Oil Price Uncertainty in a Small Open Economy

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Abstract

In this paper, we present a dynamic general equilibrium model for an oil-importing small open economy in order to assess the business cycle implications of oil price shocks. Our analysis reveals important findings about how shocks to the level and volatility of oil prices affect the economic activity and how these effects change with the degree of financial integration. While investment and output can increase in response to higher volatility in the case of financial autarky, where households can use only physical capital for precautionary savings, the availability of internationally traded bonds as an extra asset can overturn this counterfactual result. Moreover, our results suggest that the coexistence of level and volatility shocks can serve as a mechanism to generate asymmetric effects of oil price increases and decreases as seen in the data.

Keywords: Oil price, stochastic volatility, financial market integration.
JEL classification: E20; E32; F32; F41; Q43.

1 Introduction

One of the challenges faced by the world economy is the highly volatile nature of energy prices, oil prices in particular. As implied by the various measures plotted in Figures 1a-1c, the degree of volatility in oil prices displays a time-varying pattern. The coefficient of variations calculated for 90-day moving data windows (Figure 1c) show that there have been periods in which the volatility of oil prices increased even when the level is controlled for. Such periods are associated with heightened concerns by policy makers, politicians or international institutions about the possibility that the high volatility of oil prices would be detrimental for macroeconomic performance. On a joint statement published on the Wall Street Journal on July 8, 2009, the former British prime minister Gordon Brown and French president Nicolas Sarkozy wrote:

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"For two years the price of oil has been dangerously volatile, seemingly defying the accepted rules of economics. First it rose by more than $80 a barrel, then fell rapidly by more than $100, before doubling to its current level of around $70...The oil market is complex but such erratic price movement in one of the world's most crucial commodities is a growing cause for alarm...The risk is that a new period of instability [in oil prices] could undermine confidence just as we are pushing for recovery..."

More recently, on January 30, 2012, OPEC's Chief General Abdalla S. El-Badri warned about the adverse effects of oil price volatility caused by the political tensions with Iran[2]:

"Volatility is bad for investment. If there is conflict [in Iran] we really cannot invest, there will be clouds all over the investment projects."

The issues highlighted by these quotes provide a firm motivation to study the macroeconomic implications of time-varying volatility in oil prices.[3] While recent literature offers a number of empirical studies about how oil price volatility affects economic performance[4], there is little work done on the transmission of oil price volatility shocks in a general equilibrium setting.[5] In this paper, we present a dynamic general equilibrium model for an oil-importing small open economy to provide new insights into the various channels through which uncertainty about oil prices affect key macroeconomic variables such as output, investment, real exchange rate and the current account. Our analysis reveals important findings about how shocks to the level and volatility of oil prices affect the economy and how these effects change with the degree of financial openness of the small open economy. To the best of our knowledge, the only previous attempt to study business cycle implications of variations in oil price volatility in general equilibrium is Plante and Traum (2011), who analyze the effects of oil price uncertainty for the U.S. economy, abstracting from open economy questions like how the real exchange rate, current account and external debt adjust to higher oil price uncertainty.

In terms of the modeling strategy, we specify a small open economy RBC model like Mendoza (1995) with tradable and non-tradable goods and international trade in a single bond. We extend this model to include oil in consumption and production along the lines of

[2]Source:http://online.wsj.com/article/BT-CO-20120131-712362.html

[3]See also the speech by the Central Bank of Turkey governor Erdem Başçı in the G-20 Conference on Commodity Price Volatility in September 2011.

[4]For example, Ferderer (1996), Guo and Kliesen (2005) and Elder and Serletis (2010) show the negative effect of higher oil price volatility on investment and output growth for the U.S. economy.

[5]This is partly due to the technical difficulties involved with solving and simulating DSGE models with stochastic volatility. Recent contributions by Fernandez-Villaverde and Rubio-Ramirez (2010), Justiniano and Primiceri(2008) and Benigno et al.(2010) provide methods that make it possible to introduce time-varying volatility in DSGE models relying on higher order approximations.

Kim and Loungani (1992) and Blanchard and Gali (2007).[6] A novel aspect of our analysis is that we allow for stochastic volatility in the exogenous process for the real price of oil. For solving the model with stochastic volatility, we apply a novel methodology developed by Benigno et al. (2010), who show that it is sufficient to consider a second-order accurate solution to the model to have a distinct and separate role for uncertainty shocks.[7]

One key feature of our model is that it allows us to analyze the role of integration to international financial markets for the transmission of oil price shocks with an emphasis on its differential role on the transmission of level and volatility shocks. Our analysis shows that openness to international financial markets is important for the transmission of oil price volatility shocks because higher uncertainty leads to precautionary savings which affect the economy differently depending on whether agents can save in international bonds or not.[8]

In the setup without debt accumulation, there are two channels through which oil price uncertainty affects economic activity. First, higher uncertainty about oil prices makes capital more risky and discourages investment. Second, higher uncertainty increases precautionary savings, which in turn leads to higher investment as there are no other assets to accumulate. Thus, for a realistically low degree of substitutability between oil and other factors of production, the precautionary saving motive dominates and this model generates an increase in physical investment and real GDP which is at odds with the empirical findings in the literature such as Ferderer (1996), Guo and Kliesen (2005) and Elder and Serletis (2010). When the model is extended to allow for debt accumulation via international bonds, we show that the strength of the second channel diminishes as agents can increase their precautionary savings by buying international bonds rather than investing in physical capital which becomes more risky due to higher oil price uncertainty. As a result, the model with international bond as an extra asset can generate a fall in investment in response to higher oil price uncertainty in line with the data. In contrast, the degree of integration to international financial markets is not crucial for the business cycle implications of the shocks to the *level of oil prices* whereby higher oil prices necessarily dampen the investment and economic activity.

We also compare shocks to the level and volatility of oil prices in terms of their implications for the responses of key macroeconomic variables. We show that the simultaneous occurrence of changes in the level and volatility of oil prices can help generate what we

[6] See also Backus and Crucini (1998) and Bodenstein et al. (2011) who make similar modeling assumptions regarding oil use in the economy. However, they analyze the implications of shocks that change the level of oil prices in a two-country framework.

[7] This method relies on the assumption that exogenous state variables follow conditionally-linear stochastic processes where the variances of the shocks to the exogenous state variables follow linear stochastic processes. See Benigno et al. (2011) for an application of this method to exchange rates and currency risk.

[8] Küçük (2011) also shows the importance of the degree of financial market integration for the extent of precautionary savings conditional on income uncertainty shocks focusing on the dynamics of real interest rates, real exchange rate and foreign exchange risk premium in a two-country setup.

observe in the data as the asymmetric business cycle effects of changes in oil prices. Our results imply that the effects of adverse oil price level shocks can be significantly amplified when uncertainty increases at the same time. That is, if periods of serious hikes in oil prices are also associated with a significant rise in the uncertainty regarding future oil prices, the recessionary impact of oil shocks would likely to be stronger going forward. Indeed, as it was observed in some episodes, increases in the volatility of oil prices can be much higher than increases in their level. If we simulate such a case using our model, we observe that adverse effects of oil price hikes are almost doubled, while the impact of oil price declines are muted if they are accompanied by significant increases in uncertainty. These results are consistent with the findings of the empirical literature emphasizing the asymmetric effects of oil price changes.[9]

Finally, our paper is also related to the earlier theoretical literature that studies how uncertainty affects investment behavior such as Bernanke (1983) and Pindyck (1991), who discuss the importance of uncertainty for investment decisions when investment is irreversible in a partial equilibrium framework. In these papers, uncertainty about oil prices would induce firms to postpone investment decisions as it makes the return to investment more risky. This would in turn lead to a decline in investment. However, these papers overstate the negative effect of uncertainty on physical investment as they abstract from the precautionary saving motive, which induces agents to increase physical investment in order to increase savings. Plante and Traum (2011) offer a general equilibrium analysis and bring both mechanisms together but they abstract from trade in international asset markets which would channel a part of the precautionary savings to foreign bonds instead of physical capital.

The rest of the paper is structured as follows. We introduce our model economy in the next section. Section 3 briefly discusses the solution method and model calibration. Our results are presented in Section 4, and Section 5 concludes the paper.

2 The Model

We model a small open economy with tradable and nontradable good sectors similar to the one in Mendoza (1995), in which agents have access to an incomplete international bond market subject to convex portfolio adjustment costs. We introduce oil as in Blanchard and Gali (2007), where both firms and households demand imported oil at an exogenously determined price that displays stochastic volatility. Tradable and nontradable sector firms operate in perfectly competitive markets and require capital, labor and imported oil for production. Households can save either by accumulating capital or by buying international

[9] See Hamilton (1983), Mork (1989), Ferderer (1996), Guo and Kliesen (2005) and Elder and Serletis (2010).

bonds.

