{C_N} is the share of goods imported by official exchange rate in total imports of consumption goods and θ_{C_N} is the elasticity of substitution between consumption goods imported by official and free market exchange rates. By assuming the law of one price, the price of goods imported by official exchange rate and those imported by free market exchange rate are $P^F_{Nt} = S_{Ft}P^*_t$ and $P^S_{Nt} = S_{St}P^*_t$ where P^*_t is the price index of foreign economy. Following the same way above, the domestic price of (the aggregate of) imported goods is simply

$$P_{C_N t} = \left(a_{C_N}(P^F_{Nt})^{1-\theta_{C_N}} + (1-a_{C_N})(P^S_{Nt})^{1-\theta_{C_N}}\right)^{\frac{1}{1-\theta_{C_N}}}$$

We define the real exchange rates based on official exchange rate as $e_{Ft} = \frac{S_{Ft}P^*_t}{P_t}$ and nominal official exchange rate depreciation as $d_{Ft} = \frac{S_{Ft}}{S_{Ft-1}}$.

2.3 Final Good Producers

Final good uses the following aggregate CES technology, where intermediate goods, $y_t(i)$, are indexed by $i \in [0,1]$:

$$Y_{Dt} = \left(\int_0^1 y_t(i)^{\frac{1}{\theta_t}}\, di\right)^{\theta_t} \tag{2.15}$$

where θ_t is a stochastic time-varying mark-up shock which is assumed to follow

$$\log\theta_t = (1-\rho_\theta)\log\theta + \rho_\theta\log\theta_{t-1} + \varepsilon_{\theta t}, \qquad \varepsilon_{\theta t} \sim i.i.d.N(0,\sigma^2_\theta) \tag{2.16}$$

The final good producer maximizes its profit. Hence, its problem is

$$\max_{y_t(i)} \quad P_{Dt}\left(\int_0^1 y_t(i)^{\frac{1}{\theta_t}}\, di\right)^{\theta_t} - \int_0^1 P_{Dt}(i)y_t(i)di \tag{2.17}$$

where $P_{Dt}(i)$ is the price of the intermediate good i.

The profit maximization first order condition can be written in the form of a demand function for the intermediate good, $y_t(i)$

$$y_t(i) = \left(\frac{P_{Dt}(i)}{P_{Dt}}\right)^{-\frac{\theta_t}{\theta_t - 1}} Y_{Dt} \tag{2.18}$$

substituting (2.18) into (2.15) and simplifying the result give the domestic goods price index:

$$P_{Dt} = \left(\int_0^1 P_{Dt}(i)^{\frac{1}{1-\theta_t}}\, di\right)^{1-\theta_t} \tag{2.19}$$

2.4 Intermediate Good Producer

Firms producing intermediate goods operate in a monopolistically competitive market. They hire labor and capital from households and pay wages w_t and capital return R_t. Each firm, indexed by $i \in [0,1]$, produces $Y_t^{no}(i)$ units of differentiated output using the following Cobb-Douglas production technology:

$$Y_t^{no}(i) = a_t \left[\tilde{K}_{t-1}(i) K_{Gt-1}^{\psi}\right]^{\alpha} L_{Yt}(i)^{1-\alpha}, \qquad 0 < \alpha < 1 \tag{2.20}$$

where $\tilde{K}_{t-1}(i)$ is the capital services stock which is assumed to be a simple product of capital stock, K_{t-1} and capital utilization, u_t, i.e. $\tilde{K}_{t-1}(i) = u_t K_{t-1}$. K_{Gt-1} is public capital stock. The parameter $\psi \in [0,1]$ determines how the production function of intermediate good is affected by public capital stock. As we will see later, since government seeks to smooth its consumption and only adjusts public investment in case of facing oil shocks, this is the channel through which labor and capital value added is affected by oil shocks. The productivity shock a_t is assumed to follow the following AR(1) process in log form:

$$\log a_t = (1-\rho_a)\log \bar{a} + \rho_a \log a_{t-1} + \varepsilon_{at}, \qquad \varepsilon_{at} \sim i.i.d.N(0, \sigma_a^2) \tag{2.21}$$

Following Kim and Lougani (1992), de Walque et al. (2005) and Medina and Soto (2005), it is assumed aggregate output is generated by the following CES technology in which X_{et} is the use of energy (oil) in the production of $y_t(i)$:

$$y_t(i) = \left[\gamma_y^{\frac{1}{\theta_y}} \left(Y_t^{no}(i)\right)^{\frac{1-\theta_y}{\theta_y}} + (1-\gamma_y)^{\frac{1}{\theta_y}} \left(X_{et}\right)^{\frac{1-\theta_y}{\theta_y}}\right]^{\frac{\theta_y}{1-\theta_y}} - \varrho \tag{2.22}$$

where γ_y is the share of labor and capital in total value added and θ_y is the elasticity of substitution between the corresponding factors of production. ϱ is a fixed cost to ensure that profits are zero in steady state.

Energy price is determined by:

$$P_{et} = (S_{Ft} P_{Ot})^{\tau_e} \tag{2.23}$$

where π_{Ot} is international oil price inflation and $0 < \tau_e < 1$ is the rate of transfer payment on domestic consumption of energy. Consequently, the inflation rate of energy can be written as:

$$\pi_{et} = \left(\frac{S_{Ft} P_{Ot}}{S_{Ft-1} P_{Ot-1}}\right)^{\tau_e} = (d_{Ft} \pi_{Ot})^{\tau_e} \tag{2.24}$$

where d_{Ft} is depreciation rate of official market exchange rate.

From cost minimization problem of intermediate good producing firm i, the demand for labor, the demand for energy and marginal cost of producing $y_t(i)$ are revealed as follows:

$$\alpha w_t L_t(i) = (1-\alpha) R_t \tilde{K}_{t-1}(i) \tag{2.25}$$

$$X_{et}(i) = (1-\alpha)^{-\theta_y} \left(\frac{1-\gamma_y}{\gamma_y}\right) \left(\frac{w_t L_{Yt}}{\mathcal{P}_{et}}\right)^{\theta_y} \left(y_t^{no}(i)\right)^{1-\theta_y} \tag{2.26}$$

$$\begin{aligned} mc_t = \phi_t = & \Bigg\{ \gamma_y^{\theta_y} \left[\alpha^{-\alpha}(1-\alpha)^{-(1-\alpha)} a_t^{-1} R_t^{\alpha} w_t^{1-\alpha} K_{Gt-1}^{-\alpha\psi}\right]^{1-\theta_y} \\ & + (1-\gamma_y)^{\theta_y} \mathcal{P}_{et}^{1-\theta_y} \Bigg\}^{\frac{1}{1-\theta_y}} \end{aligned} \tag{2.27}$$

$$\frac{\mathcal{P}_{et}}{\mathcal{P}_{et-1}} = \frac{\pi_{et}}{\pi_t} \tag{2.28}$$

where the Lagrangian multiplier ϕ_t corresponds to marginal cost of producing intermediate good and $\mathcal{P}_{et} = \frac{P_{et}}{P_t}$ is real price of energy. mc_t is not indexed by i because it is assumed that all firms have identical marginal costs (i.e. strategic substitutability).

There is also a price rigidity type of Calvo (1983). Each period only a fraction $1-\xi$ of them, randomly chosen, can optimally readjust their prices. For the remaining ξ fraction of firms, prices are indexed to past inflation as follows:

$$P_{Dt}(i) = \pi_{Dt-1}^{\tau} P_{Dt-1}(i)$$

where $\pi_{Dt} = \frac{P_{Dt}}{P_{Dt-1}}$ is the gross rate of domestic inflation and τ is the parameter governing the degree of price indexation.

The problem of the firms is to choose a price $P_{Dt}^*(i)$ that maximizes the expected discounted sum of profit:

$$\max_{P_{Dt}(i)} \quad E_t \sum_{j=0}^{\infty} (\xi\beta)^j \frac{\lambda_{t+j}}{\lambda_t} \left[\prod_{k=0}^{j-1} (\pi_{Dt+k})^{\tau} \frac{P_{Dt}^*(i)}{P_{Dt+j}} - mc_{t+j}\right] y_{t+j}(i) \tag{2.29}$$

subject to the sequence of demand constraints:

$$y_{t+j}(i) = \left(\prod_{k=0}^{j-1} (\pi_{Dt+k})^{\tau} \frac{P_{Dt}^*(i)}{P_{Dt+j}}\right)^{-\frac{\theta_{t+j}}{\theta_{t+j}-1}} Y_{Dt+j} \tag{2.30}$$

From (2.19), the aggregate price level is expressed as

$$P_{Dt} = \left[\xi \left(\pi_{Dt-1}^{\tau} P_{Dt-1}\right)^{\frac{1}{1-\theta_t}} + (1-\xi)(P_{Dt}^*)^{\frac{1}{1-\theta_t}}\right]^{1-\theta_t} \tag{2.31}$$

We define the relative optimal domestic price as $p^*_{Dt}(i) = \frac{P^*_{Dt}(i)}{P_{Dt}}$, so the first-order condition is:

$$p^*_{Dt}(i) = \frac{E_t \sum_{j=0}^{\infty} (\xi\beta)^j \lambda_{t+j} mc_{t+j} Y_{Dt+j} \left(\prod_{k=0}^{j-1} \frac{(\pi_{Dt+k})^\tau}{\pi_{Dt+k+1}} \right)^{-\frac{1}{\theta_{t+j}-1}}}{\theta_t E_t \sum_{j=0}^{\infty} (\xi\beta)^j \lambda_{t+j} Y_{Dt+j} \left(\prod_{k=0}^{j-1} \frac{(\pi_{Dt+k})^\tau}{\pi_{Dt+k+1}} \right)^{-\frac{\theta_{t+j}}{\theta_{t+j}-1}}} \tag{2.32}$$

Log-linearizing this and taking into account the aggregate price index given by (2.27) the hybrid New Keynesian Phillips Curve can be drawn in log-linearized form as:

$$\hat{\pi}_{Dt} = \frac{\beta}{1+\beta\tau} E_t \hat{\pi}_{Dt+1} + \frac{\tau}{1+\beta\tau} \hat{\pi}_{Dt-1} + \frac{(1-\beta\xi)(1-\xi)}{(1+\beta\tau)\xi} (\widehat{mc}_t + \hat{\theta}_t) \tag{2.33}$$

where variables with hat denote the percentage deviation from their steady state values.

