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An Estimated Dynamic Stochastic General Equilibrium Model of the Jordanian Economy

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An Estimated Dynamic Stochastic General Equilibrium Model of the Jordanian Economy

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Abstract

This paper presents and estimates a small open economy dynamic stochastic general-equilibrium model (DSGE) for the Jordanian economy. The model features nominal and real rigidities, imperfect competition and habit formation in the consumer's utility function. Oil imports are explicitly modeled in the consumption basket and domestic production. Bayesian estimation methods are employed on quarterly Jordanian data. The model's properties are described by impulse response analysis of identified structural shocks pertinent to the economy. These properties assess the effectiveness of the pegged exchange rate regime in minimizing inflation and output trade-offs. The estimates of the structural parameters fall within plausible ranges, and simulation results suggest that while the peg amplifies output, consumption and (price and wage) inflation volatility, it offers a relatively low risk premium.

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I. INTRODUCTION

Dynamic stochastic general equilibrium (DSGE) models to evaluate monetary policy rules anchored in rich micro-foundations have become a popular tool for macroeconomic analysis in recent years (Tovar, 2008). In this vein, we estimate a small open economy DSGE model for Jordan. These models—often refered to as New Keynesian—demonstrate the non-trivial effects of monetary policy on real variables in the presence of nominal and real rigidities. In particular, the existence (or absence) of certain rigidities have implications for the trade-off between output and inflation stabilization that central banks face. For instance, standard new Keynesian models with nominal price rigidities and flexible wages generate a strong policy prescription: the role of monetary policy is to fully stabilize inflation. In this setup, inflation depends only on expected inflation and the gap between current output and its natural level (that is, the level that would prevail in the absence of nominal stickiness). Standard reduced-form models, with no explicit microeconomic foundations, are unable to identify, in practice, the source of nominal and real frictions.

Erceg, Henderson, and Levin (2000) find two important results when both wage and price decisions are staggered (i.e., removing the assumption that wages are flexible). First, the policymaker's welfare function depends on the variance of output, price inflation, and wage inflation; second, it becomes impossible to set more than one variance to zero in the face of exogenous shocks. They thus demonstrate that, in contrast to the standard new Keynesian model with only price rigidities, there is a trade-off between stabilizing the output gap, price inflation, and wage inflation.

The staggered wage setting imposes a welfare cost because households dislike variations in their labor supply, given that they have an increasing marginal disutility of labor. The policymaker's welfare function thus depends not only on the variance of output and inflation (as in the standard new Keynesian model with only price rigidities), but also on the variance of wage inflation, which is directly correlated with the variance of employment. The variances of output, price inflation, and wage inflation have a negative weight in the policymaker's objective function. Staggered wages also imply that marginal costs depend not only on the output gap, but also on the difference between the observed real wage and the equilibrium real wage (Blanchard and Galí, 2005). As a consequence, the New Keynesian Phillips curve is a function of both the output and real wage gap. In this context, any shock that moves the equilibrium real wage generates a movement in price inflation (because the observed real wage cannot fully adjust toward its equilibrium level). This movement can only be offset by altering the output gap. Therefore, when both wage and price stickiness are introduced, there is a trade-off between stabilizing price inflation and output. In contrast to the ad-hoc supply shocks that are usually introduced to generate a trade-off between price inflation and output gap stabilization (see Clarida, Galí, and Gerler, 1999), in the Erceg, Henderson, and Levin (2000) case this trade-off arises endogenously.

A monetary policy rule that seeks to fully stabilize inflation is clearly suboptimal in the presence of wage rigidities. In particular, it can exacerbate the volatility of both output and wage inflation. An alternative policy rule that seeks to minimize the volatility of a weighted average of wage and price inflation may perform better (Erceg, Henderson, and Levin, 2000; and Blanchard and Galí, 2005). In other words, optimal policy prescriptions depend on *the set of frictions that the economy faces* and, in particular, the importance of nominal and real rigidities in the wage setting process.

In this paper, following Smets and Wouters (2003), Christiano *et al.* (2005), Galí and Monacelli (2005), Adolfson *et al.* (2007), Medina and Soto (2007), we lay down a structural model containing both nominal and real frictions and estimate it for Jordan. Our model features habit formation in the consumer's utility function, wage and price rigidities, and imperfect competition. Oil imports are explicity modeled in the consumption basket and domestic production.[2] Following Lubik and Schorfheide (2007), in addition to the standard specification of the Taylor rule, we explore a specification for the monetary policy reaction function that gauges whether the central bank reacts to real exchange rate volatility and aims for interest rate smoothing, Finally, we analyze the impulse response functions to shocks pertinent to the Jordanian economy, including oil price shocks.

We use Bayesian methods to estimate the model. To apply this methodology we combine priors and the likelihood function to obtain the posterior distribution of structural parameters. The likelihood function of the parameters is evaluated using the Kalman filter of a log-linear approximation of the model. We use the Metropolis-Hastings algorithm to approximate the posterior distribution.

We adopt a Bayesian approach for various reasons detailed in Fernández-Villaverde and Rubio-Ramírez (2004) and Lubik and Schorfheide (2005). First, the Bayesian approach is system-based and fits the DSGE model to a vector of time series. Second, the estimation is based on the likelihood function generated by the DSGE model, rather than, for instance, the discrepancy between DSGE model responses and vector autoregression (VAR) impulse responses. Third, prior distributions can be used to incorporate additional information into the parameter estimation. Fourth, this approach can cope with potential model misspecification and possible lack of identification of the parameters of interest. In a misspecified model, if the likelihood function peaks at a value that is at odds with the prior information on any given parameter, the posterior probability will be low. The prior density thus allows us to weigh information about different parameters according to its reliability. Lack of identification, in turn, may result in a likelihood function that is flat for some coefficient values. Hence, based on the likelihood function alone, it would not be possible to

[2] However, the fiscal sector, investment (inertia) and capital are not modeled. This would entail a larger model (see Beidas-Strom, forthcoming, for such a model calibrated for a group of net-oil exporters).

identify the value of the parameters of interest. The Bayesian approach copes with this problem by introducing prior distributions. In fact, a proper prior can introduce curvature into the objective function, the posterior distribution, making it possible to identify the value of different parameters. Finally, as pointed out by Fernández-Villaverde and Rubio-Ramírez (2004) and Rabanal and Rubio-Ramírez (2005), Bayesian estimation delivers a tool for comparing models through the marginal likelihood. This makes it possible to determine the extent to which additional ingredients of the model help explain the Jordanian data.

The main results from the Bayesian estimation are as follows. Similar to other oil-importer DSGE studies (relative to advanced economies), this paper finds: (i) a low degree of substitution and share of oil in the consumption basket and production function; (ii) a smaller elasticity of labor supply; (iii) a smaller habit formation coefficient in consumption; (iv) a higher elasticity of substitution between *home* and *foreign* goods in consumption; (v) smaller estimated Calvo probabilities of optimally resetting prices and wages—implying that prices are reset optimally every 3.5 quarters whereas wages are re-optimized every 4 quarters; (vi) relatively low wage indexation; (vii) a significant degree of interest rate smoothing; (viii) the response of the interest rate to inflation's deviation from target is similar to output growth's deviation from potential; (ix) the response of the interest rate to real exchange rate volatility is quite large; and finally, (x) the pegged exchange rate regime affords a lower risk premium (relative to a *hypothetical* floating exchange rate regime).

The main results from the impulse response analysis under the current peg are as follows. First, foreign demand shocks raise income and consumption, cause real exchange rate appreciation, and deteriorate the current account/NFA position. Second, foreign interest rate shocks contract consumption and output, depreciate the real exchange rate and improve the current account. Third, monetary-policy shocks (with a high domestic interest rate) induces households to choose a consumption profile characterized by an increasing growth rate of consumption given its inertial behavior, with a rise in foreign debt and an associated deterioration in current account position. Fourth, international and domestic oil price shocks result in a large negative income effect, depreciating the real exchange rate, and improving the current account position.[3]

The rest of the paper is organized as follows. Section II describes the structure of a dynamic general equilibrium model for the Jordanian economy. Section III then explains the econometric strategy used to estimate the parameters and compare models. In this section, we also describe the data used and our choice of priors and calibrated parameters to construct the

[3] The responses of macro variables are broadly similar under a *hypothetical* flexible exchange rate regime, but with much less magnitude. This implies that a hypothetical flexible exchange rate regime could serve to lower consumption and output volatility in Jordan against external shocks. These results are available upon request.

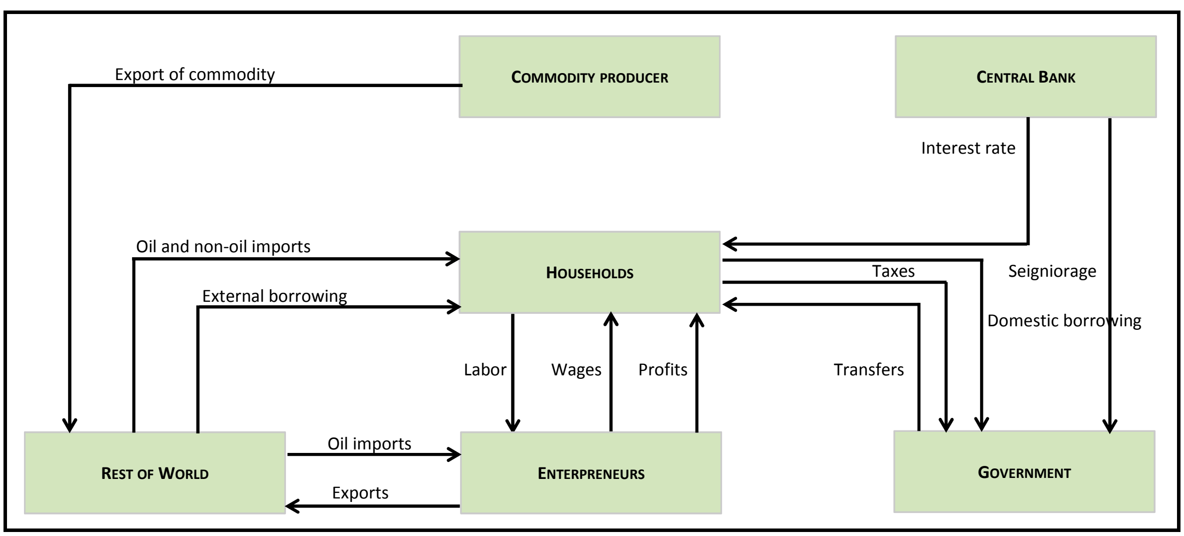
posterior distribution. In section IV, we present the results of the Bayesian estimation. Finally, section V concludes.

II. A Small Open Economy Model

In this section, we describe a dynamic stochastic general equilibrium (DSGE) model with nominal and real rigidities, which is designed to account for the main features of the Jordanian economy. This microfounded model is closely related to the new open economy literature of Christiano *et al* (2005), Altig *et al* (2003, 2004), Smets and Wouters (2003, 2007), Galí and Monacelli (2005), Medina and Soto (2007), and the monetary policy rule is based on Lubik and Schorfheide (2007).[4] To make the paper self-contained we describe the structure of the model and the decision problems facing agents.

The domestic economy is open and it is small vis-a-vis the rest of the world (see Chart 1). The latter assumption implies that international prices, the foreign interest rate and foreign demand are not affected by domestic agents' decisions. Prices and wages are sticky. They are adjusted infrequently, and they are partially indexed to past inflation. The introduction of wage rigidities together with price rigidities is very important in our model not only because it increases the realism of the model but also because it implies a stronger trade-off between inflation and output fluctuations (see Erceg et al., 2000, and Blanchard and Galí, 2005).

Chart 1: Flow Chart of the Economy



[4] The main innovation to DSGEs since this group of papers has been the introduction of financial frictions and leverage effects (e.g. Christiano *et al.*, 2009; Fernández-Villaverde and Ohanian, 2009; and Kiyotaki and Gertler, 2010).

Domestic households consume domestically-produced goods (*home* goods), imported differentiated goods (*foreign* goods), and fuel (oil). All three goods are imperfect substitutes in the consumption basket. We assume that consumption exhibits habit formation. *Home* goods are partly sold domestically and partly exported abroad. There is also a commodity good (whose endowment is exogenously determined) that is exported and not consumed domestically. The exogenous endowment of this good is subjected to stochastic shocks. Households supply a differentiated labor service and receive the corresponding wage compensations. Each household has monopolistic power over the type of labor service it provides. Furthermore, households are the owners of firms producing *home* goods, and therefore, they receive the income corresponding to the monopolistic rents generated by these firms.

Domestic firms produce differentiated varieties of *home* goods. For simplicity, we assume that labor and oil are the only variable inputs used for production. These firms have monopolistic power over the variety of goods they produce. There is a third single firm that produces a commodity good which is completely exported abroad. This firm has no market power. It takes the international price of the commodity good as given, and produces utilizing only natural resources. The stock of natural resources is determined exogenously and it is owned by the government and by foreign investors. This commodity-exporting sector is meant to characterize the potash and phosphate sector in Jordan, which accounts for about 4 percent of GDP and 12 percent of total exports.

Monetary policy is conducted through the interest rate. Despite the pegged exchange rate regime, the central bank has some room to conduct an independent monetary policy given imperfect asset substitution. Thus monetary policy is modeled as a Taylor-type rule that incorporates interest rate inertia, reflecting an interest rate premium of borrowing from abroad. In particular, the interest rate reacts to inflation, GDP growth, and its own lagged value. The rule is augmented to include a response to real exchange movements. For simplicity there is no fiscal sector.

The model exhibits a balanced growth path. We assume that in steady-state labor productivity grows at rate g_y. However, we assume that productivity is subject to both transitory and permanent shocks. A permanent productivity shock introduces a unit root in major aggregates.