2.1 Households

The representative household's final good consumption, C_t, is composed of tradable, C_t^T, and nontradable goods, C_t^N, shown as

$$C_t = \left[\gamma^{\frac{1}{\kappa}} \left(C_t^T\right)^{\frac{\kappa-1}{\kappa}} + (1-\gamma)^{\frac{1}{\kappa}} \left(C_t^N\right)^{\frac{\kappa-1}{\kappa}}\right]^{\frac{\kappa}{\kappa-1}}. \tag{1}$$

In (1), γ is the weight of tradable goods in consumption while κ is the elasticity of substitution between C_t^T and C_t^N. The final good is priced at P_t while tradable and nontradable goods are priced at P_t^T and P_t^N, respectively. Similarly, the tradable good is composed of oil, C_t^O, and a non-oil good, C_t^Q, with the CES aggregator

$$C_t^T = \left[\nu^{\frac{1}{\xi}} \left(C_t^Q\right)^{\frac{\xi-1}{\xi}} + (1-\nu)^{\frac{1}{\xi}} \left(C_t^O\right)^{\frac{\xi-1}{\xi}}\right]^{\frac{\xi}{\xi-1}}, \tag{2}$$

where ν is the weight of non-oil good in tradable goods consumption while ξ is the elasticity of substitution between oil and non-oil goods. The price of the non-oil good is normalized to 1 while price of oil follows an exogenous stochastic process given in the proceeding sections.

The representative household supplies labor to both sectors. The lifetime utility is given by

$$E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^{1-\sigma}}{1-\sigma} - \chi \frac{h_t^{1+\eta}}{1+\eta}\right), \tag{3}$$

where β is the discount factor satisfying $0 < \beta < 1$, σ is the risk aversion parameter, η is the inverse of the (Frisch) wage elasticity of labor supply, χ is a shift parameter in preferences over consumption versus leisure, and h_t is the total hours worked, which is the sum of hours worked in the tradable sector, h_t^T, and hours worked in the nontradable sector, h_t^N. The representative household is subject to the following budget constraint each period

$$I_t + \frac{\Phi^K}{2}(K_{t+1} - K_t)^2 + C_t^T + \frac{P_t^N}{P_t^T} C_t^N + B_t = w_t h_t + r_t K_t + R B_{t-1} - \frac{\Phi^B}{2}(B_t - B_{t-1})^2, \tag{4}$$

where

$$I_t = K_{t+1} - (1-\delta) K_t \tag{5}$$

is investment and δ is the depreciation rate on capital, K_t. The world interest rate is constant and gross return from holding one unit of foreign assets equals to $R > 1$. B_t is the international bond level, w_t is the wage rate[10] and r_t is the interest rate on capital.

[10] We assume perfect labor mobility among sectors. Therefore, wage rates in both sectors are equal in any

All variables except non-tradable consumption are expressed in units of the tradable good. Hence, to express non-tradable consumption in units of the tradable good, we multiply it with the relative price of non-tradable goods, P^N/P^T, which gives the definition of the real exchange rate in our model. This definition implies that an increase in the real exchange rate is a real domestic appreciation.

We specify quadratic adjustment costs for capital as in Mendoza (1991) governed by a parameter Φ^K. We also assume costly capital mobility to sustain a stationary net foreign assets equilibrium following Turnovsky (1985).[11] The scale of portfolio adjustment costs is determined by the parameter Φ^B, which can be interpreted as a measure of financial market integration, as in Sutherland (1996) and Benigno (2009). The higher the value of Φ^B, the less integrated is the economy with international financial markets. In the limiting case of $\Phi^B = \infty$, the economy operates under financial autarky.

Finally, households are subject to a no-Ponzi game constraint of the form

$$\lim_{j\to\infty} \frac{E_t B_{t+j}}{R} \leq 0. \tag{6}$$

2.2 Firms and Production

Tradable and non-tradable sector firms operate in perfectly competitive markets and require capital, labor and imported oil for production.

Tradable good producing firms have the following production function:

$$Y_t^T = \left[a_1^{\frac{1}{\theta}} \left(A_t^T (h_t^T)^{\alpha^T} (K_t^T)^{1-\alpha^T} \right)^{\frac{\theta-1}{\theta}} + (1-a_1)^{\frac{1}{\theta}} \left(O_t^T \right)^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}}, \tag{7}$$

where A_t^T is the non-oil factor productivity in the tradable sector, K_t^T is the amount of capital and O_t^T is the amount of oil used in tradable goods production. α^T is the labor share, a_1 determines the share of oil and non-oil factors in production and θ is the elasticity of substitution between oil and non-oil factors of production. Each period, by choosing h_t^T, K_t^T and O_t^T, they maximize profit

$$\Pi_t^T = Y_t^T - w_t h_t^T - r_t K_t^T - \frac{P_t^O}{P_t^T} O_t^T. \tag{8}$$

The technology used by nontradable goods producing firms is similar:

$$Y_t^N = \left[a_2^{\frac{1}{\phi}} \left(A_t^N (h_t^N)^{\alpha^N} (K_t^N)^{1-\alpha^N} \right)^{\frac{\phi-1}{\phi}} + (1-a_2)^{\frac{1}{\phi}} \left(O_t^N \right)^{\frac{\phi-1}{\phi}} \right]^{\frac{\phi}{\phi-1}}, \tag{9}$$

equilibrium.

[11] Specifying convex portfolio adjustment costs is one way of ensuring stationarity in incomplete market models as discussed by Schmitt-Grohe and Uribe (2003) for small open economies.

where A_t^N is the labor productivity shock to nontradable sector, K_t^N is the amount of capital and O_t^N is the amount of oil used in nontradable goods production. α^N is the labor share, a_2 determines the importance of oil and non-oil factors, and ϕ is the elasticity of substitution between oil and non-oil factors of production. The problem of the nontradable goods producing firms can characterized as maximizing

$$\Pi_t^N = \frac{P_t^N}{P_t^T} Y_t^N - w_t h_t^N - r_t K_t^N - \frac{P_t^O}{P_t^T} O_t^N, \tag{10}$$

by choosing h_t^N, K_t^N and O_t^N for given factor and goods prices.

The stochastic processes for non-oil factor productivity in both sectors are defined as follows:

$$\log A_{t+1}^T = (1 - \rho^T) \log \bar{A}^T + \rho^T \log A_t^T + \mu_{T,t} \varepsilon_{t+1}^T. \tag{11}$$

$$\log A_{t+1}^N = (1 - \rho^N) \log \bar{A}^N + \rho^N \log A_t^N + \mu_{N,t} \varepsilon_{t+1}^N. \tag{12}$$

where $0 \leq \rho^T < 1, 0 \leq \rho^N < 1$, ε_t^T and ε_t^N are i.i.d with zero mean and unit variance. The variance of $\log A^T$ and $\log A^N$ are given as $\mu_{T,t}^2$ and $\mu_{N,t}^2$, respectively, which have the following autoregressive processes:

$$\mu_{T,t+1}^2 = (1 - \rho^{\mu_T}) \bar{\mu}_T^2 + \rho^{\mu_T} \mu_{T,t}^2 + \psi_T^2 \zeta_{T,t+1}, \tag{13}$$

$$\mu_{N,t+1}^2 = (1 - \rho^{\mu_N}) \bar{\mu}_N^2 + \rho^{\mu_N} \mu_{N,t}^2 + \psi_N^2 \zeta_{N,t+1}. \tag{14}$$

Equations (13) and (14) tell us that variances of technology shocks in both sectors are time varying, hence volatilities of A^T and A^N are subject to random shocks. Here, $\zeta_{T,t}$ and $\zeta_{N,t}$ are i.i.d. with zero mean and unit variance. ψ_T^2 and ψ_N^2 are the respective constant variances of μ_T^2 and μ_N^2 with $0 \leq \rho^{\mu_T}, \rho^{\mu_N} < 1$ governing the persistence of $\mu_{T,t}^2$ and $\mu_{N,t}^2$.

2.3 Oil Prices

In our model, we take oil prices as exogenous but are subject to time varying stochastic volatility. Such a choice is governed by two facts. First, oil importing small open economies have no role in the determination of international oil prices, taking them entirely as given. Second, as widely accepted in the literature (e.g. Pindyck 1991, Ferderer, 1996), oil prices follow a stochastic process with time varying variances.

In particular, we assume that the (real) price of oil, defined as the log difference between domestic oil price, P_t^O, and price level of the economy, P_t, has the following stochastic process:

$$log\left(\frac{P^O_{t+1}}{P_{t+1}}\right) = \rho^P log\left(\frac{P^O_t}{P_t}\right) + \mu_{P,t}\epsilon_{t+1}, \tag{15}$$

where ϵ_t is i.i.d. with zero mean and unit variance. As a key characteristic of our model, we assume that the variance of oil prices can stochastically change over time for a given level of prices, as $\mu^2_{P,t}$ follows an autoregressive process:

$$\mu^2_{P,t+1} = (1-\rho^{\mu_P})\bar{\mu}^2_P + \rho^{\mu_P}\mu^2_{P,t} + \psi^2_P\zeta_{P,t+1}, \tag{16}$$

where $\zeta_{P,t}$ is i.i.d. with zero mean and unit variance. ψ^2_P is the variance of μ^2_P and $0 \leq \rho^{\mu_P} < 1$ governs the persistence of $\mu^2_{P,t}$.