2.5 Oil Sector

Following Balke et al. (2010), the profuction technology of the oil sector is:

$$Y_{Ot} = a_{Ot} \left[\gamma_O X_{Ot}^{1-\theta_O} + (1-\gamma_O) L_{Ot}^{1-\theta_O} \right]^{\frac{1}{1-\theta_O}} \tag{2.34}$$

The state-owned oil sector use labor L_{Ot} and oil reserves X_{Ot} to produce oil Y_{Ot}. a_{Ot} is the productivity shock in the oil sector captured by an AR(1) process:

$$\log a_{Ot} = (1-\rho_O)\bar{a}_O + \rho_O \log a_{Ot-1} + \varepsilon_{Ot}, \qquad \varepsilon_{Ot} \sim i.i.d.N(0, \sigma_O) \tag{2.35}$$

The next period oil reserves include both additions to reserves and the depletion due to production:

$$X_{Ot+1} = X_{Ot} + G_{Ot} - Y_{Ot} \tag{2.36}$$

G_{Ot} is Gross additions to reserves and is defined as:

$$G_{Ot} = \Phi_O \left(\frac{I_{Xt}}{X_{Ot}} \right) X_{Ot} \tag{2.37}$$

Where I_{Xt} denotes investment in the production of reserves. Both private I_t and government I_{Gt} investment determine I_{Xt}. That is:

$$I_{Xt} = A^I_{Xt} \left[\gamma_{IX} (b_{IG} I_{Gt})^{1-\theta_{IX}} + (1-\gamma_{IX})(b_I I_t)^{1-\theta_{IX}} \right]^{\frac{1}{1-\theta_{IX}}} \tag{2.38}$$

where $A^I_{Xt}$is a technology shock to the production of reserves and b_{IG} is the fraction of public investment in production of oil reserves. Additions to reserves have an adjustment-cost mechanism or $\Phi_O\left(\frac{I_{Xt}}{X_{Ot}}\right)$ whereby $\Phi'_O(\bullet) > 0$ and $\Phi''_O(\bullet) < 0$. In the steady state $\Phi_O\left(\frac{\bar{I_X}}{\bar{X_O}}\right) = \frac{\bar{Y_O}}{\bar{X_O}}$ and

$\Phi'_O\left(\frac{\bar{I_X}}{\bar{X_O}}\right) = 1$. Reserves can be seen as total capital in the oil sector consisting of both capital (oil production infrastructure) and oil in the ground. The level of oil production determines the extent of depreciation of oil-producing capital. The technology shock is governed by:

$$\log A^I_{Xt} = \rho_{IX} \log A^I_{Xt-1} + \varepsilon^I_{Xt}, \qquad \varepsilon^I_{Xt} \sim i.i.d.N(0, \sigma^2_{IX}) \tag{2.39}$$

The decision rule for the production of oil and reserves is set by maximizing the representative agent's utility while holding prices constant. From the FOC of labor, demand for labor in the oil sector is:

$$\frac{W_t}{(1-\gamma_O)\left(\frac{L_{Ot}}{Y_{Ot}}\right)^{-\theta_O}} = P_{Ot} - P_{Xt} \tag{2.40}$$

where P_{Xt} is the user cost of oil (price of reserves). By dividing both sides of 2.40 by P^*_t (because P_{Ot} and P_{Xt} are in foreign currency), the demand for labor in oil sector is

$$\frac{\frac{W_t}{P_t}}{(1-\gamma_O)\left(\frac{L_{Ot}}{Y_{Ot}}\right)^{-\theta_O}} = \frac{P^*_t}{P_t}\frac{P_{Ot}}{P^*_t} - \frac{P^*_t}{P_t}\frac{P_{Xt}}{P^*_t}$$

$$\frac{w_t}{(1-\gamma_O)\left(\frac{L_{Ot}}{Y_{Ot}}\right)^{-\theta_O}} = \mathcal{P}^*_t\mathcal{P}^*_{Ot} - \mathcal{P}^*_t\mathcal{P}^*_{Xt} \tag{2.41}$$

where $\mathcal{P}^*_t = \frac{P^*_t}{P_t}$ is the ratio of foreign price to domestic price index.

Due to the presence of reserves, an intertemporal element is incorporated into the oil producer's supply decision. Using a stochastic discount factor ζ_{Ot+1}, the first-order condition for the production of reserves in real term is:

$$\begin{aligned}\mathcal{P}^*_{Xt} = E_t\Bigg\{\zeta_{Ot+1}\pi^*_{t+1}\Bigg[(\mathcal{P}^*_{Ot+1} - \mathcal{P}^*_{Xt+1})\gamma_O\left(\frac{X_{Ot+1}}{Y_{Ot+1}}\right)^{-\theta_O} \\ + \mathcal{P}^*_{Xt+1}(1 + \Phi_{Ot+1} - \Phi'_{Ot+1}\frac{I_{Xt+1}}{X_{Ot+1}})\Bigg]\Bigg\}\end{aligned} \tag{2.42}$$

(2.41) and (2.42) indicate that expectations of future oil market conditions affect current oil production decisions. The market-clearing conditions in the oil and labor markets are given respectively by:

$$Y_{Ot} = X_{et} + Y^X_{Ot} \tag{2.43}$$

$$L_t = L_{Yt} + L_{Ot} \tag{2.44}$$

Where Y^X_{Ot} is oil exports.

2.6 Non-oil Exporting Sector

For simplicity, it is assumed that the exports of domestic economy or foreign demand for home goods, Y_{Xt} is given by the following demand function

$$Y_{Xt} = a_X \left(\frac{P_{Dt}}{P_t^*}\right)^{-\theta_X} Y_t^* = a_X \left(\frac{\mathcal{P}_{Dt}}{\mathcal{P}_t^*}\right)^{-\theta_X} Y_t^* \tag{2.45}$$

where a_X corresponds to the share of domestic intermediate goods in the consumption basket of foreign agents; and θ_X is the price elasticity of foreign demand.

2.7 Central Bank

The CB issues domestic credit DC_t and holds international reserves FR_t in the form of foreign currency. The money base M is decomposed to these two parts because in commodity exporting economies a major portion of money base is accumulated through FR_t. Noting that FR_t is earned by selling national wealth (here is oil reserves) and it can not be account as seigniorage. As a result, as it is shown in next section, only $\frac{DC_t - DC_{t-1}}{P_t}$ is defined as seigniorage. The CB buys all oil revenue (that is in foreign currency) at official exchange rate S_{Ft} from the government. Then the CB decides how much to supply in the official foreign exchange market or free exchange market. The amount of foreign exchange supplied in the first market is used directly to import essential consumption goods. The other amount supplied in the second market goes directly to household's financial assets and used for the importation of other kinds (than essential) of consumption goods. This last amount is assumed to be a time-varying fraction, $\hbar_t$ of foreign reserves of the CB. It is assumed that there is no operational costs for CB. Therefore, the flow balance sheet of the CB is:

$$\begin{aligned} M_t - M_{t-1} &= (DC_t - DC_{t-1}) + (S_{Ft}FR_t - S_{Ft}FR_{t-1}) - (S_{St}\hbar_t FR_t - S_{St}\hbar_{t-1}FR_{t-1}) \\ &= (DC_t - DC_{t-1}) + (S_{Ft}FR_t - S_{Ft-1}FR_{t-1}) - (S_{St}\hbar_t FR_t - S_{St-1}\hbar_{t-1}FR_{t-1}) - RCB_t \end{aligned} \tag{2.46}$$

where $RCB_t = -(S_{Ft} - S_{Ft-1})FR_{t-1} + (S_{St} - S_{St-1})\hbar_{t-1}FR_{t-1}$ is the direct receipts of government from the central bank. This indeed reflects the revenue that government can have from owning the CB. Furthermore, it is assumed for convenience that the CB's net worth is zero. Therefore, it follows that

$$M_t - DC_t - S_{Ft}FR_t + S_{St}\hbar_t FR_t = M_{t-1} - DC_{t-1} - S_{Ft}FR_{t-1} + S_{St}\hbar_{t-1}FR_{t-1} = 0$$

In terms of domestic goods, the CB balance, for all t, is:

$$m_t = dc_t + e_{Ft}fr_t - e_{St}\hbar_t fr_t \tag{2.47}$$

where $dc_t = \frac{DC_t}{P_t}$ and $fr_t = \frac{FR_t}{P^*_t}$.

2.8 Government

At t, government spends on consumption goods C_{Gt} and investment goods I_{Gt}. As well, it pays for principle and interest on last period bonds B_{t-1} and transfers TA_t, collects taxes T_t, issues domestic currency bonds B_t and receives oil revenues from oil producing firms, $Y_{Ot} = X_{et} + Y^X_{Ot}$ and seigniorage from the CB $(DC_t - DC_{t-1})$. The government budget constraint is so:

$$\begin{aligned}\mathcal{P}_{CGt}C_{Gt} + \mathcal{P}_{IGt}I_{Gt} + (1+r_{t-1})\frac{B_{t-1}}{P_t} + TA_t = T_t + \frac{B_t}{P_t} + \frac{DC_t - DC_{t-1}}{P_t} \\ + e_{Ft}\mathcal{P}^*_{Ot}Y^X_{Ot} + \mathcal{P}_{et}X_{et}\end{aligned} \tag{2.48}$$

where $\mathcal{P}^*_{Ot} = \frac{P_{Ot}}{P^*_t}$, $\mathcal{P}_{CGt} = \frac{P_{CGt}}{P_t}$ and $\mathcal{P}_{IGt} = \frac{P_{IGt}}{P_t}$ are external terms of trade, real price of government consumption and investment goods, respectively.