A. Households

The domestic economy is inhabited by a continuum of infinitely-lived households indexed by $j \in [0, 1]$. The expected present value of the utility of household j is given by:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left\{ log\left[C_t(j) - h\left(1+g_y\right)C_{t-1}(j)\right] - \frac{\zeta_{L,t}}{1+\sigma_L}\left[l_{t+i}(j)\right]^{1+\sigma_L} + \frac{a}{\mu}\left(\frac{\mathcal{M}_t(j)}{P_t}\right)^{\mu} \right\} \qquad (1)$$

Where E_t denotes the mathematical expectation conditional on information available in period *t*, $\beta \in (0,1)$ is the subjective discount factor, $l_t(j)$ is labor effort, $C_t(j)$ is total consumption, and $\mathcal{M}_t(j)$ corresponds to the total nominal balances held at the beginning of period *t*. The inverse elasticity of labor supply with respect to real wages is represented by σ_L, while ζ_L is a AR(1) preference shock that shifts the labor supply which can be interpreted as a technology change in the *home* production technology. The parameter *a* determines the weight of nominal balances in the household's utility function while μ defines the semi-elasticity of money demand to the nominal interest rate. Preferences display habit formation, whose strength is measured by the parameter *h*. The consumption bundle is a composite of core (non-fuel) consumption goods and imported fuel:

$$C_t(j) = \{(1-\delta)^{\frac{1}{\eta}}[C_{Z,t}(j)]^{\frac{\eta-1}{\eta}} + \delta^{\frac{1}{\eta}}\,[C_{O,t}(j)]^{\frac{\eta-1}{\eta}}\}^{\frac{\eta}{\eta-1}} \tag{2}$$

where $C_{O,t}$ represents fuel (oil) consumption, and $C_{Z,t}$ is a bundle of non-fuel consumption (core consumption). The parameter η is the elasticity of substitution between oil and core consumption, and δ defines their corresponding shares. The composition of this core consumption bundle is given by the following constant elasticity of substitution (CES) aggregator of *home* and *foreign* goods:

$$C_{Z,t}(j) = \left[\gamma^{\frac{1}{\theta}}\left(C_{F,t}(j)\right)^{\frac{\theta-1}{\theta}} + (1-\gamma)^{\frac{1}{\theta}}\left(C_{H,t}(j)\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}} \tag{3}$$

where $C_{H,t}$ represents a bundle of domestically produced (*home*) goods and $C_{F,t}$ corresponds to a bundle of imported goods (*foreign* goods). The parameter $1-\gamma$ represents home bias in consumtpion. Finally, the parameter θ is the intratemporal elasticity of substitution between *home* and *foreign* goods. For any level of consumption, each household purchases a composite of *home* and *foreign* goods in period *t* to minimize the total cost of its consumption basket. The aggregate consumption price level is given by:

$$P_t = \left[\delta P_{O,t}^{1-\eta} + (1-\delta)P_{Z,t}^{1-\eta}\right]^{\frac{1}{1-\eta}} \tag{4}$$

where $P_{O,t}$ and $P_{Z,t}$ are the price of oil and core consumption, respectively. Therefore, the demand for oil and core consumption goods are given by:

$$C_{Z,t}(j) = (1-\delta_c)[\tfrac{P_{Z,t}}{P_t}]^{-\eta}C_t\,; \quad C_{O,t}(j) = (\delta_c)[\tfrac{P_{O,t}}{P_t}]^{-\eta}C_t \tag{5}$$

Analogously, each household determines the optimal composition of core consumption by minimizing the cost of the core consumption basket, $P_{H,t}C_{H,t}(j) + P_{F,t}C_{F,t}(j)$, subject to equation (3). The demand functions for *home* goods and *foreign* goods are given by:

$$C_{H,t}(j) = \gamma_c \left(\frac{P_{H,t}}{P_{Z,t}}\right)^{-\theta} C_{Z,t}(j), \quad C_{F,t}(j) = (1-\gamma_c)\left(\frac{P_{F,t}}{P_{Z,t}}\right)^{-\theta} C_{Z,t}(j) \tag{6}$$

where

$$P_{Z,t} = [\gamma P_{H,t}^{1-\theta} + (1-\gamma) P_{F,t}^{1-\theta}]^{\frac{1}{1-\theta}}. \tag{7}$$

We assume that all households are Ricardian and therefore can smooth consumption intertemporally,[5] having access to three different assets: money, $\mathcal{M}_t(j)$; one-period noncontingent nominal foreign bonds, $B_t^*(j)$; and one period domestic contingent nominal bonds, $D_{t+1}(j)$. There are no adjustment costs in the portfolio composition. However, each time a domestic household borrows from abroad, it must pay a premium over the international price of external bonds. This premium is introduced in the model to obtain a well-defined steady state for the economy.[6] The household budget constraint is thus given by:

$$E_t\left[Q_{t,t+1} D_{t+1}(j)\right] + \frac{e_{t+1} B_{t+1}^*(j)}{[1+i_{t+1}^*]\Theta\left[\frac{e_{t+1} B_{t+1}^*}{P_{x,t+1} X_{t+1}}\right]} + \mathcal{M}_{t+1}(j) + P_{c,t} C_t(j) =$$

$$W_t(j) l_t(j) + D_t(j) + e_t B_t^*(j) + \mathcal{M}_t(j) + \Pi_t(j) + T_t(j) \tag{8}$$

where the variable $Q_{t,t+1}$ is the price of domestic contingent bonds in period t, normalized by the probability of the occurrence of the state; i_t^* is the return on the international bond in the international market; Π_t are profits of domestic firms retained by households; e_t is the nominal exchange rate; $W_t(j)$, is the nominal wage set by household j; and $T_t(j)$ represents per capita lump-sum net transfers from the government.

The term $\Theta\left[\frac{e_t B_t^*}{P_{X,t} X_t}\right]$ corresponds to the premium domestic households have to pay each time they borrow from abroad, where $B_t^* = \int_0^1 B_j^*(j)dj$ is the aggregate net foreign asset position of the economy and $P_{X,t} X_t$ is the nominal value of exports. Assuming the existence of a full set of contingent bonds ensures that the consumption of all households is the same, independently of the labor income they receive each period.

Our assumption that the premium depends on the aggregate net foreign asset position of the economy implies that households take $\Theta(\cdot)$ as given when deciding their optimal portfolios. In other words, households do not internalize the effect of changes in their own foreign asset position on the premium. In the steady state, the $\Theta(\cdot)$ function is parameterized as:

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[5] See Beidas-Strom (forthcoming) for a relaxation of this assumption.

[6] Another way of achieving a stationary solution would be to introduce intermediation costs as per Cespedes *et al*. (2004).

$$\Theta\left[\frac{eB^*}{P_X X}\right] = \Theta \text{ and } \frac{\Theta'(\frac{eB^*}{P_X X})}{\Theta(\frac{eB^*}{P_X X})}\frac{eB^*}{P_X X} = \varrho$$

Here B^*corresponds to the steady-state net foreign asset position (or current account evolution), while $P_X X$ is the steady-state value of nominal exports. When the country as a whole is a net debtor, ϱ is the elasticity of the upward slopping supply of international funds.[7]

Consumption and saving decisions

Ricardian households choose a consumption path and the composition of their portfolios by maximizing equation (1) subject to equation (3). Since we are assuming the existence of a complete set of contingent claims, consumption is equalized across Ricardian households. Therefore, in what follows we omit index j from consumption. Aggregating the first-order conditions on different contingent claims over all possible states we obtain the following Euler equation:

$$1 = \beta E_t\left[(1+i_t)\frac{P_t}{P_{t+1}}\left(\frac{C_{t+1}-h(1+g_y)C_t}{C_t-h(1+g_y)C_{t-1}}\right)\right] \tag{9}$$

where in equilibrium it must be true that $1 + i_t = 1/E_t[Q_{t,t+1}]$, with i_t being the domestic risk-free interest rate.

The first order condition with respect to foreign bond holdings is:

$$1 = \beta E_t\left\{(1+i_t^*)\Theta\left(\frac{e_{t+1}}{e_t}\frac{P_t}{P_{t+1}}\right)\left[\frac{C_t-h(1+g_y)C_{t-1}}{C_{t+1}-h(1+g_y)C_t}\right]\right\} \tag{10}$$

The return on international bonds in the international market, i_t^*, is assumed to follow an AR(1) process subject to orthogonal i.i.d shocks, which capture foreign financing conditions relevant to domestic agents (including risk premia and exchange rate arbitrage). Combining the two expressions above we can obtain an expression for the uncovered interest parity condition.

Labor supply decisions and wage setting

Further, following Erceg, Henderson and Levin (2000), each household j is a monopoly

[7] The premium could be endogenous and non-linear as it approaches a certain debt threshold, as in Leigh (2008). See Adolfson *et al.* (2007) for a novel specification of the risk premium which hinges on the expected change in the exchange rate.

supplier of a differentiated labor service which implies that they can set their own wage. After having set their wage, households supply the firms' demand for labor at the going wage rate. Firms, which hire labor from each household, combine it into an aggregate labor service unit, l_t, that is then used by the intermediate goods producer. The labor service unit is defined as the following Dixit-Stiglitz function:

$$l_t = \left[\int_0^1 l_t(j)^{(\epsilon_L-1)/\epsilon_L} dj\right]^{\epsilon_L/(\epsilon_L-1)} \tag{11}$$

where ϵ_L is the elasticity of substitution of different types of labor. The optimal composition of this labor service unit is obtained by minimizing its cost, given the different wages set by different households. Thus, the demand for the labor service provided by household *j* is:

$$l_t(j) = \left[\frac{W_t(j)}{W_t}\right]^{-\epsilon_L} l_t \tag{12}$$

where $W_t(j)$ is the wage rate set by household *j* and W_t is an aggregate wage index defined as:

$$W_t = \left[\int_0^1 W_t(j)^{1-\epsilon_L} dj\right]^{\frac{1}{1-\epsilon_L}}. \tag{13}$$

Following Calvo (1983), we assume that wage setting is subject to a nominal rigidity. In each period, each household faces a constant probability $(1 - \phi_L)$ of being able to re-optimize its nominal wage. In this set-up, parameter ϕ_L is a measure of the degree of nominal wage rigidity. The larger is this parameter the less frequently wages are adjusted (i.e. the more sticky they are). A particular household *j* that is able to re-optimize its wages at time *t* solves the following problem:

$$\max_{W_t(j)} = E_t \left\langle \sum_{i=0}^{\infty} \phi_L^i \Lambda_{t,t+i} \left\{ \frac{W_t(j)\Gamma_{W,t}^i}{P_{t+i}} - \zeta_t l_{t+i}(j)^{\sigma_L} \left[C_{t+i} - h\left(1+g_y\right)C_{t+i-1}\right] l_{t+i}(j) \right\} \right\rangle$$

subject to the labor demand. The variable $\Lambda_{t,t+i}$ is the relevant discount factor between periods *t* and *t+i*; it is given by:

$$\Lambda_{t,t+i} = \beta^i \frac{C_t - b(1+g_y)C_{t-1}}{C_{t+i} - b(1+g_y)C_{t+i-1}}.$$

In contrast, we assume that there is a *passive updating rule of thumb* for all households that cannot re-optimize their wages. In particular, if a household cannot optimize during *i* periods between *t* and *t+i*, then its wage at time *t+i* is given by:

$$W_{t+i}(j) = \Gamma_{w,t}^i W_t(j)$$

where $\Gamma_{w,t}^{i}$ describes a passive adjustment rule for wages, which is defined as:

$$\Gamma_{w,t}^{i} = \prod_{j=1}^{i}\left(1+\pi_{t+j-1}\right)^{\xi_L}\left(1+\ \bar{\pi}_{t+j}\right)^{1-\xi_L}\left(1+g_y\right). \tag{14}$$

This "passive" adjustment rule implies that workers who do not optimally reset their wages update them by considering a geometric weighted average of past CPI inflation and the implict inflation target set by the authority, $\bar{\pi}_t$. The parameter ξ_L captures the degree of wage indexation in the domestic economy, while the inclusion of $\left(1+g_y\right)$ prevents large real wage dispersion along the steady-state growth path.

Once a household has decided on a wage (whether through optimal or passive adjustment), it must supply any quantity of labor service that is demanded at that wage.

B. Domestic Production

Domestic firms use a CES technology to assemble *home* goods using domestic intermediate varieties. Intermediate varieties are produced by firms that have monopoly power. These firms maximize profits by choosing the prices of their differentiated good subject to the corresponding demands, and the available technology. Let $Y_{H,t}(z_H)$ be the total quantity produced of a particular variety z_H. The available technology is given by:

$$Y_{H,t}(z_H) = A_{H,t}\left[\alpha^{\frac{1}{\omega}}\left(O_{H,t}(z_H)\right)^{1-\frac{1}{\omega}} + (1-\alpha)^{\frac{1}{\omega}}\left(L_{H,t}(z_H)\right)^{1-\frac{1}{\omega}}\right]^{\frac{\omega}{\omega-1}} \tag{15}$$

where $Y_{H,t}(z_H)$ represents the total quantity of a particular variety z_H; $A_{H,t}$ represents a stationary productivity shock to the *home* goods sector that is common to all firms; $L_{H,t}$ is labor used; and $O_{H,t}$ is imported oil used both in the production of the variety z_H. The parameter α defines the weight of oil in production; and ω determines the degree of substitution between oil and the other factor of production, with its value being key to determine the effects of oil-price shocks on output, marginal cost and inflation.

Demand for inputs and marginal cost

Let $Y_{H,t}(z_H)$ be quantity of home goods sold domestically, and $Y_{H,t}^{*}(z_H)$ the quantity sold abroad. The demands for a particular intermediate variety are given by:

$$Y_{H,t}(z_H) = Y_{H,t}\left[\frac{P_{H,t}(z_H)}{P_{H,t}}\right]^{-\epsilon_H} \quad \text{and} \quad Y_{H,t}^{*}(z_H) = \left(\frac{P_{H,t}^{*}(z_H)}{P_{H,t}^{*}}\right)^{-\epsilon_H} Y_{H,t}^{*} \tag{16}$$

where $P_{H,t}(z_H)$ is the price of the variety z_H when used to assemble *home* goods sold in the domestic market; and $P_{H,t}^{*}(z_H)$ is the foreign-currency price of this variety when used to assemble *home* goods sold abroad. Variables $P_{H,t}$ and $P_{H,t}^{*}$ are the corresponding aggregate price indices and ϵ_H is the price elasticity of the demand for variety z_H.

Firms face a nominal rigidity that prevents them from adjusting prices optimally in every period and determine the optimal mix of inputs by minimizing the total cost of production, subject to the constraint imposed by the technology. From the first-order condition we obtain the following cost-minimization relationship:

$$\frac{1-\alpha}{\alpha}\frac{O_{H,t}(z_H)}{L_{H,t}(z_H)} = \left(\frac{W_t}{P_{O,t}}\right)^{\omega}$$

where the oil price in domestic currency is given by $P_{O,t} = e_t P_{O,t}^{*}$. Thus we obtain an expression for the marginal cost:

$$MC_{H,t+i} = A_{H,t}^{-1}\left[(1-\alpha)W_t^{1-\omega} + \alpha P_{O,t}^{1-\omega}\right]^{\frac{1}{1-\omega}}$$

whereby the marginal cost is common across firms which share the same technology and is independent to the scale of production. Analogous to the introduction of wage rigidities in the household optimization problem, we introduce price rigidities following Calvo (1983). The assumption is that firms adjust their prices infrequently. The adjustment occurs when they receive a signal. In every period, the probability of receiving such a signal (and thus adjusting prices) is $1 - \phi_H$ for all firms, and is independent of their history. Thus, if a firm receives a signal in period *t*, then it will optimally adjust the price of its variety, $P_{H,t}(z_H)$, so as to maximize the following expression:

$$max_{P_{H,t}(z_H)}(\phi_H)^i E_t\left\langle \sum_{i=0}^{\infty} \Lambda_{t,t+i}\frac{\Gamma_{H,t}^{i}P_{H,t}^{opt}(z_H) - MC_{H,t+i}}{P_{t+i}} Y_{H,t+i}(z_H)\right\rangle \quad (17)$$

subject to the restrictions imposed by the technology and considering the demand the firm faces for its variety z_H given by:

$$C_{H,t}(z_H) = \left(\frac{P_{H,t}(z_H)}{P_{H,t}}\right)^{-\epsilon_H}\left(C_{H,t} + C_{H,t}^{*}\right). \quad (18)$$

In contrast, if the firm does not receive a signal, then it follows a simple *passive updating rule of thumb* defined by the function $\Gamma_{H,t}^{i}$.[8] The passive updating rule—(i.e., not adjusting optimally)—is given by:

[8] Note that $\Gamma_{H,t}^{i}$ in equation (14) and $\Gamma_{w,t}^{i}$in equation (18) not only due to the additional term $(1+g_y)$, but also since wage indexation, ξ_L, and price indexation, ξ_H, in the economy are not necessarily equal.

$$\Gamma_{H,t}^{i} = \prod_{j=1}^{i}\left(1+\pi_{t+j-1}\right)^{\xi_H}\left(1+\bar{\pi}_{t+j}\right)^{1-\xi_H} \tag{19}$$

where $\pi_t = \left(P_{H,t}/P_{H,t-1}\right)$.