2.4 Equilibrium Conditions

For a given level of final good consumption C_t and prices, the optimal choices of C^T_t, C^N_t, C^Q_t and C^O_t yield the following set of static efficiency conditions

$$\begin{aligned} C^T_t &= \gamma\left(\tfrac{P^T_t}{P_t}\right)^{-\kappa} C_t, \qquad C^N_t = (1-\gamma)\left(\tfrac{P^N_t}{P_t}\right)^{-\kappa} C_t, \\ C^Q_t &= \nu\left(\tfrac{P^Q_t}{P^T_t}\right)^{-\xi} C^T_t, \qquad C^O_t = (1-\nu)\left(\tfrac{P^O_t}{P^T_t}\right)^{-\xi} C^T_t. \end{aligned} \tag{17}$$

where the appropriate consumption price index and tradable good price index are given respectively by

$$P_t = \left[\gamma\left(P^T_t\right)^{1-\kappa} + (1-\gamma)\left(P^N_t\right)^{1-\kappa}\right]^{\frac{1}{1-\kappa}} \tag{18}$$

and

$$P^T_t = \left[\nu\left(P^Q_t\right)^{1-\xi} + (1-\nu)\left(P^O_t\right)^{1-\xi}\right]^{\frac{1}{1-\xi}}. \tag{19}$$

Given prices, the optimal choice of C_t, h_t, K_{t+1} and B_t satisfy this set of dynamic first order conditions

$$C_t^{-\sigma}\frac{P^T_t}{P_t}w_t = \chi h_t^{\eta}, \tag{20}$$

$$C_t^{-\sigma}\left[1+\Phi^K(K_{t+1}-K_t)\right] = \beta E_t\left\{C_{t+1}^{-\sigma}(1-\delta+r_{t+1})\frac{P_t}{P_{t+1}}\frac{P^T_{t+1}}{P^T_t}\left[1+\Phi^K(K_{t+2}-K_{t+1})\right]\right\}, \tag{21}$$

and

$$C_t^{-\sigma}\left[1+\Phi^B(B_t-\bar{B})\right] = \beta E_t\left\{C_{t+1}^{-\sigma}R\frac{P_t}{P_{t+1}}\frac{P^T_{t+1}}{P^T_t}\right\}. \tag{22}$$

Equation (20) states that the marginal rate of substitution between final consumption good and leisure is equal to real wages. Note that, since we assume free labor mobility across sectors, wages in both sectors are equivalent, making households indifferent in choosing which sector to work. On the other hand, equation (21) equates marginal cost of foregone consumption today by saving one unit of capital to expected marginal benefit of consuming that tomorrow. Similarly, the left hand side of (22) is the marginal cost of consuming less today by saving one unit of risk-free bond while the right hand side is the expected marginal benefit of consuming more one period later.

Taking prices as given, firms operating in both sectors equate marginal product of labor to wages, marginal product of capital to interest rate and marginal product of oil to its price. In particular, tradable good producing firms' optimality conditions are given respectively by

$$(a_1 Y_t^T)^{1/\theta} \alpha^T \left(A_t^T (K_t^T)^{1-\alpha^T} \right)^{\frac{\theta-1}{\theta}} (h_t^T)^{\alpha^T \frac{\theta-1}{\theta} - 1} = w_t, \tag{23}$$

$$(a_1 Y_t^T)^{1/\theta} (1-\alpha^T) \left(A_t^T (h_t^T)^{\alpha^T} \right)^{\frac{\theta-1}{\theta}} (K_t^T)^{(1-\alpha^T)\frac{\theta-1}{\theta} - 1} = r_t \tag{24}$$

and

$$(1-a_1)\frac{Y_t^T}{O_t^T} = \left(\frac{P_t^T}{P_t^O} \right)^{-\theta}. \tag{25}$$

Similar conditions for nontradable good producing firms are given by

$$(a_2 Y_t^N)^{1/\phi} \alpha^N \left(A_t^N (K_t^N)^{1-\alpha^N} \right)^{\frac{\phi-1}{\phi}} (h_t^N)^{\alpha^N \frac{\phi-1}{\phi} - 1} = w_t \frac{P_t^T}{P_t^N}, \tag{26}$$

$$(a_2 Y_t^N)^{1/\phi} (1-\alpha^N) \left(A_t^N (h_t^N)^{\alpha^N} \right)^{\frac{\phi-1}{\phi}} (K_t^N)^{(1-\alpha^N)\frac{\phi-1}{\phi} - 1} = r_t \frac{P_t^T}{P_t^N} \tag{27}$$

and

$$(1-a_2)\frac{Y_t^N}{O_t^N} = \left(\frac{P_t^N}{P_t^O} \right)^{-\phi}. \tag{28}$$

Now we define our stationary equilibrium. Given the sequence of exogenous state variables $\{A_t^T, A_t^N, P_t^O/P_t, \mu_{P,t}^2\}_{t=0}^{\infty}$ described respectively by (11), (12), (15) and (16), a stationary equilibrium is a sequence of endogenous variables $\{C_t, C_t^T, C_t^N, C_t^Q, C_t^O, h_t, h_t^T, h_t^N, K_t, K_t^T, K_t^N, I_t, B_t, O_t^T, O_t^N, Y_t^T, Y_t^N\}_{t=0}^{\infty}$ and prices $\{P_t, P_t^T, P_t^N, P_t^O, r_t, w_t\}_{t=0}^{\infty}$ such that

i) given prices, households optimize by (17) and (20)-(22),

ii) given prices, firms optimize by (23)-(28),

iii) good prices satisfy (18) and (19), and

iv) market clearing conditions

$$C_t^N = Y_t^N, \tag{29}$$

$$K_t = K_t^T + K_t^N, \tag{30}$$

$$h_t = h_t^T + h_t^N, \tag{31}$$

$$C_t^T + I_t + B_t + \frac{\Phi^K}{2}(K_{t+1} - K_t)^2 + \frac{\Phi^B}{2}(B_t - B_{t-1})^2 = RB_{t-1} + Y_t^T - \frac{P_t^O}{P_t^T}(O_t^T + O_t^N) \tag{32}$$

are satisfied.

Note that equation (32), which describes the dynamics of the current account balance, is derived from combining household budget constraint (4), profit functions of firms (8) and (10), and the nontradable good market clearing condition, (29).

3 Solution Method and Calibration

3.1 Solution Method

As the solution method, we use the technique introduced by Benigno et al. (2010) for solving models with stochastic volatility. They show that if exogenous state variables follow conditionally-linear stochastic processes, i.e. either variances or standard deviations of the structural shocks follow linear stochastic processes, then it is sufficient to consider a second-order accurate solution to the model to have a distinct and separate role for uncertainty shocks. By defining appropriate first and second-order approximations of the solution, we can derive equilibrium allocation under time-varying exogenous risk.

3.2 Calibration

We calibrate the model at a quarterly frequency for a typical developed oil-importing small open economy. The parameter values are given in Table 1. The calibration of the parameters other than the ones regarding oil is fairly standard. σ is set so that the intertemporal elasticity of substitution is 0.5, which is in line with most of the RBC literature. Following Gali et al. (2007), the inverse of the Frisch elasticity of labor supply, η, is set to 5, which corresponds to a labor supply elasticity of 0.2. We calibrate χ so that agents devote one-third of their time to work.

For κ, the elasticity of substitution between tradable and non-tradable goods, we use the Stockman and Tesar (1995) estimate of 0.44. Given the value we set for σ, this implies that tradable and non-tradable goods are gross complements in consumption as $\kappa\sigma < 1$. The elasticity of substitution between non-oil tradable goods and oil in consumption is set at a low value, $\xi = 0.40$ as in Bodenstein et al. (2011).

We set the share of oil input in total production to 5 percent which is in the range of the values reported by Bodenstein et al. (2011) for the US (2.8 percent) and the rest of the world (5.7 percent). Assuming that steady-state share of oil in output is equal across sectors and tradable output accounts for half of the GDP, this requires setting a_1=$a_2 = 0.95$. The elasticity of substitution between oil and non-oil intermediate goods in both sectors, θ and ϕ, are both set to 0.40 as in Bodenstein et al. (2011).

The labor share in the tradable sector, α_T, is set at 0.64 while α_N is set around 1 for simplicity. We normalize the non-oil total factor productivity in the tradable sector, A_T, to 1 at the steady-state. Then, the share of tradable goods in final consumption, γ, and the total factor productivity in the non-tradable sector, A_N, are set so that the tradable and non-tradable sectors have equal weight in total production. Bodenstein et al. (2011) calibrate the weight on oil in consumption as 0.023 for the US and 0.041 for the rest of the world. We set ν such that the share of oil in total consumption basket is 0.035. As γ is around 0.40 in our calibration, this requires setting $\nu = 0.91$.