Aggregate government consumption and investment follow a CES index of domestically produced and imported consumption and investment goods:

$$C_{Gt} = \left(a_{CG}^{\frac{1}{\theta_{CG}}} \left(C^D_{Gt}\right)^{\frac{\theta_{CG}-1}{\theta_{CG}}} + (1-a_{CG})^{\frac{1}{\theta_{CG}}} \left(C^N_{Gt}\right)^{\frac{\theta_{CG}-1}{\theta_{CG}}} \right)^{\frac{\theta_{CG}}{\theta_{CG}-1}} \tag{2.49}$$

$$I_{Gt} = \left(a_{IG}^{\frac{1}{\theta_{IG}}} \left(I^D_{Gt}\right)^{\frac{\theta_{IG}-1}{\theta_{IG}}} + (1-a_{IG})^{\frac{1}{\theta_{IG}}} \left(I^N_{Gt}\right)^{\frac{\theta_{IG}-1}{\theta_{IG}}} \right)^{\frac{\theta_{IG}}{\theta_{IG}-1}} \tag{2.50}$$

where variables with superscript D and N refer to domestic and imported goods, respectively. For simplicity, we assume that the price of both domestic and imported government investment goods are the same as those of consumption. As a result, total consumption and investment of government are:

$$P_{CGt}C_{Gt} = P_{Dt}C^D_{Gt} + P^F_{Nt}C^N_{Gt} \tag{2.51}$$

$$P_{IGt}I_{Gt} = P_{Dt}I^D_{Gt} + P^F_{Nt}I^N_{Gt} \tag{2.52}$$

From (2.49)-(2.52), government consumption and investment price indices are:

$$P_{CGt} = \left(a_{CG}P_{Dt}^{1-\theta_{CG}} + (1-a_{CG})(P^F_{Nt})^{1-\theta_{CG}} \right)^{\frac{1}{1-\theta_{CG}}} \tag{2.53}$$

$$P_{IGt} = \left(a_{IG}P_{Dt}^{1-\theta_{IG}} + (1-a_{IG})(P^F_{Nt})^{1-\theta_{IG}} \right)^{\frac{1}{1-\theta_{IG}}} \tag{2.54}$$

Following Leeper et al. (2010), we model a delay between when government investment is authorized and when the investment becomes available as public capital. To do so, the budget authorized for the government investment at time t is A_{It} and the number of quarters to complete an investment project is N. The law of motion for public capital, K_{Gt}, is then:

$$K_{Gt} = (1-\delta_G)K_{Gt-1} + (1-b_{IG})A_{It-N+1} \tag{2.55}$$

where δ_G is the depreciation rate of government expenditure and the budget authorization process is assumed to follow an AR(1) process

$$\log A_{It} = (1-\rho_A)\log A_I + \rho_A \log A_{It-1} + \iota\varepsilon_t^{\pi O} + \varepsilon_{At}, \quad \varepsilon_{At} \sim i.i.d.N(0,\sigma_A^2) \tag{2.56}$$

where $\varepsilon_t^{\pi O}$ is the international oil price inflation shock (will be explained later). (2.56) indicates that the government investment is directly affected by oil price, i.e. whenever the oil price is high, public investment is high too. Otherwise, as the oil price drops, government rapidly reduces investments.

It is also assumed that the government investment implemented (or outlaid) at time t is given by

$$I_{Gt} = \sum_{n=0}^{N-1} \varphi_n A_{It-n} \tag{2.57}$$

where $\sum_{n=0}^{N-1} \varphi_n = 1$. φ captures the outlay rates of the authorized budget. When $N = 1$, the model does not separate budget authority and outlays, and there is no delay in implementing government investment: $\varphi_0 = 1$ and $I_{Gt} = A_{It}$.

Fiscal policy, for sake of simplicity, is exogenous and follows an AR(1) process

$$\log C_{Gt} = (1-\rho_G)\log C_G + \rho_G \log C_{Gt-1} + \varepsilon_{Gt},\, \varepsilon_{Gt} \sim i.i.d.N(0,\sigma_G^2) \tag{2.58}$$

Following the government problem, the evolution of the CB's net foreign reserves (in terms of domestic currency) is as follows:

$$(1-\hbar_t)FR_t = (1-\hbar_{t-1})FR_{t-1} + P_{Ot}^* Y_{Ot}^X - P_t^*(C_{Nt}^F + C_{Gt}^N + I_{Gt}^N) \tag{2.59}$$

2.9 Foreign Economy

The foreign country is specified by three equations of international oil price inflation π_{Ot}, foreign economy consumer price inflation π_t^* and and foreign economy's income Y_t^*. It is assumed that these variables are determined by AR(1) processes as follows:

$$\log \pi_{Ot} = (1-\rho_{\pi_O})\log \pi_O + \rho_{\pi_O} \log \pi_{Ot-1} + \varepsilon_t^{\pi_O} \; \varepsilon_t^{\pi_O} \sim i.i.d.N(0,\sigma_{\pi_O}^2) \tag{2.60}$$

$$\log \pi_t^* = (1-\rho_{\pi^*}) \log \pi^* + \rho_{\pi^*} \log \pi_{t-1}^* + \varepsilon_t^{\pi^*} \qquad \varepsilon_t^{\pi^*} \sim i.i.d.N(0, \sigma_{\pi^*}^2) \tag{2.61}$$

$$\log Y_t^* = (1-\rho_{Y^*}) \log Y^* + \rho_{Y^*} \log Y_{t-1}^* + \varepsilon_t^{Y^*} \qquad \varepsilon_t^{Y^*} \sim i.i.d.N(0, \sigma_{Y^*}^2) \tag{2.62}$$

2.10 The aggregate resource constraint

The real GDP identity is:

$$Y_t = (C_{Dt} + C_{Nt}) + I_t + \left(C_{Gt}^D + C_{Gt}^N\right) + \left(I_{Gt}^D + I_{Gt}^N\right) + Y_{Ot} + Y_{Xt} - \aleph_t \tag{2.63}$$

where

$$\aleph_t \equiv C_{Nt} + C_{Gt}^N + I_{Gt}^N \tag{2.64}$$

is total imports.

The domestic goods market clearing condition is

$$Y_t^D = C_{Dt} + I_t + C_{Gt}^D + I_{Gt}^D + Y_{Xt} + \Psi(u_t) K_{t-1} \tag{2.65}$$

3 CB's Intervention Policies

From household budget constraint (2.2), government budget constraint (2.48), aggregate resource constraint (2.63) and the evolution of net foreign reserves (2.59), the equilibrium condition in free exchange market is

$$\hbar_t FR_t - \hbar_{t-1} FR_{t-1} + P_t^* Y_{Xt} = M_{St} - M_{St-1} + P_t^* C_{Nt}^S \tag{3.1}$$

(3.1) indicates that, in each period, the fraction of foreign reserves that the CB decides to supply in the free market, plus the foreign currency provided by goods exporters, is equal to the change in household's demand for foreign currency plus imported goods at the free market exchange rate.

The CB minimizes the spread between the free and official exchange rates by intervening in the free market as follows. The CB changes the fraction of its reserves $\hbar_t$ in response to the ratio of free market exchange rate over official exchange rate $\left(\frac{S_{St}}{S_{Ft}}\right)$. We assume that the CB affects $\hbar_t$ by changing $\omega_\hbar$ in the following reaction function:

$$\hbar_t = \frac{\frac{S_{St}}{S_{Ft}}}{1 + \omega_\hbar \frac{S_{St}}{S_{Ft}}} \nu_t \tag{3.2}$$

where $\omega_\hbar$ is a parameter which governs steady state value of $\hbar$: the higher $\omega_\hbar$, the lower the steady state of $\hbar$. ν_t is a shock to the CB's intervention in free exchange market which follows an AR(1):

$$\log \nu_t = (1-\rho_\nu)\log \nu + \rho_\nu \log \nu_{t-1} + \varepsilon_{\hbar t}, \qquad \varepsilon_{\hbar t} \sim i.i.d.N(0,\sigma_\hbar^2) \tag{3.3}$$

If there are an unified exchange rate system i.e. $\frac{S_{St}}{S_{Ft}} = 1$), only $\omega_\hbar$ determines the degree of CB's intervention in the free market to keep the unified exchange rate system. In this situation

$$m_{St} = \frac{m_{St-1}}{\pi_t^*} + Y_{Xt} - C_{Nt}^S \tag{3.4}$$

This equation indicates that foreign currency accumulation in households' portfolio is affected by non-oil exports and unofficial imports.

In this paper, the CB has two other policy tools to intervene in the market. First, in the money market, the CB gets involve to achieve an operational target for monetary growth. To do so, the CB responds to i) the deviation of the CPI inflation rate (π_t) from a time-varying inflation target (π_{Tt}) and ii) the deviation of GDP from its steady state. As a result, monetary policy is performed with the following log-linearized rule:

$$\hat{\dot{m}}_t = \rho_{\dot{m}}\hat{\dot{m}}_{t-1} + (1-\rho_{\dot{m}})\left[\omega_\pi(\hat{\pi}_t - \hat{\pi}_{Tt}) + \omega_y \hat{y}_t\right] + \vartheta_t \tag{3.5}$$

where

$$\hat{\dot{m}}_t = \hat{d}c_t - \hat{d}c_{t-1} + \hat{\pi}_t \tag{3.6}$$

is the growth rate of nominal domestic credit and ϑ_t is a monetary growth rate shock. In PPI inflation targeting, monetary policy rule changes to

$$\hat{\dot{m}}_t = \rho_{\dot{m}}\hat{\dot{m}}_{t-1} + (1-\rho_{\dot{m}})\left[\omega_\pi(\kappa_\pi\hat{\pi}_{Dt} + (1-\kappa_\pi)\hat{\pi}_{Ot} - \hat{\pi}_{Tt}) + \omega_y \hat{y}_t\right] + \vartheta_t \tag{3.7}$$

where κ_π is the share of non-oil sector in total output.

Second, the rate of depreciation of official exchange rate. This rate responds to the same variables above as well as the official real exchange rate and its depreciation. As a result, the rate of depreciation of official exchange rate is:

$$\hat{d}_{Ft} = \rho_d\hat{d}_{Ft-1} + (1-\rho_d)\left[\varpi_\pi(\hat{\pi}_t - \hat{\pi}_{Tt}) + \varpi_y\hat{y}_t + \varpi_e\hat{e}_{Ft} + \varpi_{\Delta e}\Delta\hat{e}_{Ft}\right] + \zeta_t \tag{3.8}$$

where ζ_t is a exchange rate shock. As before, when there is PPI inflation targeting, the measure of inflation target will be $\kappa_\pi\hat{\pi}_{Dt} + (1-\kappa_\pi)\hat{\pi}_{Ot}$. The time-varying inflation target is assumed to follow the process

$$\log \pi_{Tt} = (1-\rho_\pi)\log \pi_T + \rho_\pi \log \pi_{Tt-1} + \varepsilon_{\pi t} \qquad \varepsilon_{\pi t} \sim i.i.d.N(0,\sigma_\pi^2) \tag{3.9}$$

4 Bayesian estimation

In this section, we estimate the parameters of the model for Iran. We use the Metropolis–Hastings algorithm with 10 parallel chains of length 1.5 million to extract the posterior density of the parameters. The sample period includes 100 quarterly observations spanning from 1990:1 to 2017:4. The data in sample includes growth rate of non-oil real Gross Domestic Product (GDP), growth rate of oil sector value added, Producer Price Index Inflation, private investment, government consumption, government investment, nominal domestic credit (money base minus net foreign reserves) growth rate, official exchange rate depreciation, free market exchange rate depreciation, OPEC basket oil price inflation, United States CPI inflation and real GDP. The growth rate of non-oil GDP is defined as $\dot{y}_t^{no} = \frac{y_t^{no} - y_{t-4}^{no}}{y_{t-4}^{no}}$. Private consumption, private investment, government consumption and investment gaps are generated using the Hodrick and Prescott filter with $\lambda = 677$ as Einian and Barakchian (2014) suggest. We define the growth rate of X_t as $\log \frac{X_t}{X_{t-4}}$. All variables in the model are expressed as the logarithmic deviation from the steady state and the corresponding data are used from the time series database of central bank of Iran website[5]

Table 1 presents the prior distribution[6], mean and standard deviation as well as the resulting Bayesian estimates of the parameters, including the posterior mode, posterior mean, posterior standard deviation and the corresponding 90% confidence interval. Figure 2 shows the prior and posterior distribution of the parameters. The prior mean of all variables are based on Tavakolian (2016).