Relative price changes may have a feedback impact through this adjustment rule. Firms that do not optimally adjust take into consideration the implict inflation target, which is set in terms of consumption goods inflation. The parameter ξ_H captures the degree of price indexation in the domestic economy. The larger this parameter, the larger is the weight of past inflation in defining new prices. Given the price charged by a firm producing variety z_H, its profits are given by:

$$\Pi_t(z_H) = P_{H,t}(z_H)Y_{H,t}(z_H) - W_t L_{H,t}(z_H) - P_{O,t}O_{H,t}(z_H).$$

C. Foreign Sector

For simplicity we assume that the economy exports two types of goods: *home* goods and an exportable commodity (in Jordan's case, phosphate/potash). Foreign demand for *home* goods is given by the following expression:

$$C_{H,t}^{*} = \gamma^{*}\left(\frac{P_{H,t}^{*}}{P_{F,t}^{*}}\right)^{-\eta^{*}} C_t^{*} \tag{20}$$

where γ^* corresponds to the share of domestic intermediate goods in the consumption basket of foreign agents; and η^* is the price elasticity of foreign demand. We assume that domestic firms cannot price discriminate across markets. Therefore, the law of one price holds for *home* goods sold abroad:

$$P_{H,t}^{*} = \frac{P_{H,t}}{e_t}.$$

The real exchange rate is defined as the relative price of the foreign consumption basket, $P_{F,t}^{*}$, to the price of the domestic consumption basket:

$$RER_t \equiv \frac{e_t P_{F,t}^{*}}{P_t} \tag{21}$$

whereby the assumption is that the price of foreign goods is the relevant international price to be used when constructing the real exchange rate. In other words, the consumption bundle for the rest of the world implicitly does not include oil and the share of *home* goods in this bundle, γ^*, is negligible.

The domestic real price of oil is given by the following expression:

$$\frac{P_{O,t}}{P_t} = RER_t \frac{P^*_{O,t}}{P^*_{F,t}} \psi_t \tag{22}$$

where $P^*_{O,t}$ is the foreign currency price of oil abroad. Variable ψ_t in equation (22) reflects deviations from the law of one price in the oil price, since empirical evidence shows that the pass-through from the international oil price to its price in domestic currency is not typically complete in the short run.[9] Both $P^*_{O,t}$ and ψ_t are assumed to follow a log-linear AR(1) process.

Commodity production is assumed to be completely elastic with respect to its international price, $p_{s,t} = e_t p^*_{s,t}$, and fully exported (i.e. not consumed domestically)[10] and is determined by an exogenous endowment, Y_S , given by:

$$\frac{Y_{S,t}}{(1+g_y)^t Y_S} = \left[\left(\frac{Y_{S,t-1}}{(1+g_y)^{t-1} Y_S}\right)^{\rho_S}\right]^{\varepsilon_{S,t}} \tag{23}$$

Where $Y_{S,t}$ is domestic production of the exportable commodity; $\varepsilon_{S,t} \sim N(0, \sigma^2_{y,S})$ is a stochastic shock (with the stochastic trend being the same as other aggregate variables in this paper); and ρ_S captures the persistence of the shock to the production process. An increase in the production of the commodity good directly implies an increase in domestic GDP. Since the assumption is that there are no inputs, this increase in production is a windfall gain. As with any expansion of the technological frontier biased towards tradable goods, a boom in this sector would induce a real appreciation of the exchange rate. Net exports may also rise, if no counteracting effect on *home* goods' exports dominates. The extent of real appreciation would depend on the structural parameters governing the degree of intratemporal and intertemporal substitution in aggregate demand and production.

D. Monetary Policy

Following Galí and Monacelli (2005) and Lubik and Schorfheide (2007), we assume that monetary policy in Jordan can be modeled as a Taylor-type rule with a simple nominal interest rate feedback rule:

[9] See Coady *et al.* (2006) and references to emerging markets (such as Jordan and Indonesia) therein.

[10] In Jordan commodities represent an important share of total exports, despite the country being a net commodity importer (mainly oil and gas). These commodities (potash and phosphate) are produced independently of domestic economic conditions (the interest rate, real wages, and so forth) and therefore are considered to be exogenous in the short run.

$$\frac{1+i_t}{1+i} = \left[\left\{ \left(\frac{1+i_{t-1}}{1+i}\right)^{\rho_i} \left(\frac{Y_t}{Y_{t-1}} \frac{1}{1+g_y}\right)^{(1-\rho_i)\varpi_y} \left(\frac{1+\pi_t}{1+\bar{\pi}_t}\right)^{(1-\rho_i)\varpi_\pi} \left(\frac{RER_t}{RER_{t-1}}\right)^{(1-\rho_i)\varpi_{\Delta e}} \right\}^{v_t^m} \right] \quad (24)$$

Where: Y_t is aggregate production; and the nominal interest rate, i_t, which is the monetary policy instrument. In this specification, ϖ_y, ϖ_π and $\varpi_{\Delta e}$ are, respectively, the long run responses of the central bank to deviations of GDP growth and inflation from their steady-state levels, and smoothing real effective exchange volatility. As $\varpi_y \to \infty$ the central bank would be strictly targeting the output gap; or $\varpi_\pi \to \infty$ it would be a strict inflation targeter; or $\varpi_{\Delta e} \to \infty$ it would be exchange rate targeter. If $\varpi_\pi$is finite and $\varpi_{\Delta e} > 0$ a managed float is being implemented. Finally, ρ_i controls for the degree of (nominal) interest rate smoothing, which is an important variable for the conduct of monetary policy in Jordan due to imperfect asset substitution, where $0 < \rho_i < 1$. The parameter v_t^m stands for an exogenous policy or monetary shock.

This Taylor-type rule has been estimated for Korea[11] (Elekdag *et al.,* 2005); Australia, New Zealand, Canada, and the United Kingdom (Lubik and Schorfheide, 2007); Chile[12] (Medina and Soto, 2007); and Latvia[13] (Ajevskis and Vitola, 2009) and the emprical evidence generally supports the existence of a policy reaction function that responds to inflation deviations from target, to output movements from potential, and to real exchange rate misalignments.

E. Equilibrium

For simplicity we assume that there is no public spending.[14] Therefore, the government budget constraint is simply given by:

$$\int \frac{\mathcal{M}_{t+1}(j) - \mathcal{M}_t(j)}{P_t} dj - \int T_t(j) dj - D_t = 0. \quad (25)$$

Aggregate equilibrium conditions in each market are as follows:

The labor market: $$l_t^s = \int_0^1 l_t(j) dj = L_{H,t} \quad (26)$$

[11] While Korea maintains a floating exchange rate regime, Elekdag *et al.* (2005) find evidence of a heavily managed exchange rate (due to balance sheet and external debt vulnerabilities).

[12] Prior to 2001 (when inflation targeting began), Chile targeted the exchange rate through a crawling band.

[13] Latvia maintains a pegged exchange rate regime.

[14] See Medina and Soto, 2007; Fernández-Villaverde and Ohanian, 2009; Beidas-Strom (forthcoming) for a model with a fully fledged fiscal sector.

The *home* goods market: $C_{H,t} + C^*_{H,t} = Y_{H,t}$ (27)

Letting $P_{Y,t}$ denote the implicit output deflator, then total GDP at current prices satisfies:

$$\frac{P_{Y,t}}{P_t} Y_t = C_t + \frac{P_{X,t}}{P_t} X_t - \frac{P_{M,t}}{P_t} M_t \quad (28)$$

where total exports are: $\frac{P_{X,t}}{P_t} X_t = \frac{P_{H,t}}{P_t} C^*_{H,t} + \frac{P_{S,t}}{P_t} Y_{S,t}$ (29)

total imports are: $\frac{P_{M,t}}{P_t} M_t = RER_t C_{F,t} + \frac{e_t P^*_{O,t}}{P_t} O_t$ (30)

total oil imports are: $O_t = O_{N,t} + O_{C,t}$ (31)

net foreign asset position is:

$$\frac{e_t B^*_t}{[1+i^*_t]\Theta\left[\frac{e_t B^*_t}{P_{x,t} X_t}\right] P_t} = \frac{e_t B^*_{t-1}}{P_t} + \frac{P_{X,t}}{P_t} X_t - \frac{P_{M,t}}{P_t} M_t \quad (32)$$

F. Stochastic Processes

The economy is subject to nine orthogonal AR(1) stochastic shocks representing log-linear deviation from the steady-state, denoted by lowercase variables with a symbol ˆ (see Appendix I) : a domestic productivity shock ($\hat{a}_{H,t}$); a foreign interest rate shock ($\hat{\imath}^*_t$)—which can also be considered as a shock in foreign financial conditions, e.g. increasing risk premia and any exchange rate arbitrage factors; a foreign demand shock ($\hat{c}^*_t$); a foreign inflation shock ($\hat{\pi}^*_t$); a labor supply preference shock ($\hat{\zeta}_{L,t}$); an domestic oil price shock ($\hat{\psi}_t$); an international oil price shock ($\hat{o}_t$); a shock to foreign demand of the domestic commodity (potash/phosphate) ($\hat{s}_t$); and a monetary policy shock ($\hat{v}^m_t$). See Tables 1 and 2 for baseline parameterization of shocks and estimation results, respectively.

III. Econometric Methodology

Having set up a theoretical model with nominal and real rigidities, we estimate the structural coefficients that characterize the economy. We follow Rabanal and Rubio-Ramírez (2005), Lubik and Schorfheide (2006) and Adolfson *et al.* (2005b) in using Bayesian estimation techniques for both the model estimation and our evaluation.

Appendix I presents the log-linearized version of the model developed in the previous section. Equations (A1) through (A32) form a linear rational expectation system that can be written in canonical form as:

$$\Omega_0(\vartheta)\boldsymbol{z}_t = \Omega_1(\vartheta)\boldsymbol{z}_{t-1} + \Omega_2(\vartheta)\varepsilon_t + \Omega_3(\vartheta)\boldsymbol{\xi}_t$$

where

$$\boldsymbol{z}_t = \left\{ \begin{matrix} \hat{c}_t, \hat{c}_{F,t}, \hat{c}_{H,t}, \hat{\imath}_t, \hat{r}_t, \hat{\pi}_t, \hat{\pi}_{Z,t}, \Delta\hat{e}_t, \hat{b}_t^*, \widehat{rer}_t, \hat{p}_{H,t}, \hat{p}_{O,t}, \hat{\pi}_{H,t}, \widehat{wr}_t, \widehat{mr}_{S,t}, \hat{l}_t, \hat{o}_t, \hat{o}_{C,t}, \hat{o}_{H,t}, \\ \hat{y}_t, \hat{y}_{H,t}, \hat{x}_t, \widehat{m}_t, \hat{a}_{H,t}, \hat{\zeta}_{L,t}, \hat{c}_t^*, \hat{p}_{O,t}^*, \hat{\psi}_t, \hat{\imath}_t^*, \hat{\pi}_t^*, \hat{y}_{S,t}, \hat{v}_t^m \end{matrix} \right\}$$

is a vector containing the model's variables expressed as log-deviations from their steady-state values, and

$$\boldsymbol{\varepsilon}_t = \left\{ \varepsilon_{a_{H,t}}, \varepsilon_{i^*,t}, \varepsilon_{c^*,t}, \varepsilon_{\pi^*,t}, \varepsilon_{\zeta_L,t}, \varepsilon_{\psi,t}, \varepsilon_{o,t}, \varepsilon_{S,t}, \varepsilon_{v_t^m} \right\}$$

is a vector of containing white noise innovations to the structural shocks of the model, and $\boldsymbol{\xi}_t$ is a vector containing rational expectation forecast errors. Matrices Ω_i are non-linear functions of the structural parameters contained in vector ϑ. The solution to this system can be expressed as follows:

$$\boldsymbol{z}_t = \Omega_z(\vartheta)\boldsymbol{z}_{t-1} + \Omega_\varepsilon(\vartheta)\varepsilon_t \quad (33)$$

where Ω_z and Ω_ε are functions of the structural parameters.

The Bayesian approach is a system-based methodology that fits the DSGE model to a vector of time series. The estimation is based on the likelihood function generated by the solution of the log-linear version of the model. Prior distributions are used to incorporate additional information into the parameters' estimation. Simply stated, the Bayesian approach works as follows:

Let $\boldsymbol{y}_t$ be a vector of observable variables. This vector is related to the variables in the model through a measurement equation:

$$\boldsymbol{y}_t = H\boldsymbol{z}_t \quad (34)$$

where H is the matrix that selects elements from $\boldsymbol{z}_t$. In our case we assume that the vector of observable variables is given by $\boldsymbol{y}_t$=$\{\hat{y}_t, \hat{r}_t, \hat{\pi}_{Z,t}, \Delta\hat{e}_t, \widehat{rer}_t, \hat{p}_{O,t}, \widehat{wr}_t, \hat{l}_t, \hat{o}_t\}$. The rest of the variables are assumed to be non-observable.

Equations (33) and (34) correspond to the state-space form representation of $\boldsymbol{y}_t$. If we assume that the white noise innovations are normally distributed, we can compute the conditional likelihood function for the structural parameters using the Kalman filter since the Bayesian approach first places a prior distribution with density $\mathbf{p}(\vartheta)$ on the structural parameters, ϑ. The data, $\mathbf{Y}^{\mathrm{T}}$, are then used to update the prior distribution through the likelihood function, $L(\vartheta/\mathbf{Y}^{\mathrm{T}})$, to obtain the posterior distribution of ϑ. According to Bayes' theorem, this latter distribution, $\mathbf{p}(\vartheta)/\mathbf{Y}^{\mathrm{T}}$, takes the form:

$$\mathbf{p}(\vartheta|\boldsymbol{Y}^T) = \frac{L(\vartheta|\boldsymbol{Y}^T)\mathbf{p}(\vartheta)}{\int L(\vartheta|\boldsymbol{Y}^T)\mathbf{p}(\vartheta)\, d\vartheta} \quad (35)$$

Draws from this posterior distribution can be generated through Bayesian simulation techniques (Metropolis-Hastings algorithm). Based on these draws, we can compute the summary statistics (namely, posterior means and standard deviations) that characterize the structural coefficients.

The parameter vector to be estimated is $\vartheta =$

$$\{\sigma_L, h, \theta, \eta, \eta^*, \varrho, \phi_H, \phi_L, \xi_H, \xi_L, \rho_i, \varpi_\pi, \varpi_y, \varpi_{\Delta e}, \rho_a, \rho_\zeta, \rho_c^*, \rho_\psi, \rho_i^*, \rho_\pi^*, \rho_s, \sigma_a, \sigma_\zeta, \sigma_c^*, \sigma_\psi, \sigma_i^*, \sigma_\pi^*, \sigma_s, \sigma_\nu\}.$$

Parameters ρ_o and σ_o (persistence—which introduces inertia through its effect on core consumption and marginal costs—and variance of the oil price shock, respectively) are estimated outside the model using international *World Economic Outlook* data on oil prices. Parameter ρ_ν (persistence of the monetary shock) is assumed to be zero. We kept a number of parameters fixed throughout the estimation procedure. Most of these parameters can be related to the steady-state values of the observed variables in the model, and they are therefore calibrated so as to match long-run statistics in Jordanian data (Table 1). In particular, we assume an annual long-run labor productivity growth of 3.5 percent. This is consistent with 6 percent long-run GDP growth and 2 percent labor force growth. The long-run annual inflation rate is 6 percent. The subjective discount factor, β, is set close to 0.99 (quarterly basis) to yield an annual nominal interest rate of 7.5 percent in the steady state. The share of imported goods in the consumption basket, γ, is set at 40 percent, while the share of *home* goods production in total GDP, $(C_H + C_H^*)/Y$, is set at 90 percent.[15] The ratio of net imports to GDP, $(M - X)/Y$, in the steady state is equal to 25 percent, which is consistent with the average value of this statistic in the sample period analyzed. The remaining shares can be obtained using these values and the steady-state relations (see Appendix I). Obtaining direct information on the elasticity of substitution between different types of labor is cumbersome, so we use values in the range used by other studies: $\epsilon_H = \epsilon_L = 11$[16].