The constant discount factor, β, equals 0.99 to give an annual world interest rate of 4.1 percent. δ is set at 0.025 to have an annual capital depreciation of by 10 percent. The parameter that governs the capital adjustment costs, Φ^K, is calibrated similarly to Mendoza (1995) while the parameter that scales the degree of financial market integration, Φ^B is set at 0.01 to ensure that the cost of adjusting foreign bonds is small in the baseline calibration. At the steady-state, capital and portfolio adjustment costs are zero. The steady-state ratio of foreign bond position to GDP is -0.25, implying that our small open economy is a net debtor at the steady-state, which is also in line with Mendoza (1995).

The persistence of level TFP shocks are set around 0.90 in line with the RBC literature, while oil prices are set at a higher persistence in line with the estimates of Plante and Traum (2011). The volatility shocks are assumed to have lower persistence with 0.50. We take the size of the volatility shocks to be one-tenth of the level shocks but because we report normalized impulse responses, this does not have a bearing on the main results.

4 Analyzing the Implications of Oil Price Shocks

4.1 Shocks to the Level of Oil Prices

Before analyzing the macroeconomic effects of higher oil price uncertainty, we start by discussing shocks to the level of real oil prices. Figure 2 plots the impulse responses to an adverse oil price shock under the baseline calibration summarized in Table 1 for two different values of Φ^B, which scales the degree of financial market integration in the model.[12] The

[12]Impulse responses show log-deviations from steady-state in response to a one standard deviation shock normalized by the size of the shock.

Table 1: Baseline Calibration

Parameter	Description	Baseline values
β	Constant discount factor	0.99
σ	Coefficient of constant relative risk aversion	2
η	Inverse of the Frisch elasticity of labor supply	5
κ	Elasticity of substitution between tradables and non-tradables	0.44
ξ	Elasticity of substitution between oil and non-oil goods in tradable consumption	0.25
γ	Weight on tradable goods in total consumption	0.43
$1-\nu$	Weight on oil in tradable goods consumption	0.08
$1-a_1$	Weight on oil in the production of tradable goods	0.05
$1-a_2$	Weight on oil in the production of nontradable goods	0.05
α^T	Labor share in tradable goods production	0.67
α^N	Labor share in nontradable goods production	0.99
θ	Elasticity of substitution between oil and non-oil goods in tradable production	0.40
ϕ	Elasticity of substitution between oil and non-oil goods in nontradable production	0.40
δ	Depreciation rate of capital	0.025
Φ^K	Capital adjustment cost parameter	0.028
Φ^B	Portfolio adjustment cost parameter	0.01, 1000
B/Y	Foreign bonds as a ratio of GDP	-0.25
$\Lambda=\begin{bmatrix}\rho^T & 0 & 0\\ 0 & \rho^N & 0\\ 0 & 0 & \rho^P\end{bmatrix}$	Persistence of level shocks	$\begin{bmatrix}0.90 & 0 & 0\\ 0 & 0.90 & 0\\ 0 & 0 & 0.95\end{bmatrix}$
$\rho^{\mu_T}=\rho^{\mu_N}=\rho^{\mu_P}$	Persistence of volatility shocks	0.50
$\bar{\mu}_T^2=\bar{\mu}_N^2=\bar{\mu}_P^2$	Variance of level shocks	0.009^2
$\psi_T^2=\psi_N^2=\psi_P^2$	Variance of volatility shocks	$(0.009/10)^2$

dotted lines correspond to the setup with small portfolio adjustment costs in international financial markets, i.e. $\Phi^B = 0.01$, while the solid lines represent the impulse responses in a financially closed economy represented by $\Phi^B = 1000$.

First consider the case of $\Phi^B = 0.01$ represented by the dotted lines in Figure 2. Following a rise in real oil prices, investment plummets as real interest rate falls. Firms' demand for oil declines, which also contributes to the fall in investment as oil and capital are complements in production. Because hours worked increase due to the income effect, the fall in total output is smaller compared to the fall in investment and oil input.

Under our baseline calibration with small portfolio adjustment costs, the economy gives a current account surplus in response to a rise in real oil prices. As shown by the dotted lines in Figure 2, the fall in consumption and investment exceeds the fall in tradable sector output. Oil consumption declines as a result of higher oil prices, leading to a fall in the value of oil imports and contributing to the improvement in the current account. The rise in the current account is accompanied by a real exchange rate depreciation. The price of the tradable goods basket increases as it includes oil which becomes more expensive following the shock. On the other hand, the price of non-tradable goods falls, resulting in a decline in the relative price of non-tradable goods, P_N/P_T, which is our definition of the real exchange rate. With regards to the sectoral effects of oil price shocks, both tradable and non-tradable sector output shrink as imported oil enters both production functions in a similar way.

Comparing the dotted lines with the solid lines in Figure 2 shows that the degree of financial market openness does not matter much for the transmission of level shocks to oil prices. Qualitatively, impulse responses do not change much with the financial market setup although there are some quantitative differences. In particular, because the economy is practically not allowed to run a current account surplus when $\Phi^B = 1000$, physical investment falls by less on impact in this setup. Consequently, the fall in tradable sector hours and tradable sector output following an adverse oil price shock is less dramatic under financial autarky, which mitigate the fall in total GDP.

4.2 Shocks to the Volatility of Oil Prices

Figure 3 shows the impulse responses to a rise in oil price volatility when the level of real oil prices are kept fixed. A key feature of our model is that higher oil price volatility induces an increase in the savings of the households due to a precautionary savings motive.[13] How these savings are transmitted through the economy is determined by the financial market structure and the available saving technologies.

The dotted lines in Figure 3 show how the economy responds to higher uncertainty about oil prices when it is not too costly to trade in international bonds, i.e. $\Phi^B = 0.01$. Physical investment decreases on impact as the marginal product of capital becomes more more risky due to higher oil price volatility. In this setup, agents can save by accumulating physical capital and by buying international bonds. But since capital becomes more risky following the increase in the volatility of oil prices, agents prefer to save by buying international bonds rather than investing in physical capital. Foreign bond holdings and the current account surplus increase as shown by the charts in the top row of Figure 3.

Despite the fall in physical investment, tradable sector output increases. Again, this is mainly due to the precautionary saving motive. Agents want to accumulate foreign bonds which is less risky than investing in physical capital whose return is directly affected by the increase in oil price uncertainty. Hours worked in the tradable sector increases to produce

[13]Fogli and Perri (2006) and Küçük (2011) also highlight the role of precautionary savings in driving business cycles.

more of the tradable goods so as to afford higher foreign savings. The increase in the tradable sector labor input is accompanied by an increase in firms' oil demand as oil and non-oil factors of production are complements in production.

While tradable output expands, non-tradable output slightly declines in accordance with the decline in the consumption of non-tradable goods. Capital, labor and oil used in the production of non-tradable goods all decline accordingly. Though the overall GDP response is quite small there is a mild contraction from the second quarter onward.

The real exchange rate depreciates as non-tradable good prices fall more compared to tradable good prices. To have a better understanding of this result, we combine the equations that describe the optimal choice between tradable and non-tradable goods given in (17) and get:

$$\frac{C_t^T}{C_t^N} = \frac{\gamma}{1-\gamma}\left(\frac{P_t^N}{P_t^T}\right)^{\kappa}. \tag{33}$$

This equation tells that changes in the real exchange rate, P_t^N/P_t^T, are linked to changes in the ratio of tradable to non-tradable consumption. Following a volatility shock, households want to increase their savings in foreign bonds, which implies a larger fall in tradable consumption compared to non-tradable consumption.[14] According to (33), relative price of non-tradable goods should be lower to support this allocation.

Impulse responses obtained for the case of high portfolio adjustment costs, i.e. $\Phi^B = 1000$, are depicted by the solid lines in Figure 3. This setup resembles financial autarky, where the current account always has to be in balance. In this case, physical investment actually *increases* on impact following an increase in oil price volatility. As capital is the only available asset to channel precautionary savings, investment in physical capital increases although the marginal product of capital becomes more risky due to higher oil price volatility. Accordingly, aggregate GDP slightly rises, which is the opposite of what happens with low portfolio adjustment costs.

These results show that the degree of integration to international financial markets has important implications for the effects of oil price volatility on business cycles, especially on investment and output. However, this is not the case for the level shocks. With no uncertainty regarding the level of oil prices, households in this economy have no particular reason to act in line with a precautionary saving motive. Therefore, the menu of assets available to them do not make a significant difference in terms of how they adopt their level of investment in physical capital in response to such shocks.

[14] See how foreign bonds are linked to tradable goods consumption in the current account equation given in (32).