According to Table 1, the Bayesian estimation of η suggests that labor supply in Iran is inelastic: $\frac{1}{\eta} = \frac{1}{4.2422} = 0.2357$. Since the estimation of elasticity of intertemporal substitution of consumption is $\frac{1}{\sigma} = \frac{1}{1.0596} = 0.944 \simeq 1$, it can be said that logarithmic form for consumption can be used instead of constant relative risk aversion (CRRA). According to the estimation of γ, one percent increase in public consumption is equivalent to 0.2029 percent increase in private consumption in utility term. The interest elasticity of real balances and demand for foreign currency based on estimated mode of b_m and b_S is less than unity, 0.632 and 0.717 respectively, implying inelastic demand for both domestic and foreign currencies.

The mode estimated value of elasticity of investment adjustment cost, $\epsilon = F^{''}(1)$ and elsticity

[5]http://tsd.cbi.ir/ One should be careful when using official exchange rate depreciation of Iran in estimating DSGE models because such models cannot capture structural breaks in data. This is because there are two unification policies during the sample in estimating the model: The first is on 1993-1994 and the second on 2002-2004. To rule out these two structural breaks from data, we introduce two dummy variables and regress the official exchange rate depreciation on them and use the resulting residual instead of official exchange rate depreciation in estimating the model.

[6]Regarding the choice of prior distributions and calibrated parameters, this paper follows the usual conventions in the DSGE modeling literature. In other words, given the distributional characteristics of each parameter, an appropriate prior distribution is chosen. For example, the beta distribution is characterized by mean, standard deviation and upper and lower bounds. Therefore, this distribution is suitable for the estimation of those parameters expected to be within a given range (e.g. 0 to 1). On the other hand, we use the Gama distribution, which has a positive domain ranging from 0 to infinity. The use of a normal distribution instead of the Gama distribution in these circumstances may distort the estimated parameter values.

Table 1: The prior and posterior distributions of parameters

	Prior distribution		Posterior distribution			90% HPD interval	
Parameter	type	mean	mean	mode	std deviation	10%	90 %
η	Gamma	2.890	4.2162	4.2422	0.3	3.6945	4.7566
σ	Gamma	1.197	1.0117	1.0596	0.05	0.9419	1.0811
γ	Gamma	0.191	0.1911	0.2029	0.01	0.1748	0.2076
b_m	Gamma	1.096	1.5164	1.5824	0.05	1.4244	1.6081
b_s	Gamma	1.300	1.4030	1.3955	0.05	1.3199	1.4852
ϵ	Gamma	0.018	0.0209	0.0209	0.001	0.0172	0.0246
$\varkappa$	Gamma	4.789	5.1912	5.0712	0.2	4.8657	5.5164
θ_y	Gamma	0.492	0.4872	0.4859	0.02	0.4548	0.5196
θ_o	Gamma	0.303	0.3945	0.4045	0.02	0.3550	0.4344
ϕ_o	Gamma	1.000	0.9973	0.9519	0.06	0.8992	1.0954
θ_x	Gamma	2.900	2.7911	2.8220	0.1	2.6340	2.9484
θ_C	Gamma	2.904	2.8062	2.7028	0.1	2.6483	2.9629
θ_{CG}	Gamma	5.500	5.3047	5.2595	0.15	5.0663	5.5420
θ_{IG}	Gamma	1.466	1.4511	1.4593	0.09	1.3075	1.5975
ω_π	Normal	-1.500	-2.7157	-2.5732	0.2	-2.9818	-2.4453
ω_y	Normal	-1.500	-0.6901	-0.6315	0.2	-0.9128	-0.4727
ϖ_π	Normal	-0.400	-0.3892	-0.3806	0.02	-0.4223	-0.3560
ϖ_y	Normal	-0.800	-0.8130	-0.8086	0.03	-0.8608	-0.7649
ϖ_e	Normal	-1.500	-1.8666	-1.7808	0.2	-2.1078	-1.6179
β	Beta	0.969	0.9408	0.9359	0.005	0.9354	0.9463
α	Beta	0.603	0.6015	0.6053	0.01	0.5858	0.6174
ψ	Beta	0.100	0.0991	0.0973	0.005	0.0909	0.1071
τ	Beta	0.658	0.6481	0.6456	0.03	0.5978	0.6984
τ_e	Beta	0.600	0.6041	0.5775	0.03	0.5549	0.6536
ξ	Beta	0.756	0.5374	0.5336	0.02	0.5039	0.5721
$\rho_{\dot{m}}$	Beta	0.400	0.3922	0.4058	0.02	0.3596	0.4247
ρ_d	Beta	0.700	0.6925	0.6880	0.02	0.6597	0.7261
ρ_{π_o}	Beta	0.270	0.2985	0.2935	0.02	0.2642	0.3327
ρ_z	Beta	0.800	0.6511	0.6472	0.02	0.6170	0.6867
ρ_θ	Beta	0.800	0.6824	0.6985	0.02	0.6476	0.7172
ρ_a	Beta	0.800	0.9249	0.9280	0.02	0.9121	0.9377
ρ_O	Beta	0.250	0.2838	0.2859	0.02	0.2490	0.3186
ρ_A	Beta	0.800	0.4835	0.4648	0.03	0.4289	0.5383
ρ_{CG}	Beta	0.800	0.7359	0.7231	0.03	0.6779	0.7944
ρ_ν	Beta	0.800	0.7997	0.8230	0.03	0.7569	0.8428
ρ_ϑ	beta	0.800	0.7977	0.7910	0.053	0.7522	0.8442
ρ_ζ	Beta	0.800	0.7350	0.7163	0.03	0.6826	0.7875
ρ_{π_T}	Beta	0.800	0.7992	0.7947	0.01	0.7502	0.8489
ρ_{π^*}	Beta	0.270	0.2802	0.2887	0.01	0.2632	0.2970
ρ_{y^*}	Beta	0.270	0.2787	0.2736	0.02	0.2619	0.2954
σ_{π^*}	InvGamma	0.01	0.0100	0.0098	∞	0.0089	0.0111
σ_{y^*}	InvGamma	0.01	0.0050	0.0047	∞	0.0044	0.0055
σ_{π_O}	InvGamma	0.01	0.2367	0.2266	∞	0.2107	0.2624
σ_z	InvGamma	0.01	1.3865	1.3830	∞	1.1513	1.6156
σ_θ	InvGamma	0.01	1.0719	1.0828	∞	0.8646	1.2710
σ_a	InvGamma	0.01	0.7076	0.6498	∞	0.5786	0.8357
σ_o	InvGamma	0.01	2.3190	2.1894	∞	1.8536	2.7699
σ_A	InvGamma	0.01	3.7089	3.7394	∞	3.2992	4.1048
σ_{CG}	InvGamma	0.01	0.1138	0.1132	∞	0.1008	0.1262
$\sigma_\hbar$	InvGamma	0.01	0.7124	0.7009	∞	0.6233	0.8020
$\sigma_{\dot{m}}$	InvGamma	0.01	0.1347	0.1371	∞	0.1157	0.1532
σ_d	InvGamma	0.01	0.3748	0.3779	∞	0.3257	0.4216

of capital utilization cost, $\varkappa = \frac{\Psi'(1)}{\Psi''(1)}$ are 0.0209 and 0.1972 respectively which are compatible with highly volatile investment. The Bayesian estimation of mode value of elasticity of substitution between factors of production, $\theta_y = 0.4859$ reveals a low degree of substitution between factors of production in Iran. The same result is found for elasticity of substitution between oil reserves and labor in oil producing sector.

The prior mean for elasticity of substitution between domestically produced and imported consumption and investment in both private and public sectors are found based on steady state values of relative prices and the share of corresponding share of domestic goods in total goods. The resemblance of prior and posterior densities of these parameters show that the procedure used in calculating prior mean is reliable. We use the same prior mean for both inflation and output parameters in monetary policy rule, ω_π and ω_y and normal prior density to capture indifferent preference of monetary authorities toward targets. However, the estimated mode value of these parameters reveals a high degree of tendency toward inflation rather than output: -2.5732 compared to -0.6315. On the contrary, monetary authority reacts less against inflation than recession because the absolute value mode estimation of ϖ_π is less than ϖ_y. $\varpi_e = -1.7808$ shows that the CB reacts more to real exchange rate than other targets.

Posterior mode of intertemporal discount factor, β, suggests that steady state real interest rate in Iran is around 27 percent. The share of capital in output, α is estimated to be 60% which is very close to its prior mean based on macroeconomic data. The Bayesian estimation of $\psi = 0.0973$ means that the elasticity of output to public capital is $\alpha\psi = 0.6053 \times 0.0973 \simeq 0.059$, that is one percent increase in public investment raises output by 0.058 percent. The price inflation indexation parameter, τ is estimated to be 0.6456 which is very close to its prior mean, that is one percent increase in inflation rate results in 0.6456 increase in next period inflation rate. The estimated mode value of rate of transfer payment on domestic consumption of energy, τ_e is 0.5775, that is one percent increase in international oil price results in 0.5775 percent increase in domestic energy price. The Bayesian estimation of degree of price rigidity is relatively low for Iran ($\xi = 0.5336$) which is close to what Hemmaty and Bayat (2013) find.

The ratio of steady state variables are calibrated based on macroeconomic data of Iran. We use the parameters calibrated in Balke et al. (2010), to calibrate the steady state values and parameters of oil sector. We assume that the outlay rate of the authorized budget is zero for the first quarter, only 25% of it implements in the first year and the remaining 75% is outlaid in next two years: i.e. $\varphi_0 = 0, \varphi_i = 0.25/3,\ i = 1, 2, 3$ and $\varphi_i = 0.75/8,\ i = 4, ..., 11$. The steady state value of price index of private investment is calibrated using the ratio of nominal private investment to real private investment. The same procedure is used for other price indexes. The share of domestic goods in consumption, a_C, is calibrated based on the share of non-tradable components of consumer price index[7]. The share of domestic goods in private and government investments and government consumption are calibrated based on the share of total imports to

[7]https://cbi.ir/simplelist/13587.aspx

GDP.