To compute the steady-state share of oil in the production of *home* goods O_H/Y_H we utilize the figures for the total oil imports ratio to GDP, $(O_c + O_H)/Y$, which is around 0.15, and then subtract the share of fuel consumption by households. Finally, the estimation of the

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[15] Natural commodity resources, *S*, account for the remaining 10 percent.

[16] Christiano, Eichenbaum, and Evans (2005) use $\epsilon_L = 21$ and $\epsilon_H = 6$ for a closed economy model calibrated for the United States. Adolfson *et al.* (2005b) use the same values for an open economy model calibrated for the euro area. Brubakk and others (2005) use $\epsilon_L = 5.5$ and $\epsilon_H = 6$ for a calibrated model of the Norwegian economy. Jacquinot *et al.* (2005) calibrate $\epsilon_L = 2.65$ and $\epsilon_H = 11$. Medina and Soto (2007) calibrate each at 11 for Chile. Batini *et al.* (2009) calibrate (as per Smets and Wouters (2003)) ϵ_L at 3 implying a markup of 50 percent, and ϵ_H at 7.7, corresponding to a markup of 15 percent. Peiris and Saxegaard (2010) estimate the mark up factor for intermediate goods to be 9.

autoregressive process for the real international price of oil implies that ρ_o = 0.92 and σ_o = 12.4 percent.

A. Data

To estimate the model, we use quarterly Jordanian data for the period 1992:1 to 2009:4. We choose the following seven observables variables: real GDP, the short-term real interest rate, consumer price inflation (CPI), the real exchange rate, nominal exchange rate devaluation, real wages, and labor input. Labor input is constructed as the fraction of total employment over the working-age population. Real GDP, consumer prices, real wages, and labor input are seasonally adjusted. We also utilize the series on oil imports and the real price of oil (international price of WTI oil deflated by an index of relevant external prices for the Jordanian economy). We use headline inflation as a measure of consumer price inflation. Headline inflation is also used to deflate nominal wages and construct the real exchange rate. We demean all variables. In the case of real wages and GDP, we detrend and demean the series using a linear trend in order to work with stationary series. The short-term real interest rate corresponds to the monetary policy rate and the real interest rate is constructed as the difference between the nominal monetary policy rate and the expected inflation rate implicit in the CBJ's forecast.

B. Prior Distribution

Priors' density functions reflect our beliefs about parameter values. Setting a relatively high standard deviation for a density function implies that our prior for the corresponding parameter is more diffuse. In general, we choose priors based on evidence from previous studies on emerging and developing markets with relatively similar economic structures and macroeconomic policy rules—Chile (Medina and Soto, 2007; and Batini *et al.*, 2009); Hungary (Jakab and Világi, 2007); Latvia (Ajevskis and Vītola, 2009); and Mozambique (Peiris and Saxegaard, 2010); and hereafter referred to as "other oil-importer DSGE studies". When the evidence is weak or nonexistent, we impose more diffuse priors.

Broadly in line with the estimated policy-rule coefficients of other oil-importer DSGE studies, Table 2 depicts the prior distribution for each parameter contained in ϑ, its mean and its standard deviation. For the inverse elasticity of labor supply, σ_L, we assume a truncated normal distribution with mean 1.0 and standard deviation 0.3. The habit formation coefficient, h, has a truncated normal distribution with mean 0.5 and standard deviation 0.25. The probabilities that prices and wages are not reset optimally every quarter, ϕ_H and ϕ_L, respectively, are assumed to follow a gamma distribution with mean 0.75 and standard deviation 0.05. These are similar priors to the ones considered by Adolfson *et al.* (2007) for the euro area and by Rabanal and Rubio-Ramírez (2005) for the U.S., and other oil-importer DSGE studies. The elasticity of substitution between foreign and domestic goods, θ, follows an inverse gamma distribution with mean 1.0 and standard deviation 0.3. The prior assumed for η^* follows a truncated normal distribution with mean 0.1 and standard deviation 0.01. The elasticity of the international supply of funds, ϱ, is assumed to follow an inverse gamma distribution with mean 0.75 and standard deviation 0.2.

As in these other oil-importer DSGE studies, we do not impose non-negativity restrictions on the policy rule coefficients.[17] In particular, we assume truncated normal distributions for ϖ_{π}, ϖ_{y}, and an inverse gamma distribution for $\varpi_{\Delta e}$ (the long-run responses of the central bank to deviations of GDP and inflation from their steady-state levels, respectively, and real effective exchange rate volatility). For ϖ_{π} and ϖ_{y} we set a mean of 0.75 with a standard deviation of 0.15. For $\varpi_{\Delta e}$, we set a mean of 0.5 and a standard deviation of 0.15. Finally, for the interest rate smoothing coefficient, ρ_i, we assume a gamma distribution with mean 0.75 and a standard deviation of 0.2.

Following these other oil-importer DSGE studies, we assume a low degree of substitution of oil in the consumption basket and also in the production function. In particular, our priors are such that η and ω have inverse gamma distributions with mean 0.15 and 0.10, respectively, and the same standard deviation 0.5. The autoregressive parameters (persistence) of the stochastic shocks, $\rho_{\zeta}, \rho_{i^*}, \rho_{\pi^*}, \rho_{S}, \rho_{c^*}, \rho_{\psi}, \rho_{a}$ have gamma distributions. We do not impose tight priors on these distributions, so shocks can be either persistent or non-persistent. In particular, for all parameters we set the prior mean at 0.7 and the standard deviation at 0.25. The shape of this distribution implies a rather diffuse prior (i.e., we do not have strong prior information on those coefficients).

IV. Bayesian Estimation Results

Once the priors have been specified, we estimate the model by first computing the posterior mode, and then constructing the posterior distribution with the Metropolis-Hastings algorithm. In Table 2 (last column) we present the posterior mean of each parameter under the fixed exchange rate regime specifications.[18]

The elasticity of labor supply, σ_L^{-1}, is estimated at 0.95, which is smaller than the values estimated for the U.S. (Rabanal and Rubio-Ramírez, 2005), Chile (Medina and Soto, 2007) and Mozambique (Peiris and Saxegaard, 2010), implying a stronger labor supply sensitivity to real wages. On the other hand, the estimated habit formation coefficient, *h*, is 0.49, which is coherent with an autoregressive coefficient for consumption—*h*/(1 - *h*)—of nearly 0.95.

[17] Batini *et al.* (2009) is an exception, which imposes a non-zero lower bound constraint on the nominal interest rate.

[18] As mentioned, we also experimented with an alternative hypothetical specification which considers a floating exchange regime where nominal exchange rate deviations take place. These hypothetical results are available upon request.

This is lower than the estimates for the inertial behavior of consumption found for Europe (Adolfson *et al.,* 2007); close to the Hungarian estimate (Jakab and Világi, 2007); but significantly larger than that found for Chile (Medina and Soto, 2007). This could be explained by the explicit inclusion of imported oil in the consumption basket. Since we estimate an elasticity of substitution between oil and core consumption of less than one, the persistence of oil shocks by itself will also generate more persistence in aggregate consumption, without having to rely on habit formation.

The estimated elasticity of substitution between *home* and *foreign* goods in the consumption basket of domestic households, θ, is 0.97 (larger than the Chilean estimate—Medina and Soto, 2007). In turn, the estimated value for demand elasticity of *home* goods abroad, η^*, is 0.16 (smaller than the unitary Chilean estimate) implying limited price elasticity of foreign demand. Both estimates are smaller to the corresponding estimates for the U.S. (Rabanal and Rubio-Ramírez, 2005) and the euro area (Adolfson *et al.,* 2007). Finally, in line with other fixed exchange rate regimes, the estimated risk premium facing Jordan on its foreign borrowing is 0.74.[19]

The estimated value of the elasticity of substitution between oil and core consumption, η, is comparable to the one between labor and oil in production, ω. In particular, η is estimated to be around 0.13, whereas ω is 0.09. These elasticities are much lower than those estimated for Chile (Medina and Soto, 2007), reflecting perhaps limited alternative energy sources and technological constraints. Moreover, the weight of oil in production, α, is estimated to be considerably larger than in consumption, δ, 0.29 and 0.08, respectively. This should imply larger persistence (and volatility of macro variables) in response to oil price shocks.

The posterior mean of the Calvo probability is 0.70 for *home* goods prices, ϕ_H, and 0.74 for domestic wages, ϕ_L. These results imply that domestic wages are set optimally more frequently than *home* goods prices. In particular, wages are reset optimally every 3.5 quarters whereas *home* goods prices are re-optimized, on average, every 4 quarters. This is in line with Batini *et al.* (2009) and less rigid than Hungary (Jakab and Világi, 2007) and advanced economies' results.[20] [21]

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[19] The estimated premium increases by 13 percent under a *hypothetical* float. Sweden's estimated risk premium under its pegged regime (pre-1992) was 0.61. This falls sharply (0.01–0.05) for the post-1992 period when inflation targeting was adopted (Adolfson *et al.,* 2007).

[20] Adolfson *et al.* (2007) estimations for the euro area find values for ϕ_H and ϕ_L of 0.895 and 0.710, respectively. These values imply average duration between re-optimization of prices and wages of 9.5 and 3.5 quarters, respectively. On the other hand, Rabanal and Rubio-Ramírez (2005) find that for the US, the average duration between re-optimization of prices and wages is 6.2 and 2.4 quarters. In sharp contrast to others, Medina and Soto (2007) find these values to be 0.17 and 0.82, with prices reset optimally every 1.2 quarters while wages being more rigid being optimized every 5 to 6 quarters. Batini *et al.* calibrate both at 0.75, implying adjustment every 4 quarters.

The coefficient ξ_L is estimated to be 0.05, implying relatively low wage indexation—and an indication of an ability to absorb real terms of trade shocks.[22] [23] [24] We also do not find significant evidence of large price indexation, ξ_H = 0.11. These results are consistent with Hungary (Jakab and Világi, 2007), but considerably lower than Chile (Medina and Soto, 2007) and the euro area. The reduced-form coefficient on lagged inflation in the *home* goods Phillips curve, $\xi_H/(1+\beta\xi_H)$, is close to 0.1 (relative to 0.2 for Chile (Medina and Soto, 2007)). Our estimated values for ξ_L and ξ_H are thus consistent with the lower values of rigidities estimated for some small net-oil importer economies, relative to advanced economies.

The results for the policy rule coefficients, ρ_i, ϖ_π, ϖ_y and $\varpi_{\Delta e}$ tend to confirm the findings of other oil-importer DSGE studies. First there is a significant degree of interest rate smoothing (ρ_i=0.68).[25] Second, the response of the interest rate to inflation's deviation from its implicit target or expectation is similar to output growth's deviation from its potential. In particular, ϖ_π is estimated to be 0.75, whereas ϖ_y is estimated to be 0.72.[26] Third, the response of the interest rate to the volatility in the real exchange rate is quite large. In particular, $\varpi_{\Delta e}$ is estimated to be 0.49.[27] [28]

[21] Interestingly, and contrary to the Jordanian result, ϕ_L, falls to 0.52 for a specification under the pegged Swedish regime of pre-1992, implying more flexible re-optimization of wage contracts (every 2 quarters). One could conclude therefore that if wages in Jordan were to be more flexible (i.e., adjust more frequently than the current 3.5 quarters), the response of macro variables to shocks could be less.

[22] While for Chile (Medina and Soto, 2007) this was estimated to be 0.91.

[23] However, given missing data for real wages and employment for Jordan, these results should be taken with caution, as the missing points were randomly generated.

[24] Economic theory tends to suggest that floating the exchange rate is an option when real wages are flexible and money demand is stable (Beidas-Strom and Kandil, 2005).

[25] Close to Chile's (Medina and Soto, 2007) estimate of 0.73 and lower than Latvia's (Ajevskis and Vītola, 2009) estimate of 0.9.

[26] Medina and Soto (2007) find these to be 0.85 and 0.12, respectively, implying relatively more importance to inflation than output, as can be expected given inflation targeting. Ajevskis and Vītola (2009) find these to be 0.016 and 0.51, respectively for Latvia.

[27] This is close to that of Latvia, which is to be expected given the pegged exchange rate regime.

[28] The estimates under an alternative specification, a hypothetical floating exchange rate regime—available upon request—are broadly similar with a few differences; namely: the coefficients for the share of oil in consumption doubles; the risk premium increases by about 30 percent; the elasticity of labor supply with respect to real wages increases; the probabilities of re-optimizing wages and prices increase; the weight of oil in domestic production falls; price indexation increases; monetary policy rule differ in that reaction of the interest rate to deviations from inflation and output in the steady state increase while the weigh assigned to real exchange rate volatility falls.

V. Effects of Shocks

A. Baseline Results

In order to gauge the importance of the individual shocks, we estimate impulse response functions. The results for simulations with posterior mean parameters under the current fixed exchange rate cases are reported in Figures 2–8.[29] Bayesian estimates of impulse responses to shocks are also reported in Table 2. The posterior distributions of the impulse responses are constructed by pulling parameters, together with the variances of the shocks, from the corresponding posterior distributions and for each set of draws generating an impulse response. Repeating this process many times generates posterior distributions of impulse responses.

Figures 2–8 show 90 percent confidence intervals of impulse response distributions to seven shocks: a foreign demand shock ($\hat{c}_t^*$); a foreign interest rate shock ($\hat{\imath}_t^*$); a monetary policy shock ($\hat{v}_t^m$); an international oil price shock ($\hat{o}_t$); a domestic oil price shock ($\hat{\psi}_t$); a shock to foreign demand of the domestic commodity (potash/phosphate) ($\hat{s}_t$); and a labor supply preference shock ($\hat{\zeta}_{L,t}$).[30] The posterior distributions of the impulse responses look quite similar to the ones obtained from simulations with posterior mean parameters. The confidence intervals of the impulse responses appear to be quite narrow, indicating that the responses are statistically significant.

Impulse responses of our model to different structural shocks are calculated and displayed (Figures 2–8) as reactions of endogenous variables for a 1 standard deviation increase of innovation in the initial period. Price and wage inflation, nominal and real interest rates are defined as annualized growth rates.

A positive *foreign demand shock* raises domestic production of *home* goods and induces an even larger positive income effect/expansion in total output on impact (Figure 2). The large income effect results in higher total consumption, with this being tilted more towards foreign consumption goods, rather than domestic goods. Consumption of imported oil increases, more towards consumption than production. As a result, imports rise faster than exports and the current account/NFA position deteriorates—measured by an increase in foreign debt. With productivity held constant, this expansion leads firms to demand more labor/employment and given relatively low indexation of wages, real wages rise. With higher

[29] We also ran these for *a hypothetical* flexible exchange rate regime and found smaller responses of macro variables, although the risk premium rose. This implies that a flexible exchange rate regime could serve to lower volatility of macro variables in response to shocks. These results are available upon request.

[30] We do not report the impact of a productivity shock or foreign inflation shock. The former is available upon request while the latter is immaterial given the pegged exchange rate.

marginal costs of production, domestic prices—core and headline inflation, as well as real *home* goods prices rise inducing the central bank to tighten the monetary stance by raising the nominal interest rate inducing real exchange rate appreciation[31] which also contributes in turn to dampening export growth.

An increase in foreign interest rates—*a foreign interest rate shock*—sharply contracts consumption and output on impact (Figure 3). The contraction in aggregate demand in turn induces firms to hire less and employment/labor falls, exerting downward pressure on real wages and core and headline inflation. With lower aggregate demand, imported oil and goods fall. Lower marginal costs and sluggish domestic demand induce the central bank gradually lower its policy rate. Jordanian firms benefit from lower interest rates and marginal costs, shifting their production to exportation. This results in real exchange rate depreciation; a fall in the stock of foreign debt; and thus an improvement in the current account/NFA position.