4.3 Comparing the Quantitative Implications of Level and Volatility Shocks to Oil Prices

Because volatility shocks are second-order shocks, one standard deviation shock to the volatility of oil prices naturally has a much smaller effect on the economy compared to one standard deviation shock to the level of oil prices even if we normalize the impulse responses by the respective standard deviations of the shocks (see Figures 2 and 3). However, this does not mean that oil price volatility shocks are unimportant. We know that some episodes are associated with a rapid surge in uncertainty regarding future oil prices which is over and above the increase in current oil prices. Hence, it is useful to scale volatility shocks relative to level shocks to have a meaningful comparison of their quantitative implications for the economy.

For this purpose, we calculate the increases in the level and volatility of oil prices with respect to their respective last-five-year-averages and divide these by their respective standard deviations calculated for the same five-year period. We observe that there are a few years where the volatility of oil prices increased by more than the level of oil prices. A case in point is the year 2007, in which the increase in the volatility of oil prices was almost three times higher than the increase in the level. In line with this example, Figure 4 plots the impulse responses to a one standard deviation level shock along with the impulse responses to a three standard deviation volatility shock under the baseline calibration with small portfolio adjustment costs. The former are depicted by the dotted lines, while solid lines are used for the latter.

Comparing the quantitative implications of scaled level and volatility shocks depicted in Figure 4 shows that the decline in output at the trough following an adverse level shock is more than three times the decline in output following an increase in volatility. This is partly due to the fact that when agents are faced with higher uncertainty, they increase the hours worked in the tradable sector so as to afford higher foreign savings for precautionary purposes. This in turn, limits the adverse response of total output conditional on a volatility shock. Note that the difference in the response of tradable output across level and volatility shocks is mainly due to differences in the responses of labor rather than capital. Capital input falls conditional on both shocks but for different reasons. For level shocks the reason behind the fall in capital is the decline in the return to capital following the increase in oil prices, whereas for volatility shocks the main reason is that capital becomes more risky. However, the decrease in tradable sector capital is more limited compared to that in the non-tradable sector because of the increase in the demand for tradable output as explained above.

Real exchange rate depreciates on impact in response to both shocks but depreciate more conditional on a volatility shock. To understand this result, it is useful to refer to equation (33), which links changes in the real exchange rate, P_t^N/P_t^T, to changes in the ratio of tradable consumption to non-tradable consumption. After a volatility shock, households want to increase their savings in foreign bonds, which in turn reduces tradable consumption more compared to non-tradable consumption implying a real depreciation. On the other hand, level shocks affect both tradable and non-tradable consumption in a similar way. Hence, the real exchange rate depreciation is smaller on impact following a level shock.

Finally, level shocks reduce oil imports substantially, leading to an improvement in current account. But because households borrow from abroad to smooth their consumption this improvement remains limited. Volatility shocks, on the other hand, work mainly through the savings channel, hence result in a larger current account surplus on impact.

4.3.1 Addressing the Asymmetry Puzzle

Empirical literature documents that oil price changes have asymmetric effects on key macroeconomic variables. Mork (1989) shows that while increases in oil prices are associated with a slowdown in growth, decreases in oil prices do not necessarily lead to higher growth in the US. For OECD countries, Mork et al. (1994) finds similar evidence. Ferderer (1996) empirically analyzes three channels which can generate such asymmetry. Because sharp increases and decreases in oil prices increase volatility and increased volatility leads to a decline in investment and economic activity, considering such sharp changes in oil prices can yield asymmetric responses.[15]

When we scale volatility shocks as described above, consumption and investment respond in quantitatively similar ways to both level and volatility shocks on impact (see Figure 4).[16] This means that the decline in consumption and investment in response to an increase in oil prices would almost be doubled if there is a significant rise in uncertainty at the same time. On the other hand, if there is a fall in oil prices together with a rapid rise in uncertainty regarding future oil prices, the effects of these two shocks on consumption and investment would cancel each other out. This result suggests that the co-existence of level and volatility shocks can generate an asymmetry in the way the economy responds to increases and decreases in oil prices in line with the empirical evidence.

4.4 How do oil price shocks compare with TFP shocks?

Given that TFP and oil enter the production process similarly, a particular question that comes to mind is how the implications of oil price shocks would compare with those of TFP shocks. Adverse oil price shocks affect investment, current account, tradable output and real interest rates in qualitatively similar ways but have qualitatively and quantitatively

[15]See also Guo and Kliesen (1995) and Elder and Serletis (2010).

[16]Because volatility shocks are less persistent, responses to volatility shocks converges to zero faster.

different effects compared to TFP shocks for aggregate consumption, output, hours and the real exchange rate (Figure 5). The main difference between oil price and TFP shocks is that the former affects both sectors in a similar way while TFP shocks are introduced as sector specific, hence have sectoral effects. For example, an adverse oil price shock leads to a decline in consumption and output in both sectors while an adverse TFP shock to tradable sector decreases consumption and output only in the tradable sector. This asymmetry is observed in all factors of production, i.e. labor, capital and oil demand decrease only in the tradable sector after an adverse TFP shock.

On the other hand, increases in the volatilities of these shocks have quite similar effects. This is because volatility shocks mainly work through the precautionary savings channel, which stems from the output uncertainty caused by these shocks (Figure 6). In other words, all volatility shocks, whether sector specific or not, increase total uncertainty in the economy. Thus, qualitative differences in oil price and TFP shocks are mainly observed for the level shocks.

Quantitatively, oil price shocks have much smaller effects compared to TFP shocks. This stems from the low weight of oil in production in our benchmark calibration. Figures 7 and 8 show how responses of key macroeconomic variables to oil price shocks change when we increase the weight of oil in production from 5 percent to 20 percent. The effects of both level and volatility shocks are amplified as expected. For this higher weight of oil in production, i.e. $a_1 = a_2 = 0.80$, impulse responses to the volatility of oil prices become larger in magnitude than those of the volatility of TFP shocks (see Figure 9).

5 Conclusion

In this paper, we present a dynamic general equilibrium model for an oil-importing small open economy in order to assess the business cycle implications of oil price shocks. Our analysis reveals important findings about how shocks to the level and volatility of oil prices affect the economic activity and how these effects respond to the degree of financial integration. In particular, an exogenous increase in the price of oil mainly works as a negative supply side shock depressing the overall economic activity. On the other hand, whether domestic households have access to international bond markets plays an important role for the response of the economic activity to volatility shocks. While the economic activity can increase in response to higher volatility in the case of financial autarky, where households can use only capital for precautionary saving, the availability of internationally traded bonds as an extra asset can overturn this result which is at odds with the data. Therefore, the asset market structure plays an important role for the reconciliation of the data with the implications of small open economy models focusing on the effects of oil price volatility shocks.

Our model offers a way to address the asymmetry puzzle which refers to the fact that the economy responds differently to increases and decreases in oil prices. We show that the decline in consumption and investment in response to an increase in oil prices would almost be doubled if there is a significant rise in uncertainty at the same time. On the other hand, if there is a fall in oil prices together with a rapid rise in uncertainty regarding future oil prices, the effects of these two shocks on consumption and investment would cancel each other out. This result suggests that the co-existence of level and volatility shocks can generate an asymmetry in the way the economy responds to increases and decreases in oil prices in line with the empirical evidence.

Finally, we analyze the extent to which dynamic responses of key macroeconomic variables to oil price shocks differ from those of sectoral TFP shocks. The main difference is that shocks to the level of oil prices affect both sectors in a similar way while TFP shocks have sectoral effects. On the other hand, increases in the volatilities of these shocks have quite similar effects. This is because volatility shocks mainly work through the precautionary savings channel, which stems from the output uncertainty caused by these shocks.