5 Results

5.1 IRFs

We consider four scenarios. Two first scenarios are: the dual-exchange rate system combined with CPI and PPI inflation targeting in which the CB applies three policy instruments, $\dot{m}_t$, d_F and $\hbar$. Two other scenarios are: unified exchange rate regime (official exchange rate is equal to free market exchange rate, thus, official and free exchange markets merges together) combined with CPI and PPI inflation targeting. A collections of impulse response functions to selected structural shocks are shown in Figures 3-10. All Figures shows responses to one standard deviation positive orthogonalized innovations to the vector of structural shocks, computed by using the VAR representation of the model. All model parameters are fixed at the corresponding posterior mode values and the variance-covarinace matrix is transformed into a diagonal form.

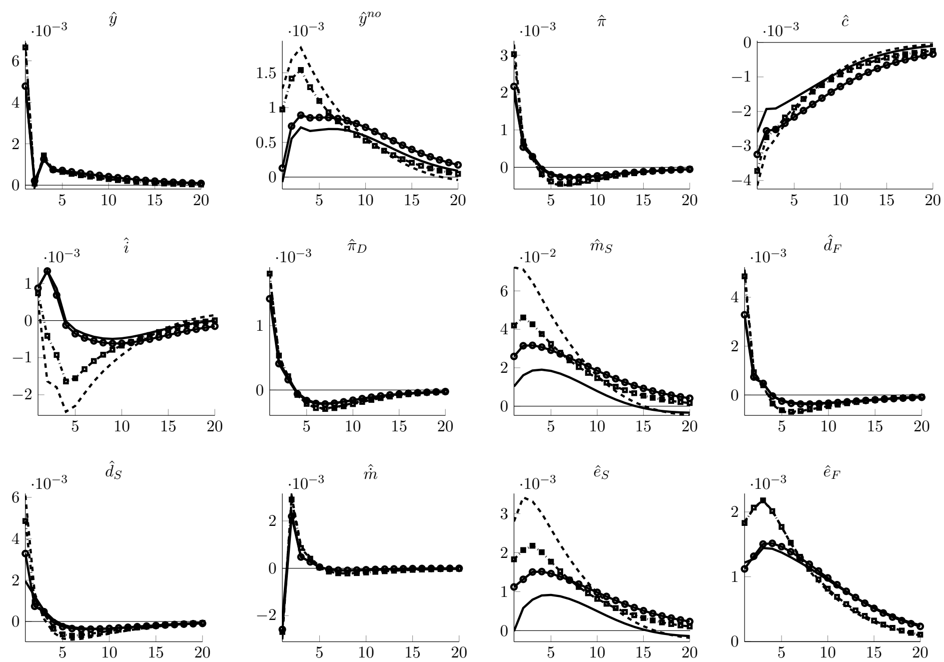

Figure 3: Impulse Response to $\varepsilon_{\dot{m}}$. CPIT-DUAL: Solid, PPT-DUAL: Dashed, CPIT-UNIFIED: Circle, PPT-UNIFIED: Square.

Figure 3 shows the impulse responses to monetary policy shock $\varepsilon_{\dot{m}}$. A positive monetary policy shock leads to a higher inflation, higher oil and non-oil output, more depreciation of domestic currency and real exchange rate and higher demand for foreign currency. A positive monetary policy innovation has higher nominal and real effects in PPIT than in CPIT under both unified and dual-exchange rate environment. The significant difference between scenarios can be seen in monetary policy impact on non-oil sector output, which is more affected under

PPIT. The CPIT and dual-exchange rate system lead to the lowest response to monetary policy. Under CPIT, free real exchange rate increases less than that under PPIT, regardless of exchange rate regime. This happens because the CB targets CPI inflation which is used in the real exchange rate definition. This results in higher response of free market exchange rate under PPIT. Therefore, demand for foreign currency is less under CPIT. In addition, official exchange rate reacts more to monetary policy shock under unified exchange rate regime and PPIT. The figure also shows that the positive impact of expansionary monetary policy on investment is more under CPIT.

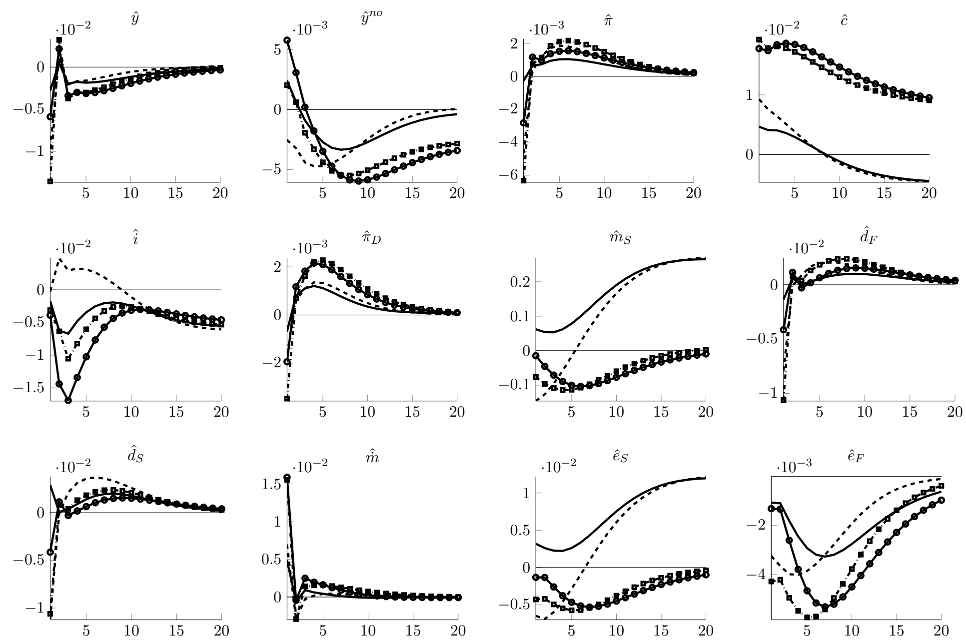

Figure 4: Impulse Response to ε_{π_o}. **CPIT-DUAL: Solid, PPT-DUAL: Dashed, CPIT-UNIFIED: Circle, PPT-UNIFIED: Square.**

Figure 4 displays impulse responses for oil price inflation shock ε_{π_o}. This shock immediately boosts oil output. This results in a rise in government oil revenues and the central bank's foreign assets. The latter is followed by an improvement in the balance of payments and an appreciation of domestic currency. The rise in the central bank's foreign assets increases the monetary base which thus increases inflation. Higher inflation also results in less investment. Under the unified exchange rate system, an oil price inflation shock exerts noticeably more fall in non-oil manufacturers. in the dual-exchange rate environment, oil price inflation shocks can destabilize the economy and create relatively deeper cycles. In other words, the so called Dutch disease is more tangible under dual-exchange rate system than the other one. Due to losing a policy instrument by CB, such a shock results in relatively higher inflation in very short term under unified system. However, the CB can better stabilize inflation in longer term in unified than dual system. Higher inflation results in higher official exchange rate depreciation. The substantial increase in inflation than that of official exchange rate results in a decrease in real exchange rate. The higher official exchange rate and inflation also increase the expected exchange rate depreciation in the free market. This results in a higher free market exchange rate and higher intervention of the CB in this market.

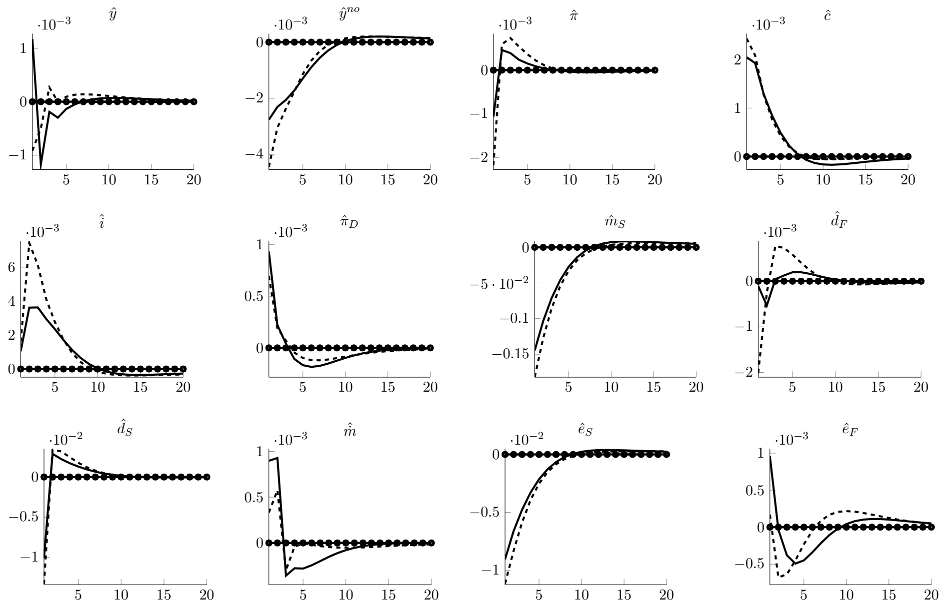

Figure 5: Impulse Response to $\varepsilon_{\hbar}$. **CPIT-DUAL: Solid, PPT-DUAL: Dashed, CPIT-UNIFIED: Circle, PPT-UNIFIED: Square.**

Since there is no CB intervention in unified exchange rate scenario, figure 5 shows the impulse response functions to a positive free market exchange rate policy, $\varepsilon_{\hbar}$, only in dual-exchange rate case. A higher intervention of the CB in the free market through supplying more fraction of foreign reserves in this market reduces the free market exchange rate. This, as well, leads to a higher demand for foreign currency and a national currency appreciation. These channels all together reduce the inflation rate and increase the official real exchange rate. A large drop in free market exchange rate results in lower free real exchange rate. Although this policy have a small positive effect on total output in first period, lower nominal exchange rate (national currency appreciation) deteriorates non-oil exports. This causes lower non-oil output in short term. The national currency appreciation however induces a contraction in investment prices, higher investment and therefore, higher output in medium term.