A *monetary-policy shock* in traditional Keynesian models with no frictions result in intertemporal consumption smoothing—(i.e., households shift consumption from today to tomorrow). However, New Keynesian models with frictions suggest that a high interest rate induces households to choose a consumption profile characterized by an increasing growth rate of consumption (Christiano *et al.*, 2005).[32] In the case of Jordan ($h = 0.49$), with a one off increase to the interest rate, the intertemporal budget balance generates a hump-shaped consumption profile given its inertial behavior and not fully flexible prices and wages, reflecting an inability to shift quickly from consumption to savings in response to the one off nominal interest rate shock (Figure 4).[33] As a result import growth and foreign debt rise. It appears that in Jordan the intertemporal positive effect of a contractionary monetary policy shock does not dominate its negative intratemporal effect.

Given that Jordan is an oil importer and that a fraction of households' expenditure and firm costs are devoted to oil, an unanticipated *international or domestic oil price shock* implies a negative income effect that contracts total consumption and output on impact (Figure 5). As a consequence, the demand for all types of goods in the consumption basket falls, particularly foreign goods—and to a lesser extent imported oil and *home* goods, given low substitution

[31] Note that the hump shape of the impulse response function for the real exchange rate (with a peak after about one year) is similar to vector autoregressive (VAR) model evidence and unlike standard uncovered interest parity (UIP) evidence from estimated DSGEs (implying a peak effect within the quarter followed by a relatively quick mean reversion). This is due to our model's inclusion of the risk premium, similar to Adolfson *et al*. (2008).

[32] This is particularly obvious when investment/capital formation is present in the model.

[33] When Christiano *et al* (2005) eliminated habit formation, h=0, they found that while the monetary shock led to a large rise in output the rise in inflation was even larger, as consumption responded quickly without nominal frictions.

elasticities. Given that firms face increasing marginal costs due to the higher real oil price and have a low elasticity of substitution between oil and labor in production, they shed labor given lower output due to weaker domestic demand and contracting income. As a result real wages and prices fall fast, while core and headline inflation rise initially due to the higher oil price but then adjust downward, on the back of falling real wages and real home good prices. Monetary policy responds to the contraction in output and initial uptick in inflation by lowering its nominal interest rate. Firms still manage to shift production towards exports and this is helped by lower prices and a depreciating real exchange rate. As a result, of the large fall in imports and some pickup in exports, the current account improves and the stock of foreign debt falls. There is no difference between the international and domestic oil price shock (Figure 5 versus Figure 6) other than that the magnitude of the former is much larger.

A positive production *shock to the exportable commodity* (potash/phosphate) increases production of the commodity good and directly implies an increase in output and consumption (Figure 7). The expansion is inflationary, with higher real domestic prices and wages, prompting the central bank to tighten monetary policy. As with any expansion biased towards tradable goods, a boom in this sector would induce real appreciation of the exchange rate. While exports of potash rise, net exports growth does not rise since the appreciation harms non-commodity exports. The extent of real appreciation would depend on the structural parameters governing the degree of intratemporal and intertemporal substitution in aggregate demand and production.

B. Robustness

Two approaches to robustness are employed in the DSGE literature. The first approach is to estimate in parallel a VAR (or a BVAR). If a particular DSGE prior is overruled by the data when estimating the VAR this questions the theoretical restrictions included in the DSGE model and indicates misspecification. The second approach is comparing priors and posteriors within the DSGE model to assess overlap; concentration, symmetry, mean and pile up, and overall reasonableness. We adopt this second approach.

First, we modify the distributional assumption on parameters and set all distributions to a truncated Normal. This is in line with other computational packages, such as the IMF's GPM+ and IRIS, in which truncated Normal distribution is the only choice available to the researcher. The estimation results (Table 3) do not reveal any substantial differences from the baseline model. Posterior estimates for some parameters are slightly higher (e.g., the elasticity of foreign demand parameter goes up from 0.16 to 0.20), while estimates for other parameters are slightly lower (e.g., the domestic interest rate smoothing parameter goes down from 0.68 to 0.60). However, these differences are insubstantial and go in both directions, supporting the robustness of our findings to the set of distributional assumptions.

Next, we expand the standard deviation of the prior distribution by 0.05 in order to allow the posterior estimate to move around the mean more freely. Estimation results (Table 4) provide further evidence of the robustness of Bayesian estimation. Similar to the previous robustness check, the posterior estimates do not differ much from the baseline model and the differences go in both directions. This implies that prior distributions are not too tight and do not restrict the posterior estimates to deviate largely from their priors.

Finally, we increase prior means by 5 percent from their benchmark value to check robustness of the results to a shift in the mean. The estimation results (Table 5) show that while most posterior estimates indeed shifted upward in response to the increase in the prior means, some parameters (e.g., the elasticity of foreign demand) have actually shifted downwards. This finding provides further evidence of robustness, since it shows that not all values of posterior parameters are driven by the assumption on prior means.

Overall, the above discussion suggests that the model parameters are stable and robust to the distributional assumptions on priors.

VI. Conclusions

In this paper we present an estimated dynamic stochastic general equilibrium (DSGE) model for the Jordanian economy. The model is framed in the New Keynesian tradition, where firms are assumed to adjust prices infrequently and wages are set in a staggered fashion. Oil is used as an input to production, and it is also part of the consumption basket of households. We allow for a flexible elasticity of substitution between oil and other types of consumption goods in the consumption bundle, and also in the technology utilized by domestic firms. Key structural parameters of the model are jointly estimated following a Bayesian approach. The estimates of the structural parameters fall within plausible ranges. To evaluate different exchange rate policies for Jordan, we simulate the model using different policy parameters and compare the results under various policy rules.

Our main results are as follows. First, foreign demand shocks raise income and consumption, cause real exchange rate appreciation, and deteriorate the current account/NFA position. Second, foreign interest rate shocks contract consumption and output, depreciate the real exchange rate and improve the current account. Third, monetary-policy shocks (of a high domestic interest rate) induce households to choose a consumption profile characterized by an increasing growth rate of consumption, while foreign debt rises deteriorating the current account. Fourth, international and domestic oil price shocks result in a large negative income effect, depreciating the real exchange rate, and improving the current account. Fifth, models with both price and wage rigidities best account for the Jordanian data.

Notably, the degree of wage rigidities is lower than that of domestic prices. Our results show that nominal wages are adjusted optimally every four quarters, on average, whereas prices are re-optimized every three and a half quarters, on average. On the other hand, low wage indexation generates a less persistent response of inflation to shocks, and it is not therefore one of the main determinants of the policy trade-off. Finally, real rigidities such as habit formation also provide a better account of the aggregate data, and the estimated values are quantitatively larger than for other net-oil importer models.

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APPENDIX I

Log-linearized Model

The model is log-linearized using Taylor expansions around the steady state. In order to simplify the model we normalize the steady state level of productivity to $A_H = \frac{\epsilon_H}{\epsilon_H - 1}$. We also normalize the steady state labor disutility parameter ζ so that the real wage is one. Under these two normalizations and properly choosing the foreign currency price level of imported goods all relative prices are one.

Let a variable in lowercase with a hat (^) represent the log deviation with respect to the steady state. In what follows a "real" price, denoted by $\widehat{pr}_{J,t}$, the corresponding nominal price of good *J* relative to the price of the consumption bundle $\widehat{pr}_{J,t} = \hat{p}_{J,t} - \hat{p}_t$. Analogously, the real wage corresponds to the nominal wage relative to the CPI, $\widehat{wr}_t = \widehat{w}_t - \hat{p}_t$. For a pegged exchange rate regime we set nominal exchange rate movement to naught, $\Delta\hat{e} = 0$.[34]

A.1 Aggregate Demand

We detrend and log-linearize expressions (4) and (5) to obtain the following expressions for domestic consumption of *home* and *foreign* goods, and *oil* consumption

$$\hat{c}_{H,t} = (1-\gamma)(\theta-\eta)\widehat{rer}_t - (\theta(1-\gamma)+\gamma\eta)\widehat{pr}_{H,t} + \hat{c}_t \quad \text{(A1)}$$

$$\hat{c}_{F,t} = -(\theta\gamma + \eta(1-\gamma))\widehat{rer}_t - \gamma(\theta-\eta)\widehat{pr}_{H,t} + \hat{c}_t \quad \text{(A2)}$$

$$\hat{o}_{C,t} = -\eta\widehat{pr}_{O,t} + \hat{c}_t \quad \text{(A3)}$$

where $\widehat{rer}_t = \hat{e}_t + \hat{p}^*_{F,t} - \hat{p}_t$ is the log-deviation of the real exchange rate from its steady-state level. We are assuming that the law of one price holds for the imported good, meaning that $\hat{p}_{F,t} = \hat{e}_t + \hat{p}^*_{F,t}$, where $\hat{p}^*_{F,t}$is the imported good price in foreign currency.

The optimal conditions can be combined to obtain the log-linear expressions for the Euler equation and the uncovered interest parity condition

$$\hat{c}_t = \frac{1}{1+h}E_t(\hat{c}_{t+1}) + \frac{h}{1+h}\hat{c}_{t-1} - \frac{1-h}{1+h}[\hat{\imath}_t - E_t(\hat{\pi}_{t+1})] \text{ and} \quad \text{(A4)}$$

[34] Note that the interest rate will respond sharply to nominal exchange rate movements so as to keep it constant, with this formulation the interest rate will, for instance, respond almost one to one to foreign interest rate movements (see Adolfson *et al.* 2007). For the *hypothetical* flexible exchange rate regime, we removed the restriction on the nominal exchange rate movement, $\Delta\hat{e}_t > 0$.

$$\hat{\imath}_t = \hat{\imath}_t^* + E_t(\Delta\hat{e}_{t+1}) + \varrho\hat{b}_t^* \tag{A5}$$

where $\hat{b}_t^* = \ln\left(\frac{e_t B_t^*}{P_{x,t}X_t} / \frac{eB^*}{P_x X}\right)$. The foreign interest rate $\hat{\imath}_t^*$ capture not only the relevant interest rate in the international market but also any exogenous fluctuation in the risk premium not captured by $\varrho\hat{b}_t^*$. The stochastic process for this variable is given by

$$\hat{\imath}_t^* = \rho_{i^*}\hat{\imath}_{t-1}^* + \varepsilon_{i^*,t} \tag{A6}$$

A.2 Aggregate Supply and Inflation

From the optimal price setting and the passive resetting price equation (19) we obtain the following expression for the inflation of *home* goods:

$$\hat{\pi}_{H,t} = \frac{(1-\phi_H)(1-\beta\phi_H)}{\phi_H(1+\beta\xi_H)}\left((1-\alpha)\widehat{wr}_t + \alpha\widehat{pr}_{O,t} - \hat{\alpha}_{H,t} - \widehat{pr}_{H,t}\right) + \frac{\beta}{1+\beta\xi_H}E_t\hat{\pi}_{H,t+1} + \frac{\xi_H}{1+\beta\xi_H}\hat{\pi}_{H,t-1} \tag{A7}$$

The first-order condition for cost minimization problem of firms producing *home* goods determines the following relation between the quantity demanded of both inputs, labor and oil, and their relative prices:

$$\hat{o}_{H,t} - \hat{l}_t = \omega\left(\widehat{wr}_t - \widehat{pr}_{O,t}\right) \tag{A8}$$

From the production function we obtain the following log-linearized version output in the *home* goods sector:

$$\hat{y}_{H,t} = \hat{a}_{H,t} + (1-\alpha)\hat{l}_t + \alpha\hat{o}_{H,t} \tag{A9}$$

where the technology in the *home* goods sectors evolves according to:

$$\hat{\alpha}_{H,t} = \rho_a\hat{\alpha}_{H,t-1} + \varepsilon_{a,t.} \tag{A10}$$

Combining the optimal choice of wages with the updating rule and the definition of the aggregate real wage, we obtain the following log-linear expression for real wages, *wr*:

$$\left[\frac{1+v_L\phi_L+\sigma_L\epsilon_L(\phi_L+v_L)}{1+\sigma_L\epsilon_L}\right]\widehat{wr}_t - \phi_L\widehat{wr}_{t-1}v_L E_t(\widehat{wr}_{t+1}) = \frac{(1-v_L)(1-\phi_L)}{1+\sigma_L\epsilon_L}[\widehat{mrs}_t] - (\phi_L + v_L\xi_L)\hat{\pi}_t + \phi_L\xi_L\hat{\pi}_{t-1} + v_L E_t(\hat{\pi}_{t+1}) + \hat{\zeta}_t \tag{A11}$$

and where $v_L = \beta\phi_L$. Variable $\hat{\zeta}_t = \frac{(1-v_L)(1-\phi_L)}{1+\sigma_L\epsilon_L}\ln\left(\frac{\zeta_t}{\zeta}\right)$ is a preference shock—a shock to the labor disutility parameter. We assume that this variable is stochastic and it follows:

$$\hat{\zeta}_t = \rho_\zeta \hat{\zeta}_{t-1} + \varepsilon_{\zeta,t} \tag{A12}$$

with $E_{t-1}(\varepsilon_{\zeta,t}) = 0$ and $E_{t-1}(\varepsilon_{\zeta,t}^2) = \sigma_\zeta^2$.

The marginal rate of substitution between labor and consumption, $\widehat{mrs}_t$, is given by

$$\widehat{mrs}_t = \sigma_L \hat{l}_t + \frac{1}{1-h}\hat{c}_t - \frac{h}{1-h}\hat{c}_{t-1} \tag{A13}$$

A.3 Relative Prices

The real price of *home* goods and the domestic currency real price of oil evolve according to the following equations:

$$\widehat{pr}_{H,t} = \widehat{pr}_{H,t-1} + \hat{\pi}_{H,t} - \hat{\pi}_t, \tag{A14}$$

$$\widehat{pr}_{O,t} = \widehat{rer}_t + \widehat{pr}_{O,t}^* + \hat{\psi}_t. \tag{A15}$$

The real price of oil abroad—the relative price of oil abroad with respect to the foreign price index—evolves according to the following expression:

$$\widehat{pr}_{O,t}^* = \rho_o \widehat{pr}_{O,t-1}^* + \varepsilon_{o,t} \tag{A16}$$

with $E_{t-1}(\varepsilon_{o,t}) = 0$ and $E_{t-1}(\varepsilon_{o,t}^2) = \sigma_o^2$.

We assume that the variable that captures the deviation of the law of one price for oil, $\hat{\psi}_t$, follows an AR(1) process:

$$\hat{\psi}_t = \rho_\psi \hat{\psi}_{t-1} + \varepsilon_{\psi,t} \tag{A17}$$

Let $\hat{\pi}_t^* = \hat{p}_{F,t}^* - \hat{p}_{F,t-1}^*$ be the foreign inflation expressed in foreign currency. From the definition of the real exchange rate we obtain the following expression for the evolution of this variable:

$$\widehat{rer}_t = \widehat{rer}_{t-1} + \Delta\hat{e}_t + \hat{\pi}_t^* - \hat{\pi}_t \tag{A18}$$

Foreign inflation evolves according to the following exogenous stochastic process:

$$\hat{\pi}_t^* = \rho_\pi \hat{\pi}_{t-1}^* + \varepsilon_{\pi^*,t} \tag{A19}$$

with $E_{t-1}(\varepsilon_{\pi^*,t}) = 0$ and $E_{t-1}(\varepsilon_{\pi^*,t}^2) = \sigma_{\pi^*}^2$.