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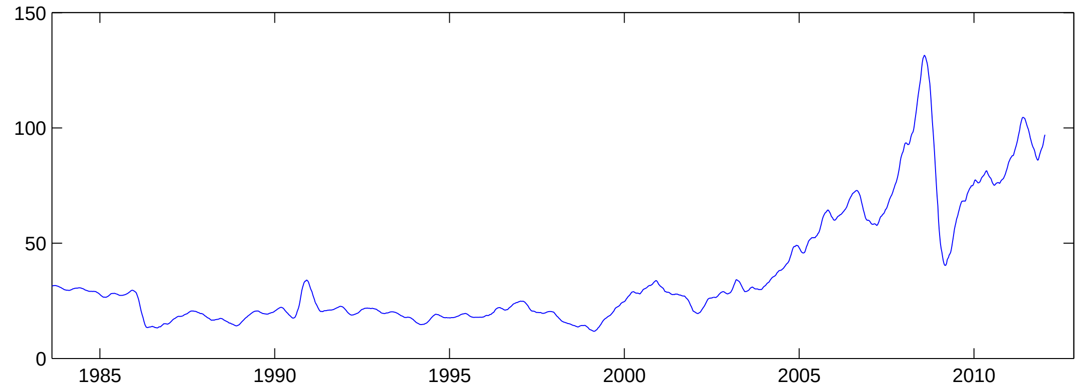
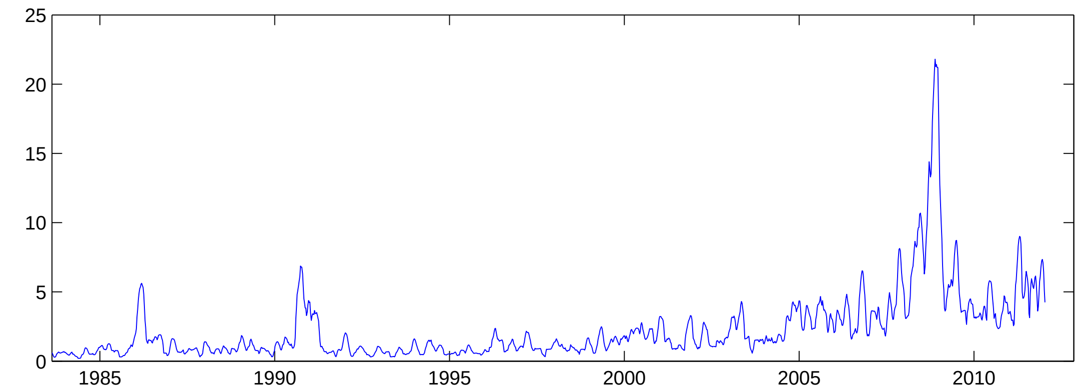
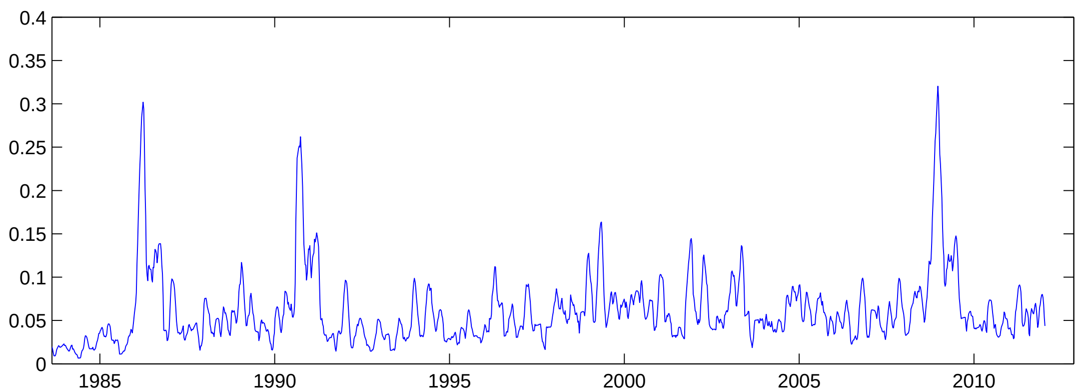
Figure 1: Oil Price Level and Volatility in Data



(a) Mean



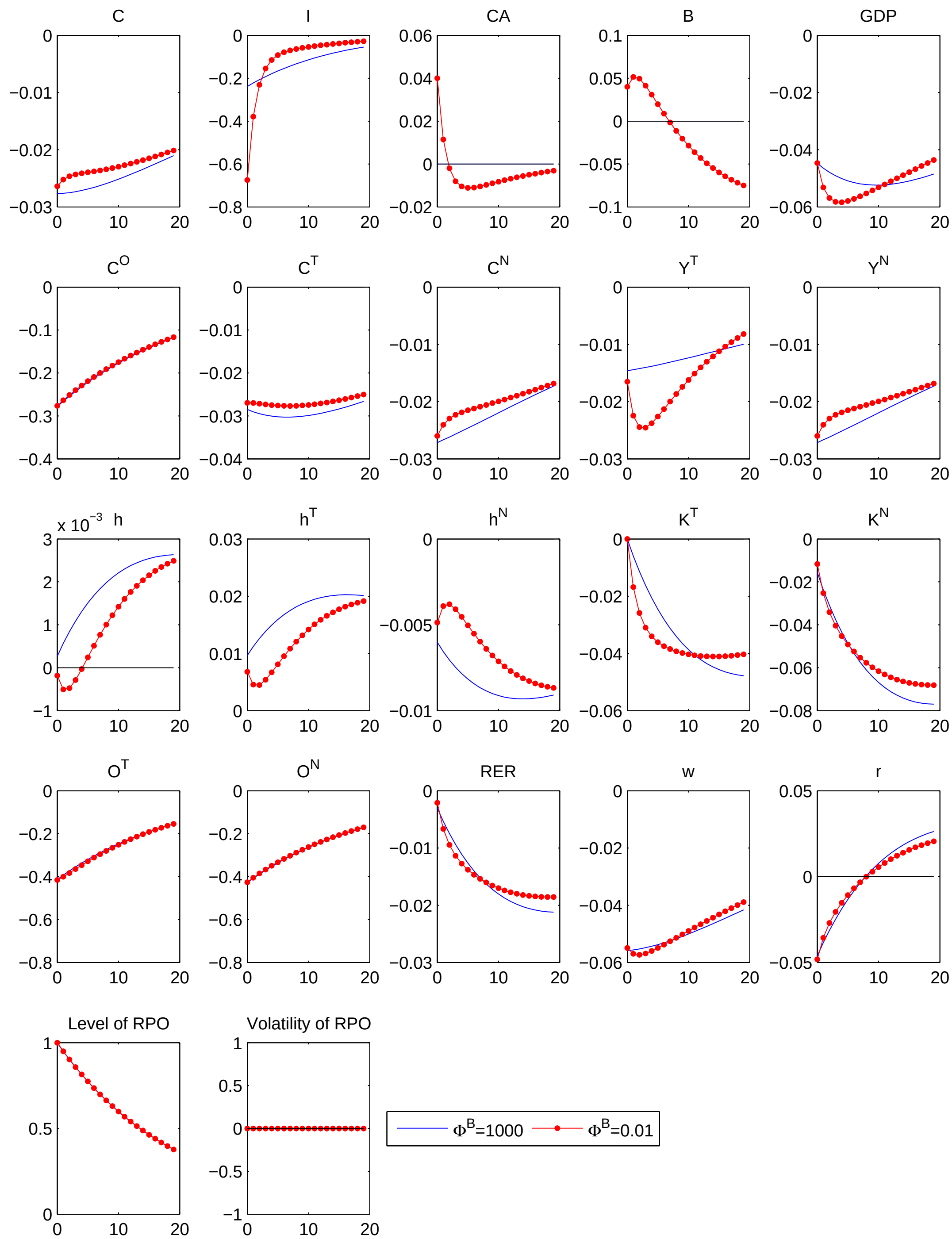
(b) Standard Deviation



(c) Coefficient of Variation

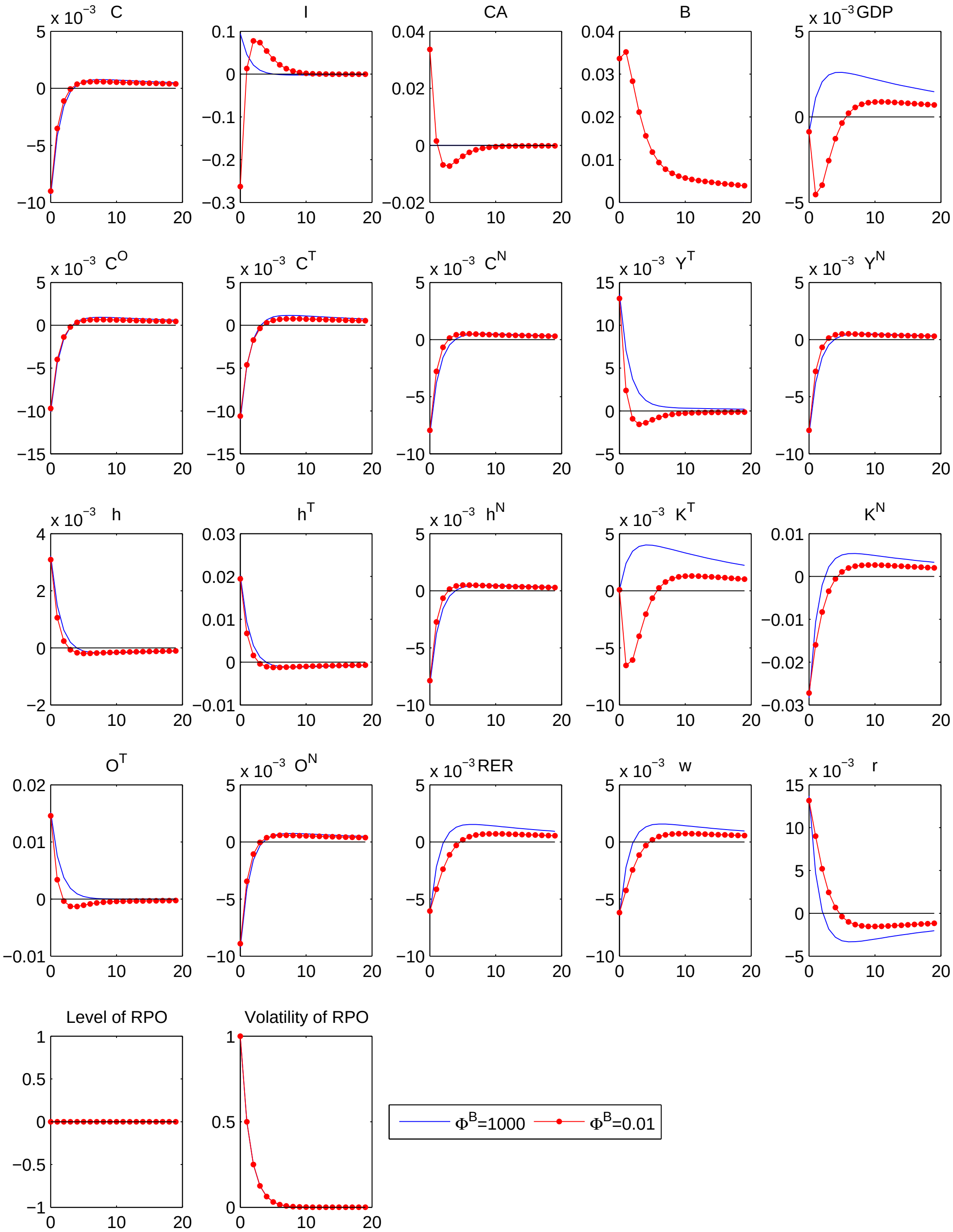
Notes: Weekly WTI prices. Data source is Bloomberg.