The impulse responses to a one standard deviation shock to productivity, ε_a, are depicted in Figure 6. This shock impacts on the domestic economy by boosting both labor and capital productivity in the production of intermediate goods. As a result, real marginal cost falls and this, in turn, reduces producer prices and hence inflation. Due to rising output/income and falling prices, private consumption and investment exhibit oscillatory behavior. With an appreciation of the domestic currency, and an increase in the real exchange rate, output is stimulates. The real exchange rate and its volatility increase more under the dual-exchange rate system than under unified exchange rate regime. In medium term, official exchange rate appreciation reduces expected exchange rate in the free market. This results in a lower free market exchange rate and less intervention of the CB in this market. When productivity shock hits the economy, cyclicality of the major macroeconomic variables is considerably more under dual-exchange rate regime.

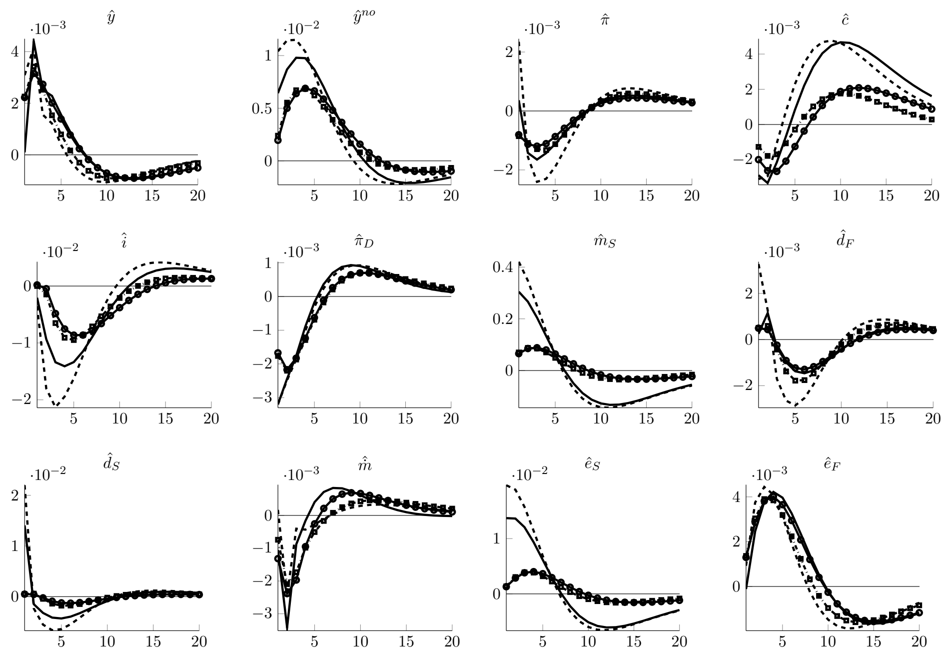

Figure 6: Impulse Response to ε_a. **CPIT-DUAL: Solid, PPT-DUAL: Dashed, CPIT-UNIFIED: Circle, PPT-UNIFIED: Square.**

Impulse responses for a positive official exchange rate policy shock, ε_d, are depicted in Figure 7. The higher official exchange rate depreciation has a positive impact on output in short run. However, after two quarters it turns to negative. Indeed, in short term the higher real exchange rate, by increasing export, results in higher output. In longer term, the higher exchange rate leads to higher imported investment prices, less investment and output. Such a policy also results in a higher inflation, higher expected free market exchange rate and therefore, higher demand for foreign currency in this market. This forces the CB to intervene more in this market. As can be seen, there is a significant difference between impulse responses in unified and dual-exchange rate regimes. This indicates that the economy is more cyclical under dual regime.

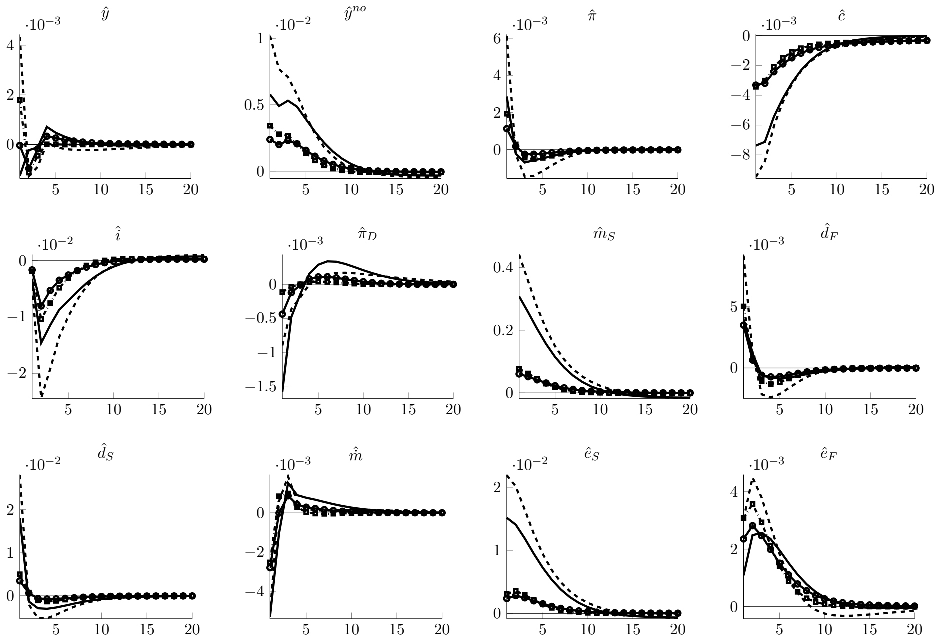

Figure 7: Impulse Response to ε_d. **CPIT-DUAL: Solid, PPT-DUAL: Dashed, CPIT-UNIFIED: Circle, PPT-UNIFIED: Square.**

The set of impulse responses, arising from one standard deviation shock in the mark-up, ε_θ, is shown in Figure 8. A positive shock reduces substitutability between the variety of differentiated domestically produced intermediate goods. As well, the sock drives up the mark-ups charged by the intermediate good producers. As a result, the domestic price inflation jumps up. This leads to a lower real exchange rate and the initial drop in exports. At the same time, consumers shift from relatively more expensive domestic goods to the cheaper foreign goods. All these together lead to a slump in both non-oil and total output. Consequently, the resulting boosted inflation leads to a higher official and free market exchange rates and more intervention of the CB in free foreign currency market. Although nominal variables have same responses in both scenarios, real variables meet less volatility under the unified exchange rate system. From this point, reduced economic activity drives the marginal cost down, compensating for the initial jump in mark-ups. In addition, domestic prices start falling, the real exchange rate increases and the exports rebound.

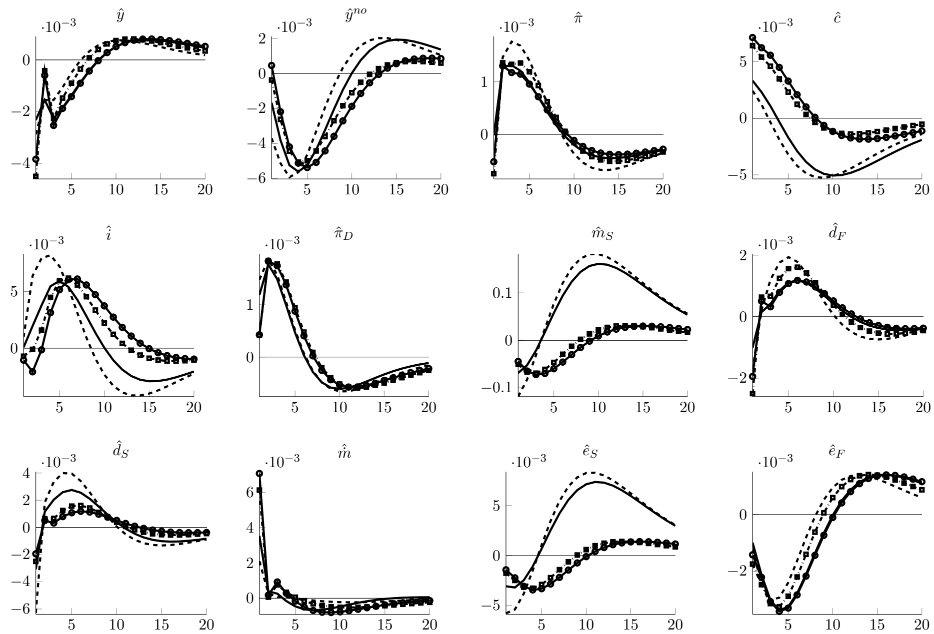

Figure 8: Impulse Response to ε_θ. **CPIT-DUAL: Solid, PPT-DUAL: Dashed, CPIT-UNIFIED: Circle, PPT-UNIFIED: Square.**

Figure 9 presents the set of impulse responses to one standard deviation shock in oil production technology[8], ε_O. A positive technology shock to oil sector production boosts oil production in this sector leading to immediate increase in total output. Boosted oil production and oil revenues help the policy maker to control inflation through higher imports. This also leads to build-up of massive foreign reserves contributing to national currency appreciation. The lower exchange rate in official market decreases expected exchange rate in free market. This results in the free rate appreciation and as well, less demand for foreign currency in this market. The short term disinflation and national appreciation together with the higher real exchange rate boost non-oil exports and investment. This results in higher non-oil output. However, such a honeymoon ends with the sediment of foreign reserves in the CB balance sheet which results in a higher money supply, higher inflation, decreasing investment, lower real exchange rate and non-oil exports, higher free market exchange rate and increasing demand for foreign currency in free market. Although, there is same response of real sector to such a shock in all scenarios in very short term, but in longer term the economy recovers more rapidly under unified system than the other one.

[8]Here, we discuss a positive oil production technology shock, but, a negative technology shock can be interpreted as oil sanction which might be more relevant in recent years of Iran.