Finally, from the definition of the CPI and the core consumption price level we have the following relation among the real price of oil, the real price of *home* goods and the real exchange rate:

$$0 = \delta \widehat{pr}_{O,t}^* + (1-\delta)\gamma \widehat{pr}_{H,t} + (1-\delta)(1-\gamma)\widehat{rer}_t \tag{A20}$$

A.4 Aggregate Equilibrium

Using the log-linear expression of equations (A20) and (10) we can express the market clearing condition for the *home* goods sector as an *open economy IS curve*:

$$\hat{y}_{H,t} = \left(\frac{C_H}{Y}\right)\hat{c}_{H,t} + \left(\frac{Y_H - C_H}{Y_H}\right)\hat{c}_t^* - \eta^*\left(\frac{Y_H - C_H}{Y_H}\right)\left(\widehat{pr}_{H,t} - \widehat{rer}_t\right) \quad \text{(A21)}$$

where $\frac{C_H}{Y}$ corresponds to the steady state fraction of *home* goods that is consumed by domestic households. From the definition of total GDP we get the following expression for the log-linearized total output:

$$\hat{y}_t = \frac{C}{Y}\hat{c}_t + \frac{X}{Y}\hat{x}_t - \frac{M}{Y}\widehat{m}_t \quad \text{(A22)}$$

where $\frac{C}{Y}$ corresponds to the consumption ratio to GDP in steady state, $\frac{X}{Y}$ is the total exports to GDP ratio and and $\frac{M}{Y}$ is the total imports to GDP ratio.

The detrended and log-linearized expression for exports is:

$$\hat{x}_t = -\eta^*\left(\frac{C_H^*}{X}\right)\left(\widehat{pr}_{H,t} - \widehat{rer}_t\right) + \left(\frac{C_H^*}{X}\right)\hat{c}_t^* + \frac{Y_S}{X}\hat{y}_{S,t} \quad \text{(A23)}$$

The evolution of commodity exports, $\hat{y}_{S,t}$, and total foreign consumption, $\hat{c}_t^*$, are assumed to be determined by the following exogenous processes:

$$\hat{y}_{S,t} = \rho_S \hat{y}_{S,t-1} + \varepsilon_{S,t} \quad \text{(A24)}$$

$$\hat{c}_t^* = \rho_{C^*}\hat{c}_{t-1}^* + \varepsilon_{c^*,t} \quad \text{(A25)}$$

The real price index of exports is—exports deflator relative to the CPI—is given by $\widehat{pr}_{x,t} = (c_H^*/X)\widehat{pr}_{H,t}$, where we are assuming that the real price of commodity exports is constant, which implies that $\widehat{pr}_{S,t} = 0$.

The detrended and log-linearized expression for imports and its real price are given by:

$$\widehat{m}_t = \frac{C_F}{M}\hat{c}_{F,t} + \frac{M - C_F}{M}\hat{o}_t \quad \text{(A26)}$$

where total oil imports are given by:

$$\hat{o}_t = \frac{O_C}{O}\hat{o}_{C,t} + \frac{O_H}{O}\hat{o}_{H,t} \quad \text{(A27)}$$

The real price index of imports—i.e. the imports deflator relative to the CPI—is given by

$$\widehat{pr}_{M,t} = \frac{C_F}{M}\widehat{rer}_t + \frac{O}{M}\widehat{pr}^*_{O,t}$$

The net foreign asset position of the domestic economy evolves according to the following expression:

$$(1-\varrho)\beta\hat{b}^*_t = \beta i^*_t + \chi\hat{b}^*_{t-1} + \chi\hat{x}_{t-1} + \frac{C^*_H}{X}\chi\widehat{pr}_{H,t} + \chi(\Delta\hat{s}_t - \pi_t) + \left(\frac{P_xX}{eB} - \beta\right)\hat{x}_t + \left(\frac{P_xX}{eB} - \beta\right)\widehat{pr}_{H,t} - \frac{P_xX}{eB}\frac{M}{X}\widehat{m}_t - \frac{P_xX}{eB}\frac{C_F}{X}\widehat{rer}_t - \frac{P_xX}{eB}\frac{O}{X}\widehat{pr}^*_{O,t} \quad \text{(A28)}$$

where $\chi = 1/\left[(1+\pi^*)\left(1+g_y\right)\right]$.

A.5 Policy Rule

The linearized version of the baseline policy rule can be expressed as:

$$\hat{r}_t = \rho_i\hat{r}_{t-1} + (1-\rho_i)\left(\varpi_\pi\hat{\pi}_t + \varpi_y\hat{y}_t + \varpi_{\Delta e}\Delta\hat{e}_t\right) + \hat{v}_t \quad \text{(A29)}$$

where $\hat{r}_t$corresponds to the deviation of the real interest rate from its steady state, defined as:

$$\hat{r}_t = \hat{\imath}_t - E_t\hat{\pi}_{t+1} \quad \text{(A30)}$$

In this specification, ϖ_π and ϖ_y are, respectively, the long run responses of the monetary authority to deviations of inflation and GDP growth from their steady-state levels. We also include a reaction to real devaluation, $\varpi_{\Delta e}$ and ρ_i controls for the degree of interest rate smoothing. Finally, the monetary shock is given by

$$\hat{v}_t = \rho_v\hat{v}_{t-1} + \varepsilon_{v,t} \quad \text{(A32)}$$

Table 1. Baseline Parameterization

Parameter	Value	Descritpiton
Households and labour		
β	0.99	Subjective discount rate (quarterly)
σ_L	1.00	Inverse of the elasticity of labor supply
h	0.50	Coefficient of habit formation
g_y	3.50	Annual productivity growth rate
Private consumption basket		
δ	0.10	Share of imported oil in consumption
η	0.20	Elasticity of substitution in consumption between core consumption and imported oil
1-γ	0.60	Home bias in core consumption
θ	1.00	Intratemporal elasticity of substitution between domestic and foreign goods
Nominal rigidities		
ϕ_L	0.75	Probability of adjusting wages
ξ_L	0.50	Wage indexation/weight of past inflation
ϕ_H	0.75	Probability of adjusting $P_{H,t}$
ξ_H	0.50	Domestic goods indexation at home
Domestic production technology		
α	0.40	Share of imported oil in domestic production
ω	0.30	Elasticity of substitution between oil and other factors of production
ε_L	9.00	Elasticity of substitution of different labour varieties
Foreign sector		
NX/Y	0.27	Net exports to GDP ratio
γ*	1.00	Price elasticity of foreign demand for domestic goods
ϱ	0.001	Elasticity of FX borrowing (supply)
Y_S/Y	0.12	Share of potash/phosphate in total exports
Monetary policy		
ρ_i	0.75	Interest rate smoothing
ϖ_π	0.75	Reaction to inflation
ϖ_y	0.70	Reaction to output gap
$\varpi_{\Delta e}$	0.70	Reaction to real exchange rate misalignment

Table 2. Baseline specification: Results from Posterior Maximization

Parameter	Description	Prior			Posterior
		Density	Mean	St. Dev.	Mode
Consumers					
h	Habit formation of preferences	Normal	0.5000	0.2500	0.4871
Θ	Intratemporal elasticity of substitution between *home* and *foreign* goods	Inverse gamma	1.0000	0.3000	0.9730
η	Elasticity of substitution between oil and core consumption	Inverse gamma	0.1500	0.0500	0.1322
$\eta*$	Elasticity of foreign demand	Normal	0.1000	0.0100	0.1607
φ	Share of oil in consumption	Gamma	0.1000	0.0100	0.0771
σ_L	Inverse elasticity of labor supply with respect to real wages	Normal	1.0000	0.3000	0.9529
	Risk premium on FX borrowing	Inverse gamma	0.7500	0.2000	0.7350
Producers					
ω	Degree of substitution between oil and the other factor of production	Inverse gamma	0.1000	0.5000	0.0865
α	Weight of oil in domestic production	Gamma	0.3000	0.1000	0.2893
Rigidity					
ϕ_H	Calvo probability of re-optimizing domestic goods prices	Gamma	0.7500	0.0500	0.7027
ϕL	Calvo probability of re-optimizing domestic wage contracts	Gamma	0.7500	0.0500	0.7436
ξ_H	Measure of the domestic price rigidity/indexation	Gamma	0.1000	0.0100	0.1108
ξ_L	Measure of nominal wage rigidity/indexation	Gamma	0.1000	0.0100	0.0496
Monetary policy					
ρ	Domestic interest smoothing	Gamma	0.7500	0.2000	0.6832
ω_π	MPC reaction to inflation deviations from its steady-state value	Normal	0.7500	0.1500	0.7514
ω_y	MPC reaction to output deviations from its steady-state value	Normal	0.7500	0.1500	0.7201
$\omega_{\Delta e}$	MPC reaction to real exchange misalignment from its steady-state value	Inverse gamma	0.5000	0.1500	0.4893
Shocks					
ρ_{ah}	Perisitence of domestic productivity shock	Gamma	0.7000	0.2500	0.7029
ρ_s	Persistence of potash/phosphate shock	Gamma	0.7000	0.2500	0.6941
ρ_{c*}	Persistence of foreign demand shock	Gamma	0.7000	0.2500	0.7070
ρ_{i*}	Persistence of foreign interest rate shock	Gamma	0.7000	0.2500	0.7196
$\rho_{\pi*}$	Persistence of foreign inflation shock	Gamma	0.7000	0.2500	0.6692
ρ_ζ	Persistence of preference shock	Gamma	0.7000	0.2500	0.6928
ρ_ψ	Persistence of domestic oil price shock	Gamma	0.7000	0.2500	0.6768

Table 3. Robustness check: Distribution density function

		Prior			Posterior
Parameter	Description	Density	Mean	St. Dev.	Mode
Consumers					
h	Habit formation of preferences	Normal	0.5000	0.2500	0.4738
Θ	Intratemporal elasticity of substitution between *home* and *foreign* goods	Normal	1.0000	0.3000	0.9353
η	Elasticity of substitution between oil and core consumption	Normal	0.1500	0.0500	0.1327
η^*	Elasticity of foreign demand	Normal	0.1000	0.0100	0.2036
ϱ	Share of oil in consumption	Normal	0.1000	0.0100	0.0387
σ_L	Inverse elasticity of labor supply with respect to real wages	Normal	1.0000	0.3000	0.9163
	Risk premium on FX borrowing	Normal	0.7500	0.2000	0.6871
Producers					
ω	Degree of substitution between oil and the other factor of production	Inverse gamma	0.1000	0.5000	0.0899
α	Weight of oil in domestic production	Normal	0.3000	0.1000	0.2880
Rigidity					
ϕ_H	Calvo probability of re-optimizing domestic goods prices	Normal	0.7500	0.0500	0.6456
ϕL	Calvo probability of re-optimizing domestic wage contracts	Normal	0.7500	0.0500	0.7569
ξ_H	Measure of the domestic price rigidity/indexation	Normal	0.1000	0.0100	0.0773
ξ_L	Measure of nominal wage rigidity/indexation	Normal	0.1000	0.0100	0.0373
Monetary policy					
ρ	Domestic interest smoothing	Normal	0.7500	0.2000	0.6001
ω_π	MPC reaction to inflation deviations from its steady-state value	Normal	0.7500	0.1500	0.7410
ω_Y	MPC reaction to output deviations from its steady-state value	Normal	0.7500	0.1500	0.7406
$\omega_{\Delta e}$	MPC reaction to real exchange misalignment from its steady-state value	Inverse gamma	0.5000	0.1500	0.4776
Shocks					
ρ_{ah}	Perisitence of domestic productivity shock	Normal	0.7000	0.2500	0.7138
ρ_s	Persistence of potash/phosphate shock	Normal	0.7000	0.2500	0.7127
ρ_{c*}	Persistence of foreign demand shock	Normal	0.7000	0.2500	0.6741
ρ_{i*}	Persistence of foreign interest rate shock	Normal	0.7000	0.2500	0.7041
$\rho_{\pi*}$	Persistence of foreign inflation shock	Normal	0.7000	0.2500	0.6405
ρ_ζ	Persistence of preference shock	Normal	0.7000	0.2500	0.6559
ρ_ψ	Persistence of domestic oil price shock	Normal	0.7000	0.2500	0.6305

Table 4. Robustness check: Wider standard deviation

Parameter	Description	Prior			Posterior
		Density	Mean	St. Dev.	Mode
Consumers					
h	Habit formation of preferences	Normal	0.5000	0.3000	0.4776
Θ	Intratemporal elasticity of substitution between *home* and *foreign* goods	Normal	1.0000	0.3500	0.9553
η	Elasticity of substitution between oil and core consumption	Normal	0.1500	0.1000	0.1224
η^*	Elasticity of foreign demand	Normal	0.1000	0.0600	0.1550
ϱ	Share of oil in consumption	Normal	0.1000	0.0600	0.0569
σ_L	Inverse elasticity of labor supply with respect to real wages	Normal	1.0000	0.3500	0.9217
	Risk premium on FX borrowing	Normal	0.7500	0.2500	0.7256
Producers					
ω	Degree of substitution between oil and the other factor of production	Inverse gamma	0.1000	0.5500	0.0767
α	Weight of oil in domestic production	Normal	0.3000	0.1500	0.2880
Rigidity					
ϕ_H	Calvo probability of re-optimizing domestic goods prices	Normal	0.7500	0.1000	0.6838
ϕL	Calvo probability of re-optimizing domestic wage contracts	Normal	0.7500	0.1000	0.7302
ξ_H	Measure of the domestic price rigidity/indexation	Normal	0.1000	0.0600	0.1027
ξ_L	Measure of nominal wage rigidity/indexation	Normal	0.1000	0.0600	0.0250
Monetary policy					
ρ	Domestic interest smoothing	Normal	0.7500	0.2500	0.6414
ω_π	MPC reaction to inflation deviations from its steady-state value	Normal	0.7500	0.2000	0.7352
ω_y	MPC reaction to output deviations from its steady-state value	Normal	0.7500	0.2000	0.6980
$\omega_{\Delta e}$	MPC reaction to real exchange misalignment from its steady-state value	Inverse gamma	0.5000	0.2000	0.4747
Shocks					
ρ_{ah}	Perisitence of domestic productivity shock	Normal	0.7000	0.3000	0.7013
ρ_s	Persistence of potash/phosphate shock	Normal	0.7000	0.3000	0.6852
ρ_{c^*}	Persistence of foreign demand shock	Normal	0.7000	0.3000	0.7076
ρ_{i^*}	Persistence of foreign interest rate shock	Normal	0.7000	0.3000	0.7168
ρ_{π^*}	Persistence of foreign inflation shock	Normal	0.7000	0.3000	0.6529
ρ_ζ	Persistence of preference shock	Normal	0.7000	0.3000	0.6816
ρ_ψ	Persistence of domestic oil price shock	Normal	0.7000	0.3000	0.6576