Figure 2: Impulse Response to a One S.D. Adverse Oil Price Level Shock



Notes: $\Phi^B = 0.01$ corresponds to low financial trading costs while $\Phi^B = 1000$ corresponds to the case of financial autarky.

Figure 3: Impulse Response to a One S.D. Adverse Oil Price Volatility Shock



Notes: $\Phi^B = 0.01$ corresponds to low financial trading costs while $\Phi^B = 1000$ corresponds to the case of financial autarky.

Figure 4: Impulse Response Comparison of One S.D. Adverse Shock to Oil Price Level Shock and Three S.D. Adverse Shock to Oil Price Volatility Shock

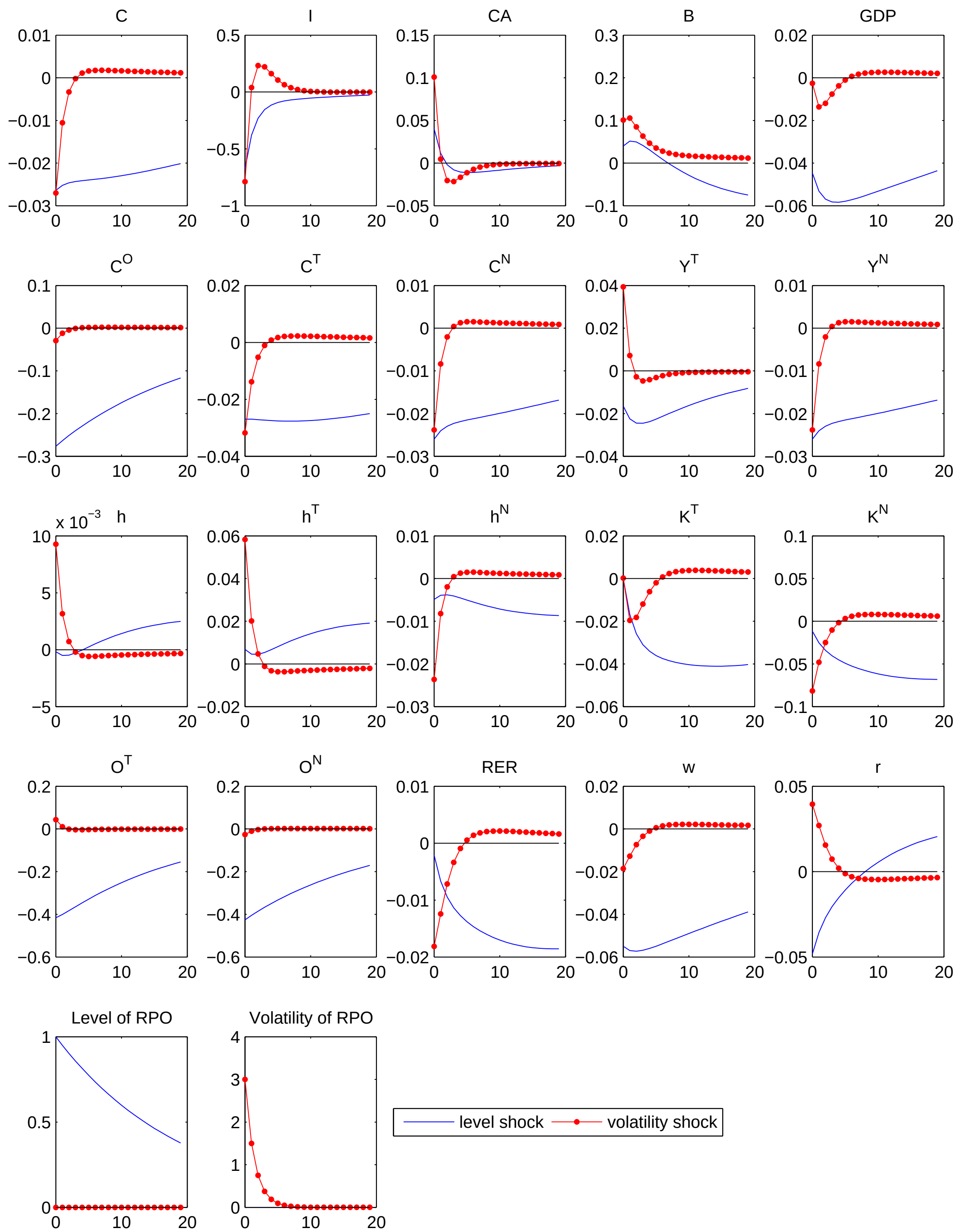


Figure 5: Impulse Responses to One S.D. Adverse Shocks to Oil Price, Tradable TFP and Non-Tradable TFP

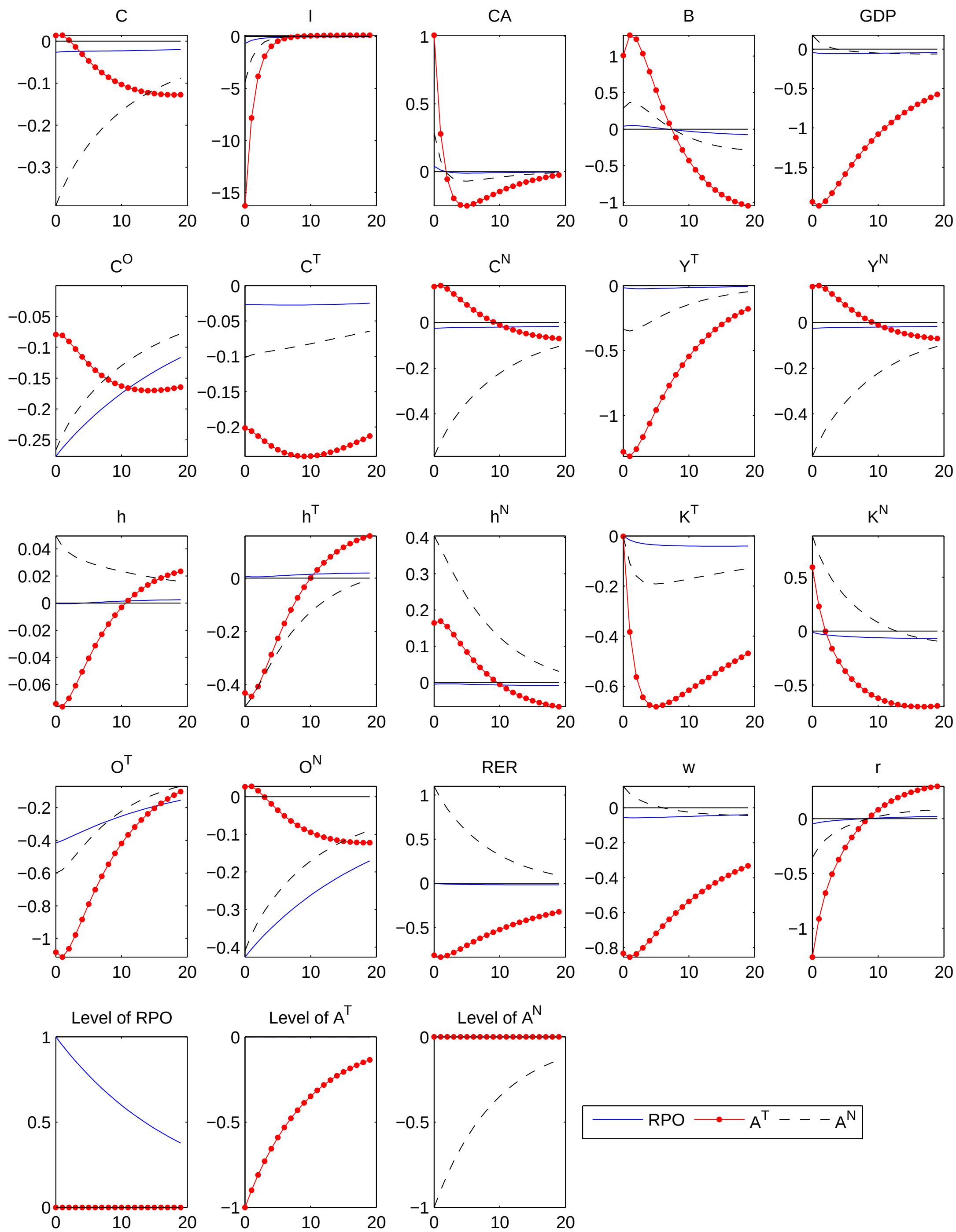


Figure 6: Impulse Responses to One S.D. Adverse Shocks to Volatilities of Oil Price, Tradable TFP and Non-Tradable TFP