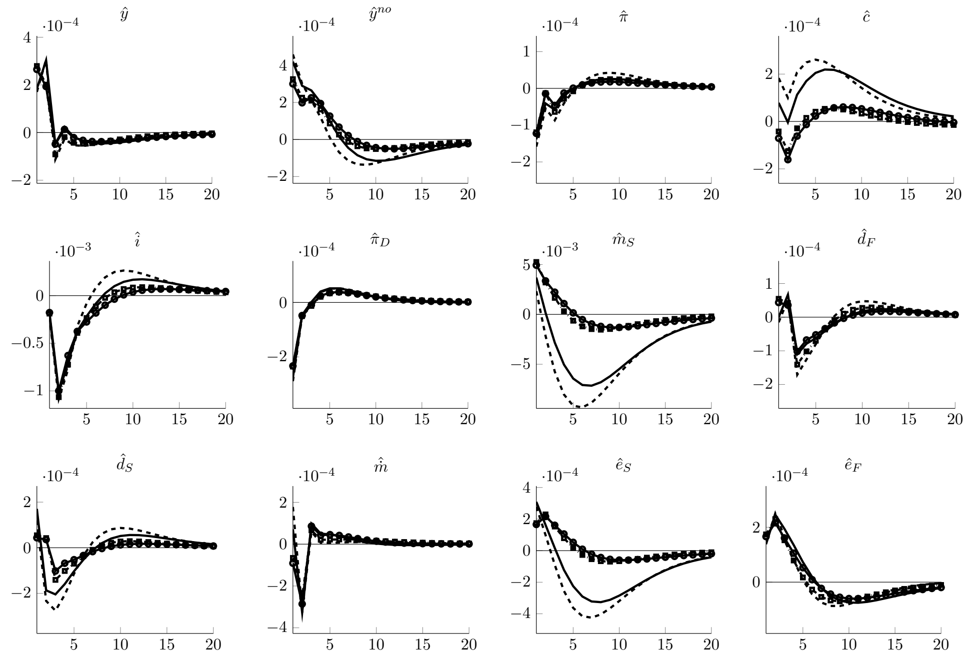

Figure 9: Impulse Response to ε_O. **CPIT-DUAL: Solid, PPT-DUAL: Dashed, CPIT-UNIFIED: Circle, PPT-UNIFIED: Square.**

Finally, Figure 10 presents impulse response functions for the budget authorized for government investment, ε_A. Here, we assume an implementation delay of $N = 12$. This implies 12 quarters (4 years) to build-up public capital after the budget is authorized for government investment. The figure shows that when there is an implementation delay, due to an increase in government investment, non-oil output increases immediately while PPI inflation and investment decrease. A higher government investment results in more demand for foreign currency to import investment goods. This results in a higher CPI inflation and less intervention in the free market. In consequence, this causes a higher expected depreciation of free market exchange rate and more demand in this market. As depicted in the figure, the volatility of variables is higher under dual-exchange rate system.

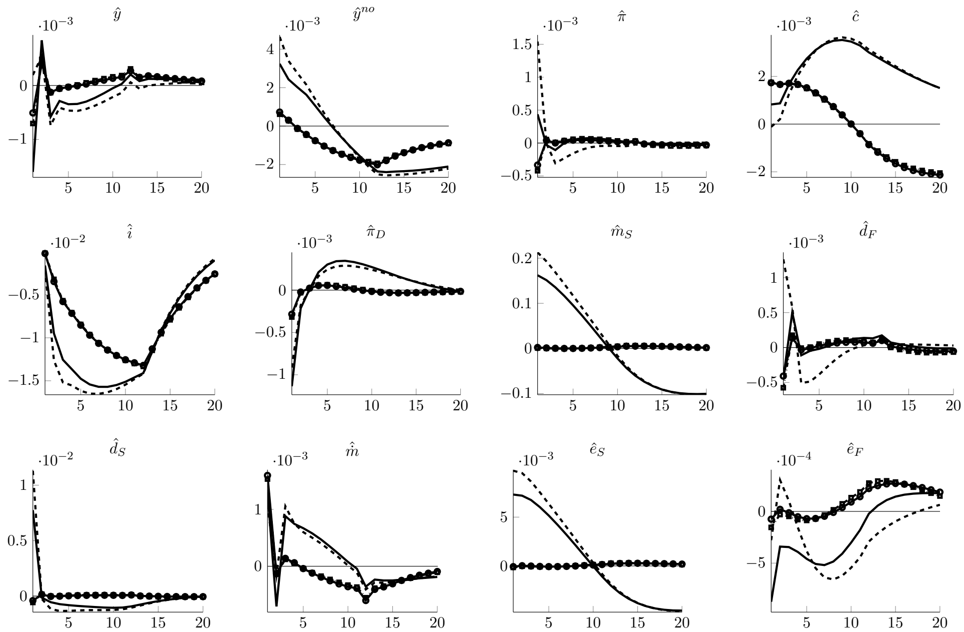

Figure 10: Impulse Response to ε_A. **CPIT-DUAL: Solid, PPT-DUAL: Dashed, CPIT-UNIFIED: Circle, PPT-UNIFIED: Square.**

5.2 Loss Function

We assess the model by using a welfare analysis based on a structural loss function. De Paoli (2009), following Benigno and Benigno (2006), shows that a second order approximation of households' utility can be represented as a loss function. So the loss function is:

$$l = E_0 \sum_{t=0}^{\infty} \frac{1}{2}\beta^t \left[\Upsilon_y \hat{y}_t^2 + \Upsilon_\pi \hat{\pi}_t + \Upsilon_e \widehat{RER}_t^2\right] \tag{5.1}$$

where $\widehat{RER}_t$ is the real exchange rate and Υ_y, Υ_π and Υ_e are the weights that monetary authority gives to the output target values, inflation and real exchange rate, respectively. Since in this model there are two markets for foreign currencies, the real exchange rate is defined as a weighted average of official and free real exchange rates: e_F and e_S. Therefore, the modified form of loss function for the CPI inflation targeting monetary policy is

$$l = E_0 \sum_{t=0}^{\infty} \frac{1}{2}\beta^t \left[\Upsilon_y \hat{y}_t^2 + \Upsilon_\pi \hat{\pi}_t + \Upsilon_e(\kappa_S \hat{e}_{Ft}^2 + (1-\kappa_S)\hat{e}_{St}^2)\right] \tag{5.2}$$

As well, the loss function for PPI inflation targeting is:

$$l = E_0 \sum_{t=0}^{\infty} \frac{1}{2}\beta^t \left[\Upsilon_y \hat{y}_t^2 + \Upsilon_\pi(\kappa_\pi \hat{\pi}_{Dt} + (1-\kappa_\pi)\hat{\pi}_{Ot}) + \Upsilon_e(\kappa_S \hat{e}_{Ft}^2 + (1-\kappa_S)\hat{e}_{St}^2)\right] \tag{5.3}$$

Table 2: Sensitivity analysis of loss function with CPI inflation measure

Model	**Loss**		
	$\Upsilon_\pi = 1, \Upsilon_y = 1, \Upsilon_e = 1$	$\Upsilon_\pi = 1.5, \Upsilon_y = 1, \Upsilon_e = 1$	$\Upsilon_\pi = 1, \Upsilon_y = 1.5, \Upsilon_e = 1$
CPIT DUAL	0.2095	0.21958	0.22976
CPIT UNIFIED	0.033895	0.039712	0.042522
PPT DUAL	0.14668	0.15493	0.15599
PPT UNIFIED	0.030858	0.036776	0.038309

where κ_S is the share of goods imported by official exchange rate.

The loss measures in equation 5.2 and 5.3 are Losses in CPIT and PPIT monetary policy combined with dual-exchange rate system; in unified exchange rate system $\hat{e}_{Ft} = \hat{e}_{St}$ and κ_S is neutral. We calibrate $\kappa_\pi = 0.6$ based on the share of the oil sector in GDP and, as well, $\kappa_S = 0.4$ based on imports value by the official exchange rate. The sensitivity analysis of these two parameters will be discussed at the end of this section.

We first focus on the sensitivity analysis of monetary authority's weights on output, inflation and real exchange rate. This allows us to analyze the impact of the CB's target weights on loss function. We consider $\Upsilon_y = \Upsilon_\pi = \Upsilon_e = 1$, in case there is no priority for the CB's targets. The value of 1.5 for coefficient of output or inflation means a priority for the target.

Table 2 reports the welfare loss based on CPI inflation for policy authority's weights. The results shows that a combination of PPI targeting with both the unified exchange rate system, and equal weights on targets, i.e. $\Upsilon_y = \Upsilon_\pi = \Upsilon_e = 1$, results in the lowest value of loss function: $\rightarrow l = 0.030858$. A deeper look at this table depicts that under the unified exchange rate system and for the same weight of targets, PPIT dominates CPIT. However, it seems that the target priority has a higher impact on loss value than that of inflation targeting. The combination of PPIT and unified exchange rate system results in less loss when the monetary authority considers the same weights on its targets. However, the combination of CPIT, the unified exchange rate system and the same weights on targets dominates PPIT under unified exchange rate system with more weights on inflation or output. The PPIT, again, dominates CPIT, if inflation priority is applied on the loss function. The results illustrate that in the dual-exchange rate system, the PPIT- regardless of the weight of the targets- performs better than the CPIT. The dual-exchange rate system, PPIT and equal weights on targets lead to less losses.

Table 3 reports the welfare loss when the PPI inflation acts as the inflation measure to weights on targets. The results indicate that the loss values are numerically affected by the inflation measure. In other words, similar to the results of table 2, the unified exchange rate system under both monetary policy types gives less losses and the sensitivity to weights on targets are the same under the both inflation measures. As a result, the unified exchange rate system is preferred to the dual-exchange rate system. This is not affected by the priority of monetary authority's targets. On the other hand, PPIT type of monetary policy is preferred if

Table 3: Sensitivity analysis of loss function with product price inflation measure

Model	**Loss**		
	$\Upsilon_\pi = 1, \Upsilon_y = 1, \Upsilon_e = 1$	$\Upsilon_\pi = 1.5, \Upsilon_y = 1, \Upsilon_e = 1$	$\Upsilon_\pi = 1, \Upsilon_y = 1.5, \Upsilon_e = 1$
CPIT DUAL	0.2011	0.20698	0.22136
CPIT UNIFIED	0.032407	0.03748	0.041034
PPT DUAL	0.14131	0.14687	0.15062
PPT UNIFIED	0.02906	0.034078	0.036511

monetary authority puts the same weights on its targets. The CPIT with the same weights on targets results in higher welfare than when the CB priorities inflation or output under PPIT. This confirms that the inflation priority is more welfare-effective than the output priority in the CB's loss function.