Table 5. Robustness check: Increase prior mean

Parameter	Description	Prior			Posterior
		Density	Mean	St. Dev.	Mode
Consumers					
h	Habit formation of preferences	Normal	0.5250	0.2500	0.5225
Θ	Intratemporal elasticity of substitution between *home* and *foreign* goods	Normal	1.0500	0.3000	1.1007
η	Elasticity of substitution between oil and core consumption	Normal	0.1575	0.0500	0.1593
η^*	Elasticity of foreign demand	Normal	0.1050	0.0100	0.1101
ϱ	Share of oil in consumption	Normal	0.1050	0.0100	0.1078
σ_L	Inverse elasticity of labor supply with respect to real wages	Normal	1.0500	0.3000	1.0543
	Risk premium on FX borrowing	Normal	0.7875	0.2000	0.7881
Producers					
ω	Degree of substitution between oil and the other factor of production	Inverse gamma	0.1050	0.5000	0.1090
α	Weight of oil in domestic production	Normal	0.3150	0.1000	0.2880
Rigidity					
ϕ_H	Calvo probability of re-optimizing domestic goods prices	Normal	0.7875	0.0500	0.7817
ϕL	Calvo probability of re-optimizing domestic wage contracts	Normal	0.7875	0.0500	0.7893
ξ_H	Measure of the domestic price rigidity/indexation	Normal	0.1050	0.0100	0.0912
ξ_L	Measure of nominal wage rigidity/indexation	Normal	0.1050	0.0100	0.1073
Monetary policy					
ρ	Domestic interest smoothing	Normal	0.7875	0.2000	0.7826
ω_π	MPC reaction to inflation deviations from its steady-state value	Normal	0.7875	0.1500	0.7986
ω_y	MPC reaction to output deviations from its steady-state value	Normal	0.7875	0.1500	0.7957
$\omega_{\Delta e}$	MPC reaction to real exchange misalignment from its steady-state value	Inverse gamma	0.5250	0.1500	0.5198
Shocks					
ρ_{ah}	Perisitence of domestic productivity shock	Normal	0.7350	0.2500	0.7334
ρ_s	Persistence of potash/phosphate shock	Normal	0.7350	0.2500	0.7302
ρ_{c*}	Persistence of foreign demand shock	Normal	0.7350	0.2500	0.7272
ρ_{i*}	Persistence of foreign interest rate shock	Normal	0.7350	0.2500	0.7429
$\rho_{\pi*}$	Persistence of foreign inflation shock	Normal	0.7350	0.2500	0.7341
ρ_ζ	Persistence of preference shock	Normal	0.7350	0.2500	0.7365
ρ_ψ	Persistence of domestic oil price shock	Normal	0.7350	0.2500	0.7340