5.3 Welfare Effects of Fiscal Rule

In previous sections, it is assumed that the fiscal policy is neutral. Here, we relax this assumption. A procyclical fiscal policy rule along with monetary policy combination is considered in this section. In this case, to be more close to the reality of oil economies, a national development fund (NDF) in which a time-varying fraction of oil revenues are saved is also taken into account. The share of oil revenues which is transfered to the NDF, Ω_{Ot}, is an exponential function of real oil price $\mathcal{P}^*_{Ot}$, as follows:

$$\Omega_{Ot} = \frac{\mathcal{P}^*_{Ot}}{1 + \omega_o \mathcal{P}^*_{Ot}} \tag{5.4}$$

where ω_o is a parameter (very similar to $\omega_\hbar$ discussed before) governing the steady state value of Ω_{Ot}. The higher ω_o, the lower the steady state of Ω_O. Therefore, the evolution of NDF reserves and the CB's net foreign reserves in real term is:

$$ndf_t = \frac{ndf_{t-1}}{\pi^*_t} + \Omega_{Ot}\mathcal{P}^*_{Ot}Y^X_{Ot} \tag{5.5}$$

$$(1-\hbar_t)fr_t = (1-\hbar_t)\frac{fr_{t-1}}{\pi^*_t} + (1-\Omega_{Ot})\mathcal{P}^*_{Ot}Y^X_{Ot} - (C^F_{Nt} + I_{Nt} + C^N_{Gt} + I^N_{Gt}) \tag{5.6}$$

It is assumed that the budget authorization process is a function of the both oil export growth rate and change in national development fund reserves. As a result, (2.56) and (2.58) are changed to:

$$\log A_{It} = (1-\rho_A)\left[\log A_I + \Gamma^I_O \frac{Y^X_{Ot}}{Y^X_{Ot-1}} + \Gamma_F \frac{ndf_t}{ndf_{t-1}}\pi^*_t\right] + \rho_A \log A_{It-1} + \varepsilon_{At} \tag{5.7}$$

$$\log C_{Gt} = (1-\rho_G)\left[\log C_G + \Gamma^C_O \frac{Y^X_{Ot}}{Y^X_{Ot-1}}\right] + \rho_G \log C_{Gt-1} + \varepsilon_{Gt} \tag{5.8}$$

Table 4 reports the welfare losses to weights on targets when the procyclical fiscal rule ex-

Table 4: Sensitivity analysis of loss function with product price inflation measure and fiscal rule

Model	Loss		
	$\Upsilon_\pi = 1, \Upsilon_y = 1, \Upsilon_e = 1$	$\Upsilon_\pi = 1.5, \Upsilon_y = 1, \Upsilon_e = 1$	$\Upsilon_\pi = 1, \Upsilon_y = 1.5, \Upsilon_e = 1$
CPIT UNIFIED	0.032407	0.03748	0.041034
CPIT UNIFIED FR*	0.027431	0.032211	0.033951
PPT UNIFIED	0.02906	0.034078	0.036511
PPT UNIFIED FR	0.025277	0.030325	0.031514

*In this table FR refers to fiscal rule

plained in (5.4)-(5.8) along with unified exchange rate system are applied on the economy. In this case, the PPI acts as the inflation measure in loss function. The results show that the procyclical fiscal rule reduces the loss value, regardless of target weights. However, under the same weights on targets, the combination of the fiscal rule and PPIT results in lower loss. The lowest value of loss, $l = 0.025277$, occurs under the PPIT and fiscal rule when there is no priority between targets. On the other hand, the results show that the loss value is highly affected by target weights under both CPIT and PPIT. This behavior is very similar to that of table 2 in which the CPIT with no priority between targets results in higher welfare than the PPIT with more weights on inflation.

Here, we improve our example by applying the PPIT monetary policy, the dual-exchange rate regime and the fiscal rule. Then We compare this model with the same model without the fiscal rule. This helps better understand how the fiscal rule affect welfare. In addition, we are interested in tracking the impacts of κ_π and κ_S on welfare. This shed lights on how loss values are affected by the weights on domestic product price inflation and official real exchange rate. The results are shown in figure 11. The figure shows that the combination of the PPIT and procyclical fiscal rule highly affects welfare, regardless of the value of κ_π and κ_S. The difference between the two losses is more, the lower is κ_π. In other words if monetary authority tends more toward oil price inflation than domestic product price inflation, the fiscal rule increases welfare. As a result, when κ_π tends to 1 i.e. that the monetary authority priorities domestic price inflation to that of oil price, the two losses tends to each other and at the same time tends to their minimum level. The value of κ_S has a minimal effect on welfare in each value of κ_π. The key result of figure 11 is that if there is the dual-exchange rate system, the procyclical fiscal rule highly increases welfare. In addition, the combination of the fiscal policy and PPIT in which domestic product price inflation has more weight than oil price inflation, regardless of the weight on official RER, reduces the loss.

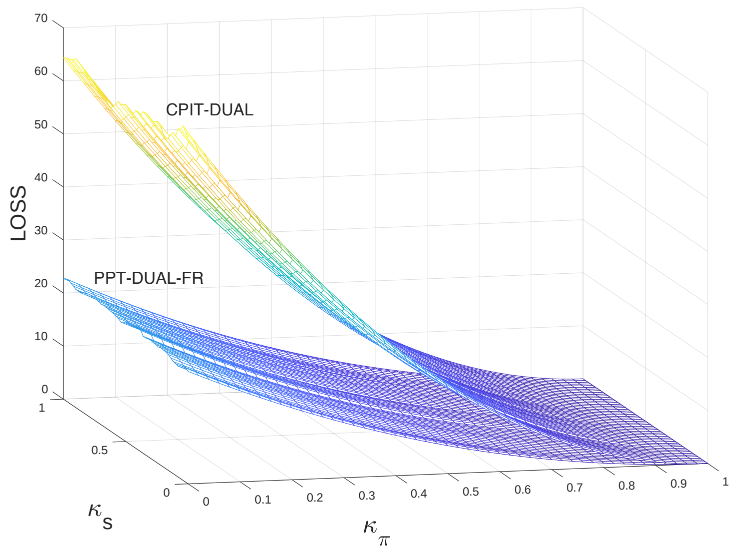

Figure 11: Loss function

6 Conclusion

This paper studies a DSGE model of a small open developing oil economy which has applied dual-exchange rate regime. In such economies, the exchange rate regime is highly affected by oil price shocks. As a result, the real exchange rate behavior is mostly determined by real oil revenues. The results of this paper reveal that the best policy combination for this economy includes a procyclical fiscal rule and PPI inflation targeting along with unified exchange rate system. Indeed, the fiscal discipline and product price inflation targeting allow policy makers to achieve a higher level of output. This result, however, directly depends on how monetary authorities weigh the targets. In addition, the results of this paper indicate that the economy is more volatile under dual-exchange rate system than unified one. While there is not a significant difference between impulse responses in medium term, in short term a positive official exchange rate shock under the the dual-exchange rate system results in a higher inflation, higher expected free market exchange rate and thus higher demand for foreign currency in the free market. This also forces the CB to intervene more in this market.

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Appendix A Calculations

A.1 Domestic and Imported Consumption Goods

Solving (2.11) and (2.12) together for a given C_t gives the following relations:

$$C_{Dt} = a_C \left(\frac{P_{Dt}}{P_t}\right)^{-\theta_C}, \quad C_t = a_C \mathcal{P}_{Dt}^{-\theta_C} C_t \tag{A.1}$$

$$C_{Nt} = (1 - a_C) \left(\frac{P_{C_N t}}{P_t}\right)^{-\theta_C}, \quad C_t = (1 - a_C) \mathcal{P}_{C_N t}^{-\theta_C} C_t \tag{A.2}$$

where

$$\mathcal{P}_{Dt} = \frac{P_{Dt}}{P_t} \tag{A.3}$$

$$\mathcal{P}_{C_N t} = \frac{P_{C_N t}}{P_t} \tag{A.4}$$

substituting these equations into (2.11) results

$$P_t = \left(a_C P_{Dt}^{1-\theta_C} + (1 - a_C)(P_{C_N t})^{1-\theta_C}\right)^{\frac{1}{1-\theta_C}} \tag{A.5}$$

Following the same way as above the demands for two imported consumption goods are

$$C_{Nt}^F = a_{C_N} \left(\frac{P_{Nt}^F}{P_{C_N t}}\right)^{-\theta_{C_N}}, \quad C_{Nt} = a_{C_N} \left(\mathcal{P}_{C_N t}^F\right)^{-\theta_{C_N}} C_{Nt} \tag{A.6}$$

$$C_{Nt}^S = (1 - a_{C_N}) \left(\frac{P_{Nt}^S}{P_{C_N t}}\right)^{-\theta_{C_N}}, \quad C_{Nt} = (1 - a_{C_N}) \left(\mathcal{P}_{C_N t}^S\right)^{-\theta_{C_N}} C_{Nt} \tag{A.7}$$

$$\mathcal{P}^F_{C_N t} = \frac{P^F_{Nt}}{P_{C_N t}} \tag{A.8}$$

$$\mathcal{P}^S_{C_N t} = \frac{P^S_{Nt}}{P_{C_N t}} \tag{A.9}$$

As a result, the domestic price of (the aggregate of) imported goods is simply

$$P_{C_N t} = \left(a_{C_N} (P^F_{Nt})^{1-\theta_{C_N}} + (1 - a_{C_N})(P^S_{Nt})^{1-\theta_{C_N}} \right)^{\frac{1}{1-\theta_{C_N}}}$$

A.2 Government

From (2.49)-(3), the demand for domestically produced and imported government consumption and investment goods is:

$$C^D_{Gt} = a_{CG} \left(\frac{P_{Dt}}{P_{CGt}} \right)^{-\theta_{CG}}, \quad C_{Gt} = a_{CG} \left(\mathcal{P}^D_{CGt} \right)^{-\theta_{CG}} C_{Gt} \tag{A.10}$$

$$C^N_{Gt} = (1 - a_{CG}) \left(\frac{P^F_{Nt}}{P_{CGt}} \right)^{-\theta_{CG}}, \quad C_{Gt} = (1 - a_{CG}) \left(\mathcal{P}^N_{CGt} \right)^{-\theta_{CG}} C_{Gt} \tag{A.11}$$

$$I^D_{Gt} = a_{IG} \left(\frac{P_{Dt}}{P_{IGt}} \right)^{-\theta_{IG}}, \quad I_{Gt} = a_{IG} \left(\mathcal{P}^D_{IGt} \right)^{-\theta_{IG}} I_{Gt} \tag{A.12}$$

$$I^N_{Gt} = (1 - a_{IG}) \left(\frac{P^F_{Nt}}{P_{IGt}} \right)^{-\theta_{IG}}, \quad I_{Gt} = (1 - a_{IG}) \left(\mathcal{P}^N_{IGt} \right)^{-\theta_{IG}} I_{Gt} \tag{A.13}$$

substituting (A.10) and (A.11) into (2.49), and (A.12) and (A.13) into (3.2) government consumption and investment price indices are:

$$P_{CGt} = \left(a_{CG} P^{1-\theta_{CG}}_{Dt} + (1 - a_{CG})(P^F_{Nt})^{1-\theta_{CG}} \right)^{\frac{1}{1-\theta_{CG}}} \tag{A.14}$$

$$P_{IGt} = \left(a_{IG} P^{1-\theta_{IG}}_{Dt} + (1 - a_{IG})(P^F_{Nt})^{1-\theta_{IG}} \right)^{\frac{1}{1-\theta_{IG}}} \tag{A.15}$$