Figure 1. Priors

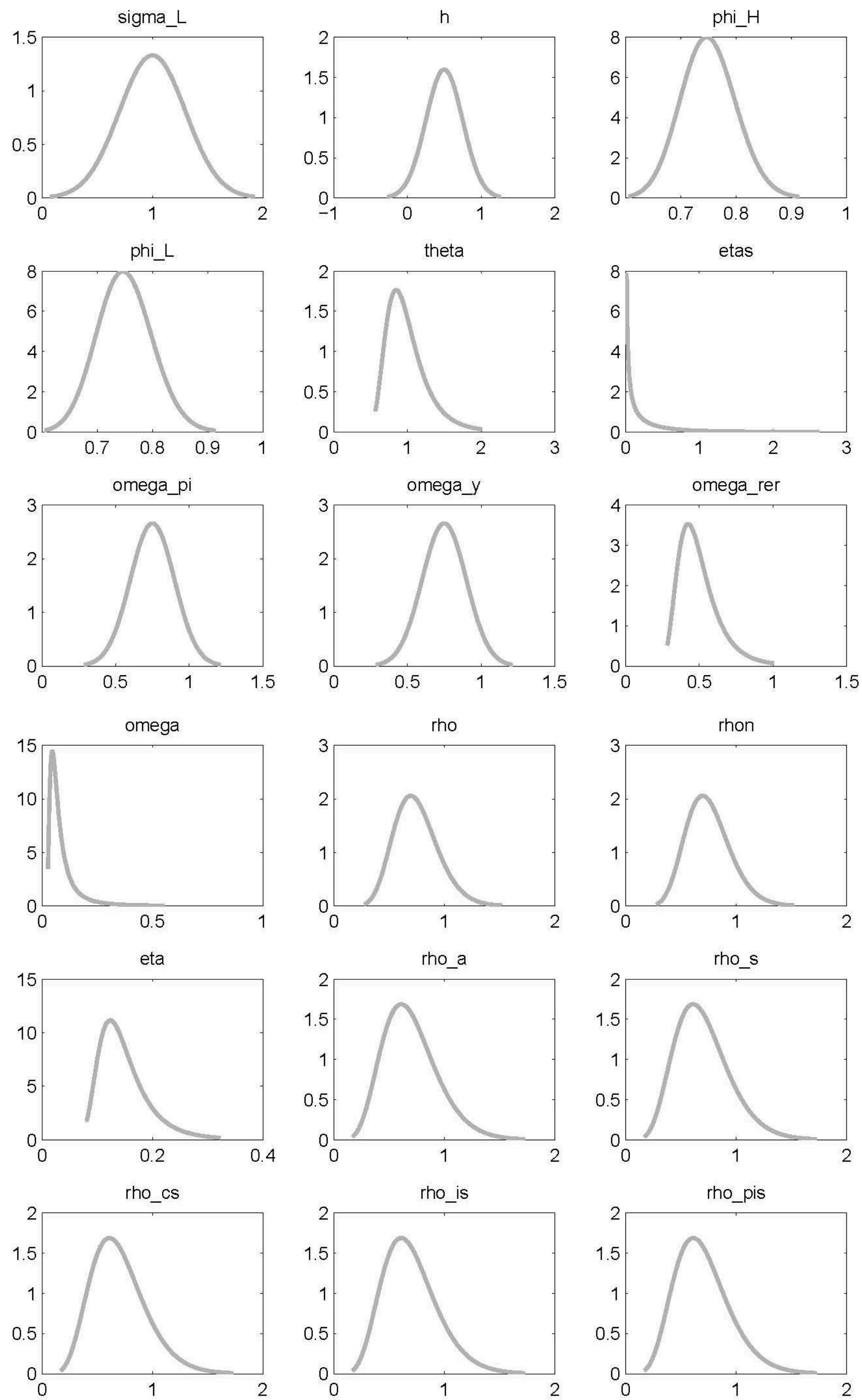

Figure 1 (Concluded). Priors

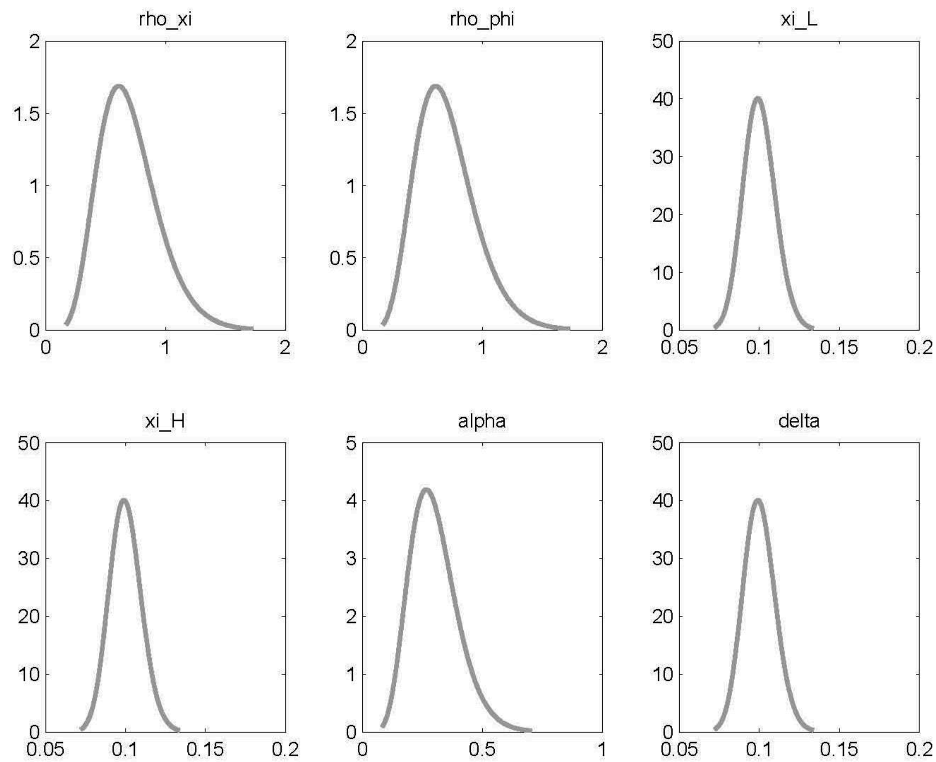

Figure 2. Impulse Response to a Foreign Demand Shock—$\hat{c}_t^*$

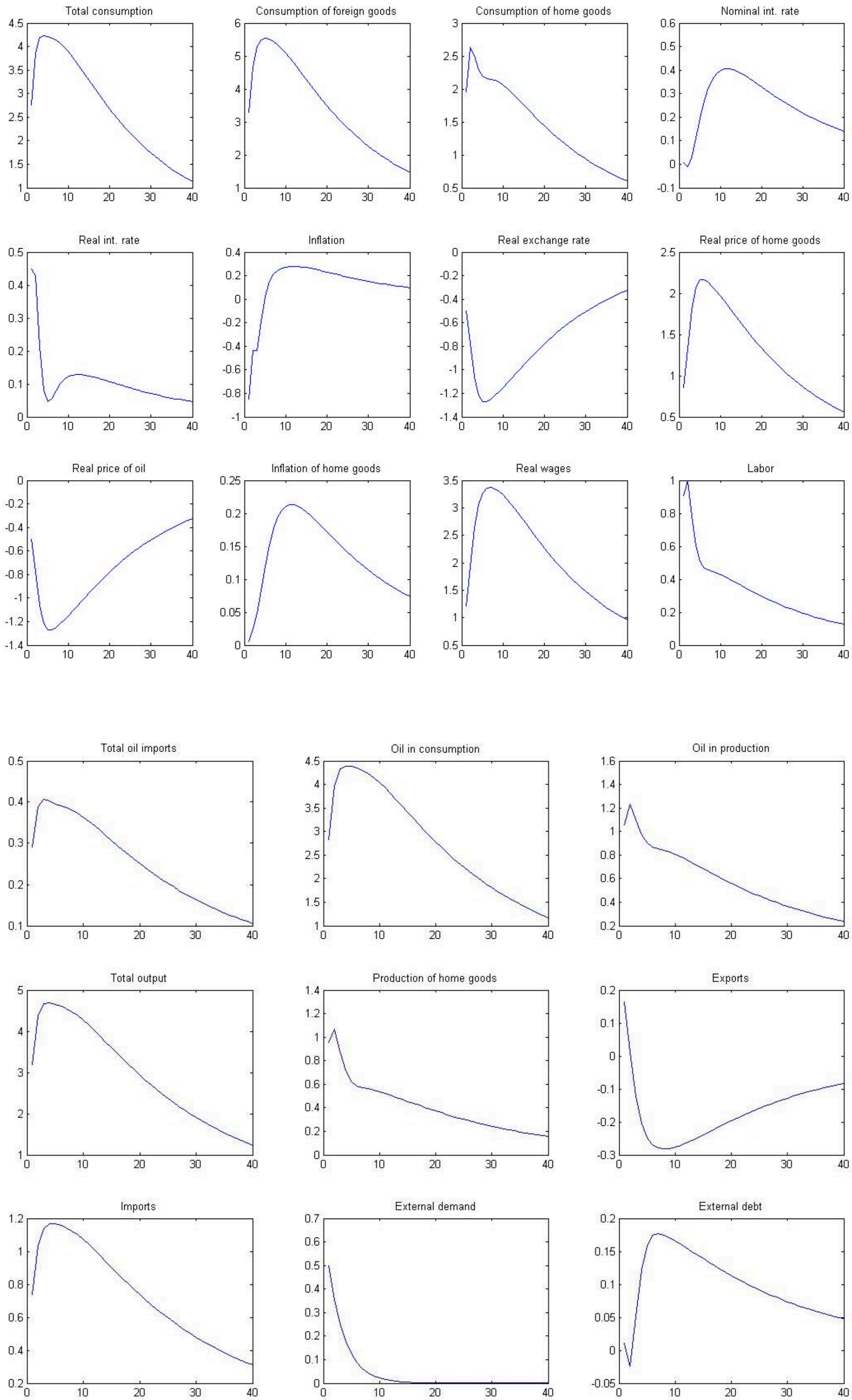

Figure 3. Impulse Response to a Foreign Interest Rate Shock—$\hat{\imath}_t^*$

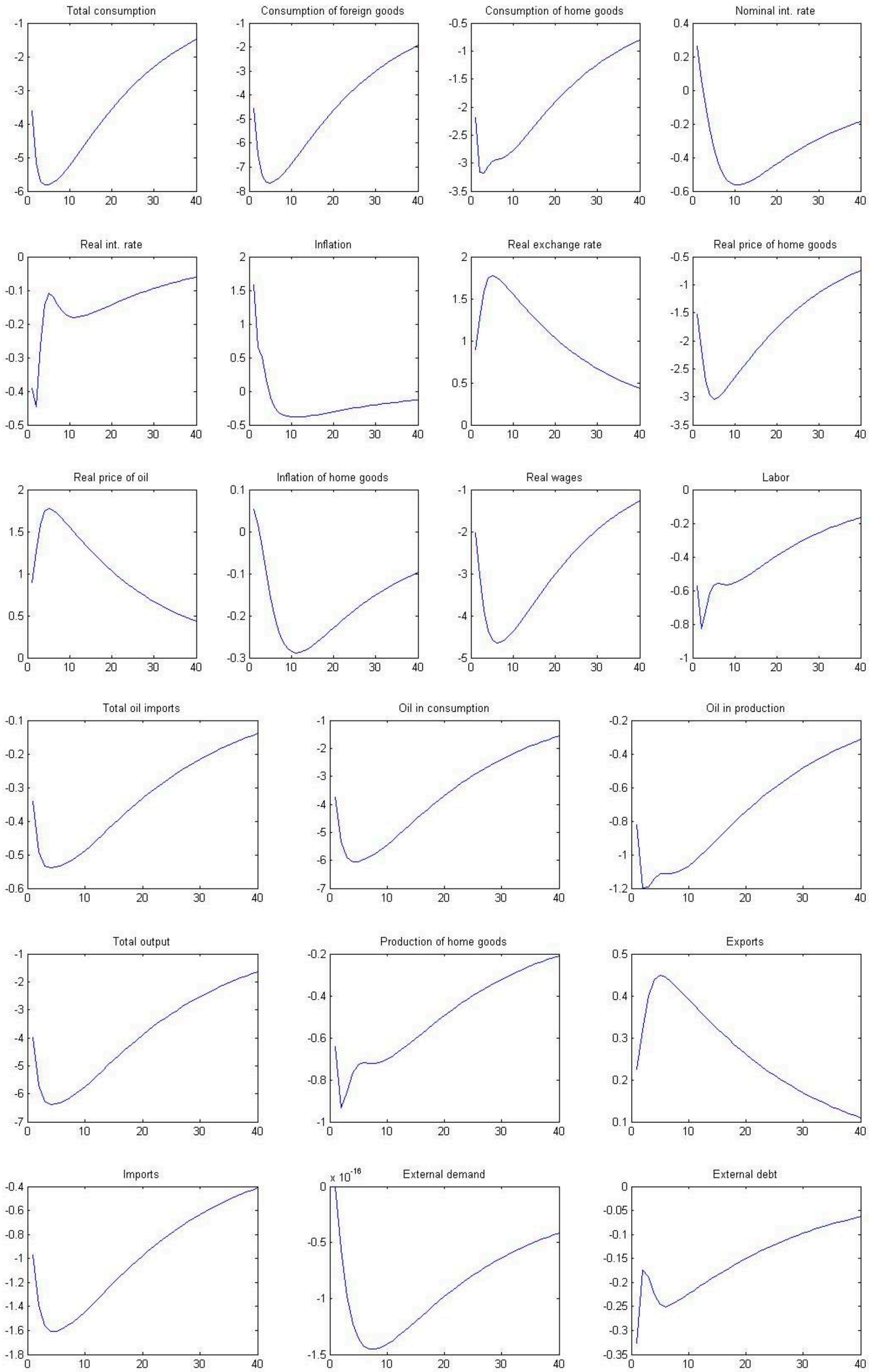

Figure 4. Impulse Response to a Monetary Shock—$\hat{v}_t^m$

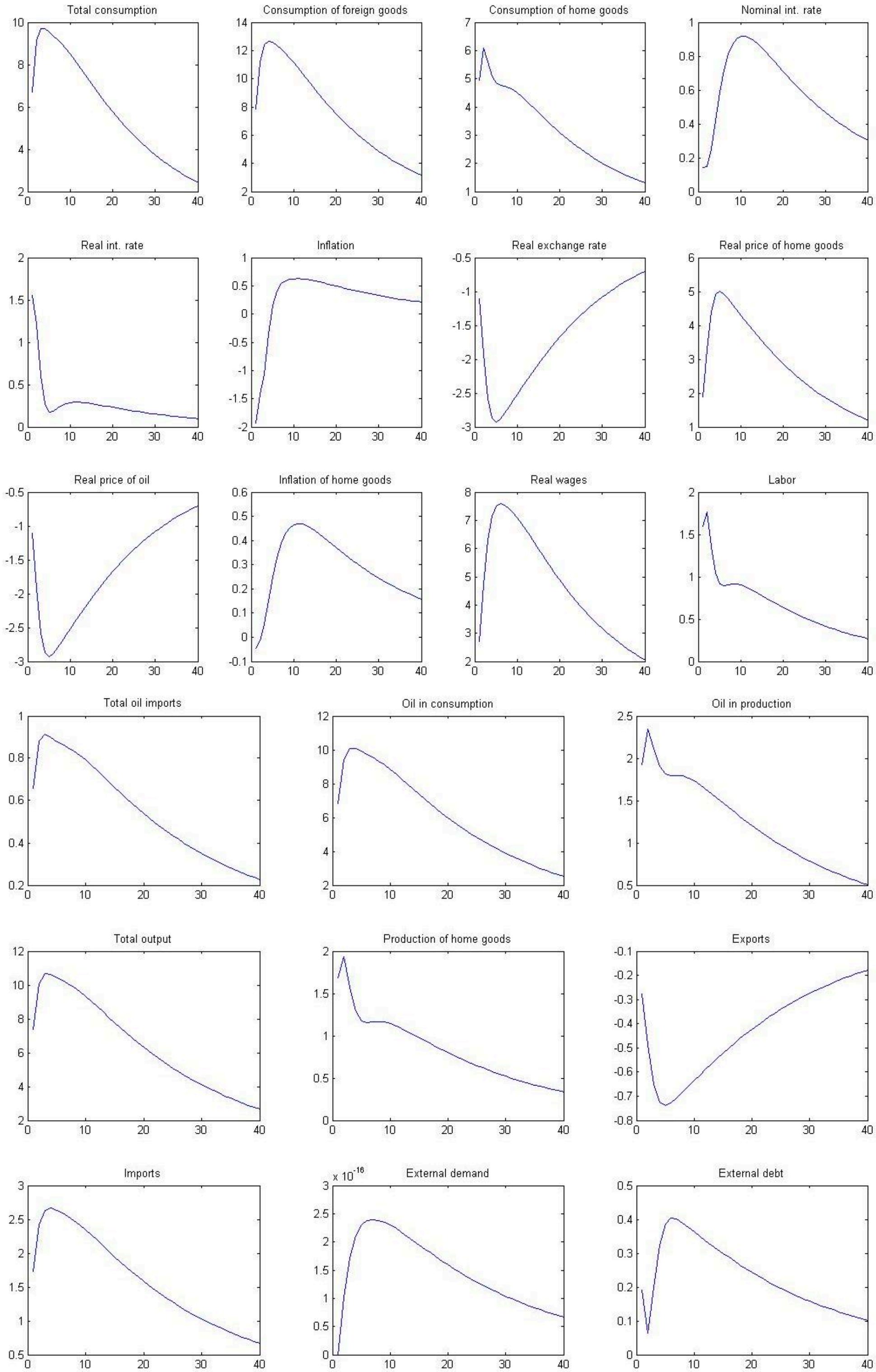

Figure 5. Impulse Response to an International Oil Price Shock—$\hat{o}_t$

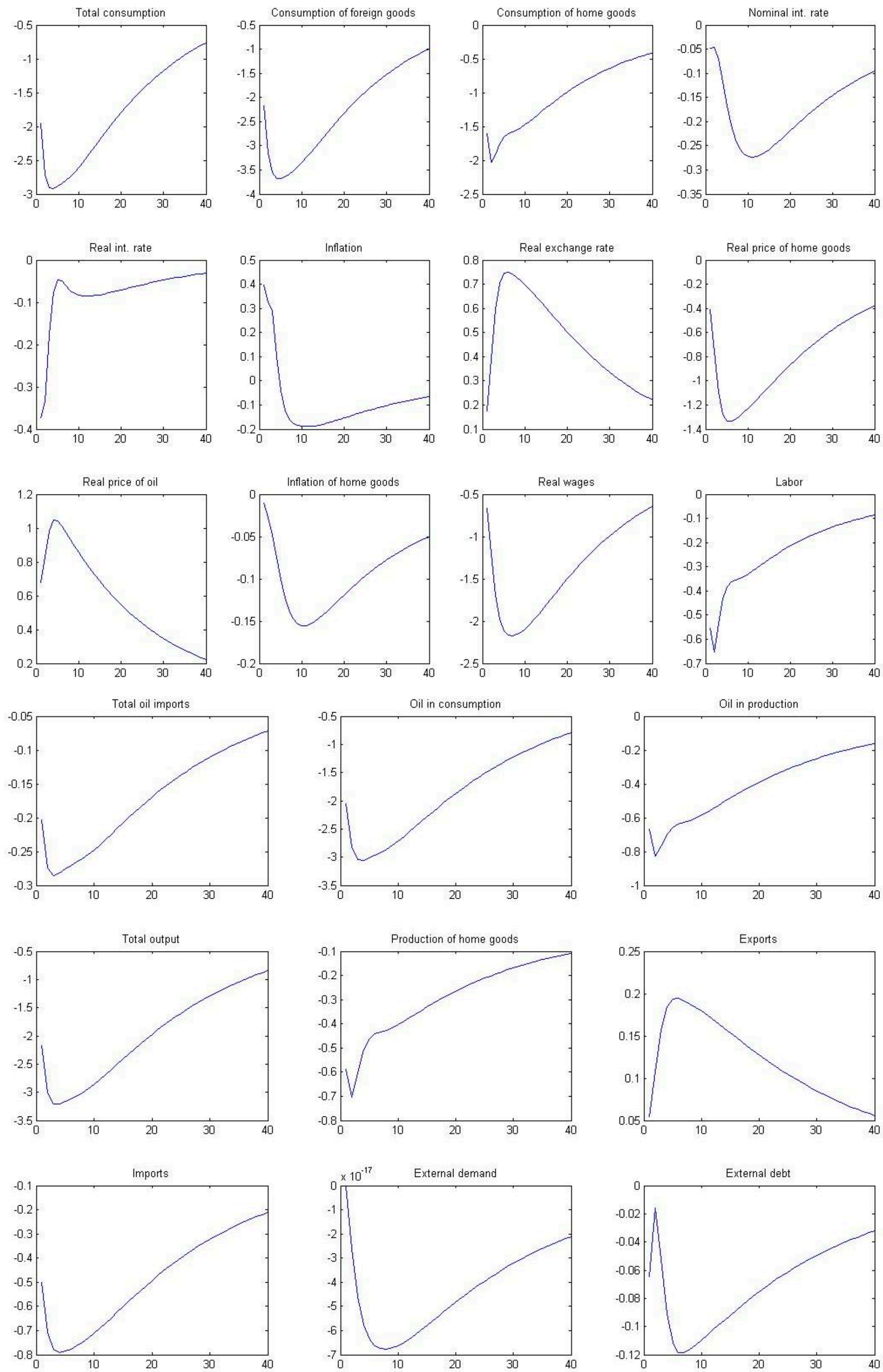

Figure 6. Impulse Response to a Domestic Oil Price Shock—$\hat{\psi}_t$

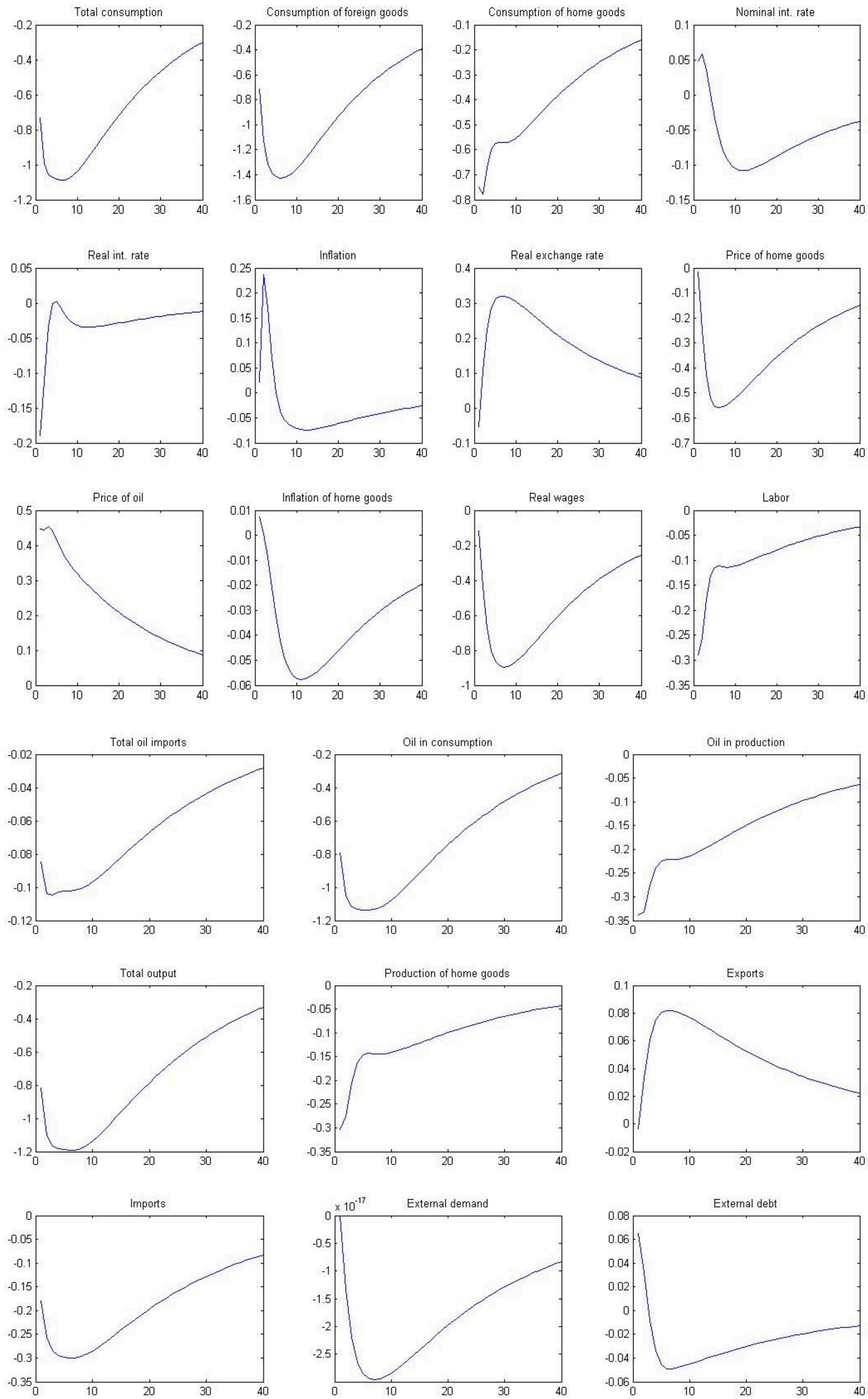

Figure 7. Impulse Response to a Foreign Demand Shock to Potash—$\hat{s}_t$

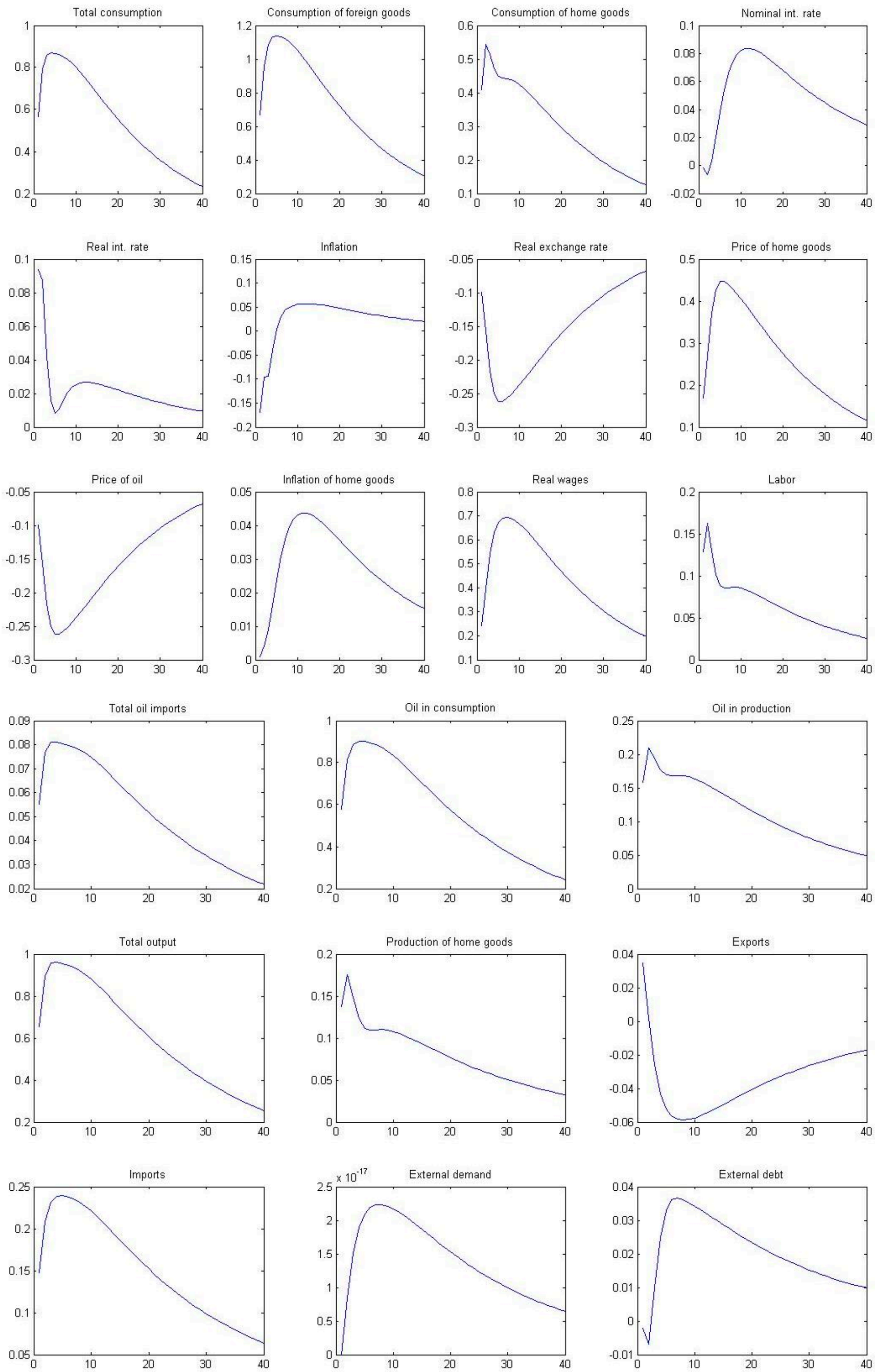

Figure 8. Impulse Response to a Labor Preference Shock—$\hat{\zeta}_{L,t}$