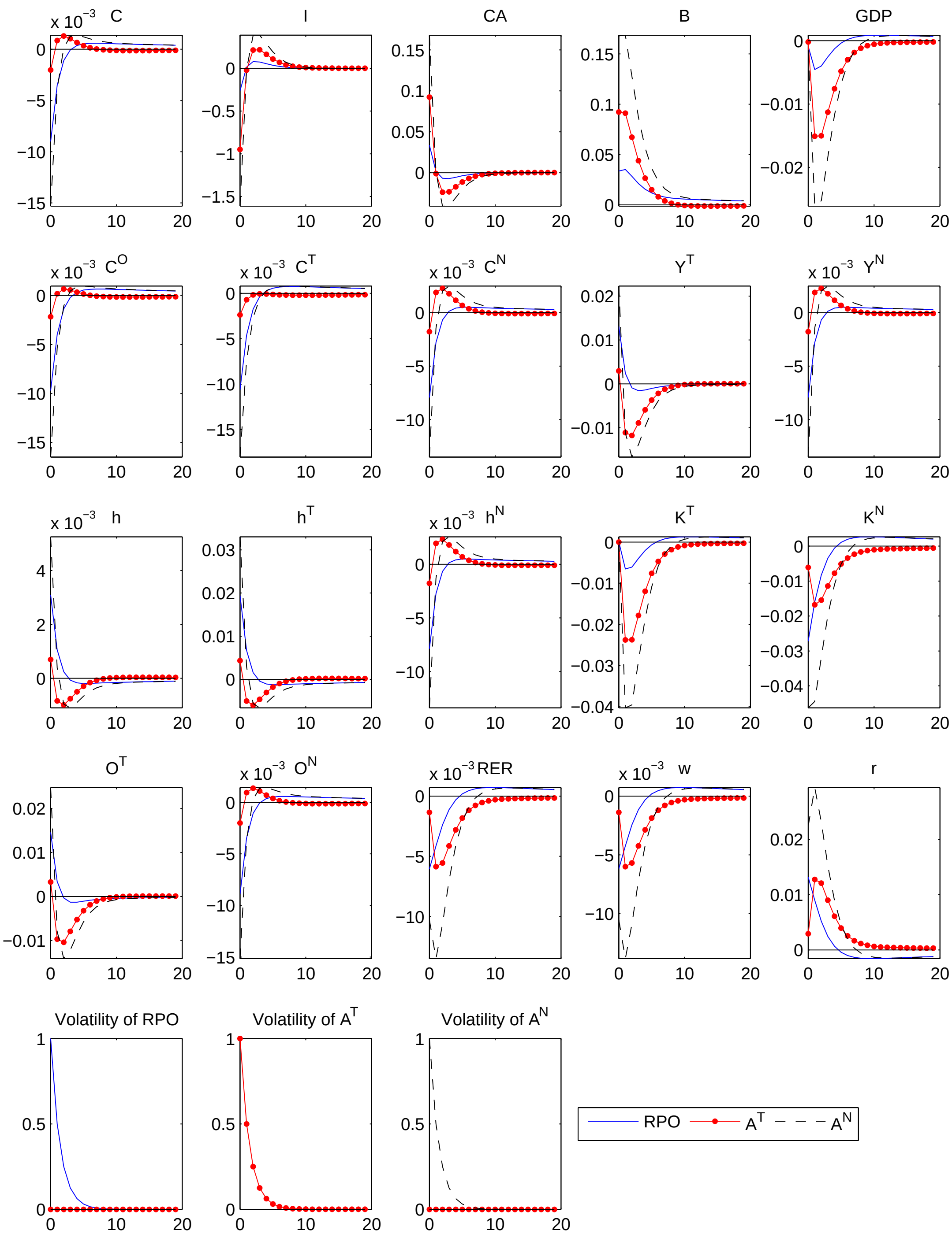


Figure 7: Impulse Responses to One S.D. Adverse Oil Price Level Shocks with Higher Weight of Oil in Production

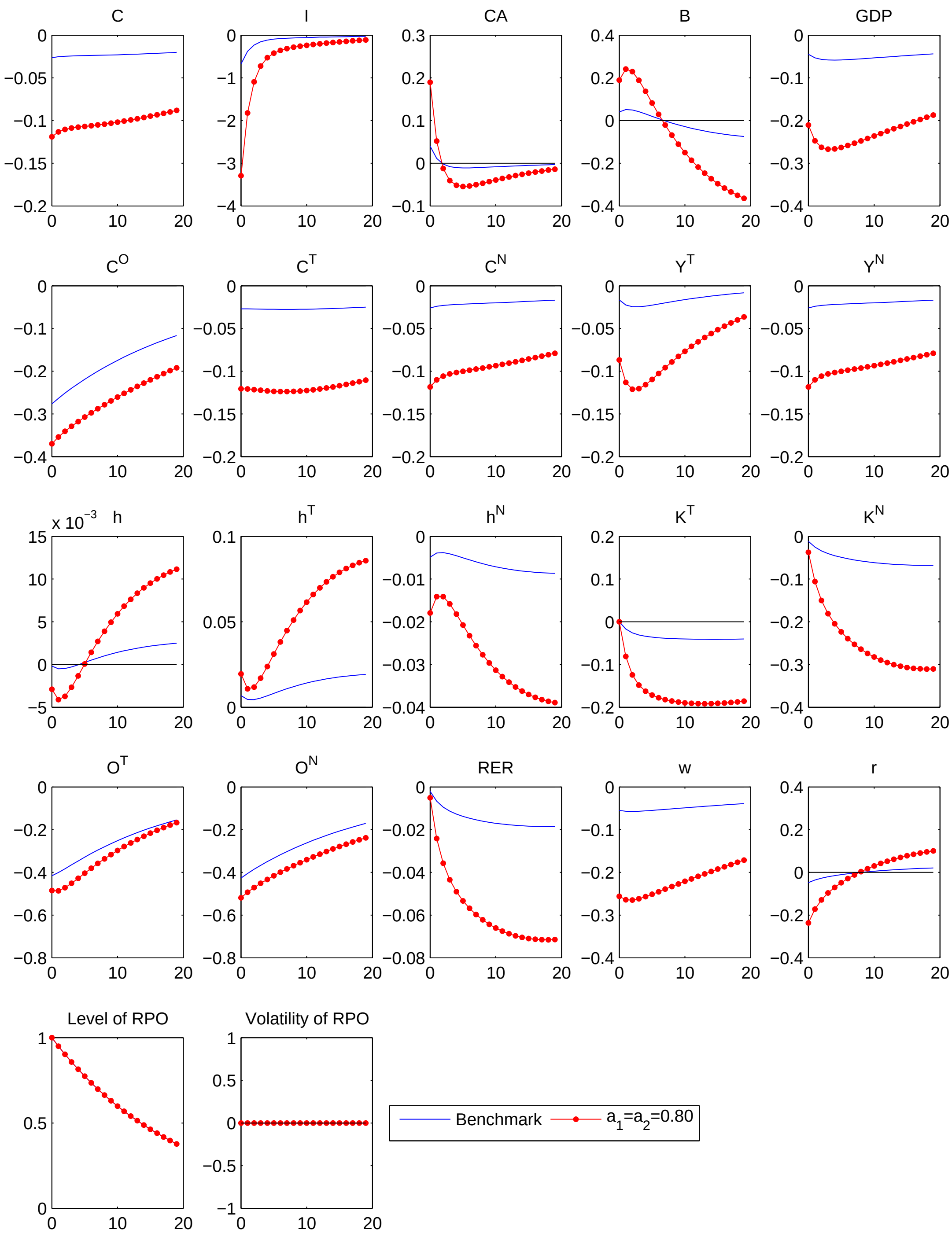


Figure 8: Impulse Responses to One S.D. Adverse Oil Price Volatility Shocks with Higher Weight of Oil in Production

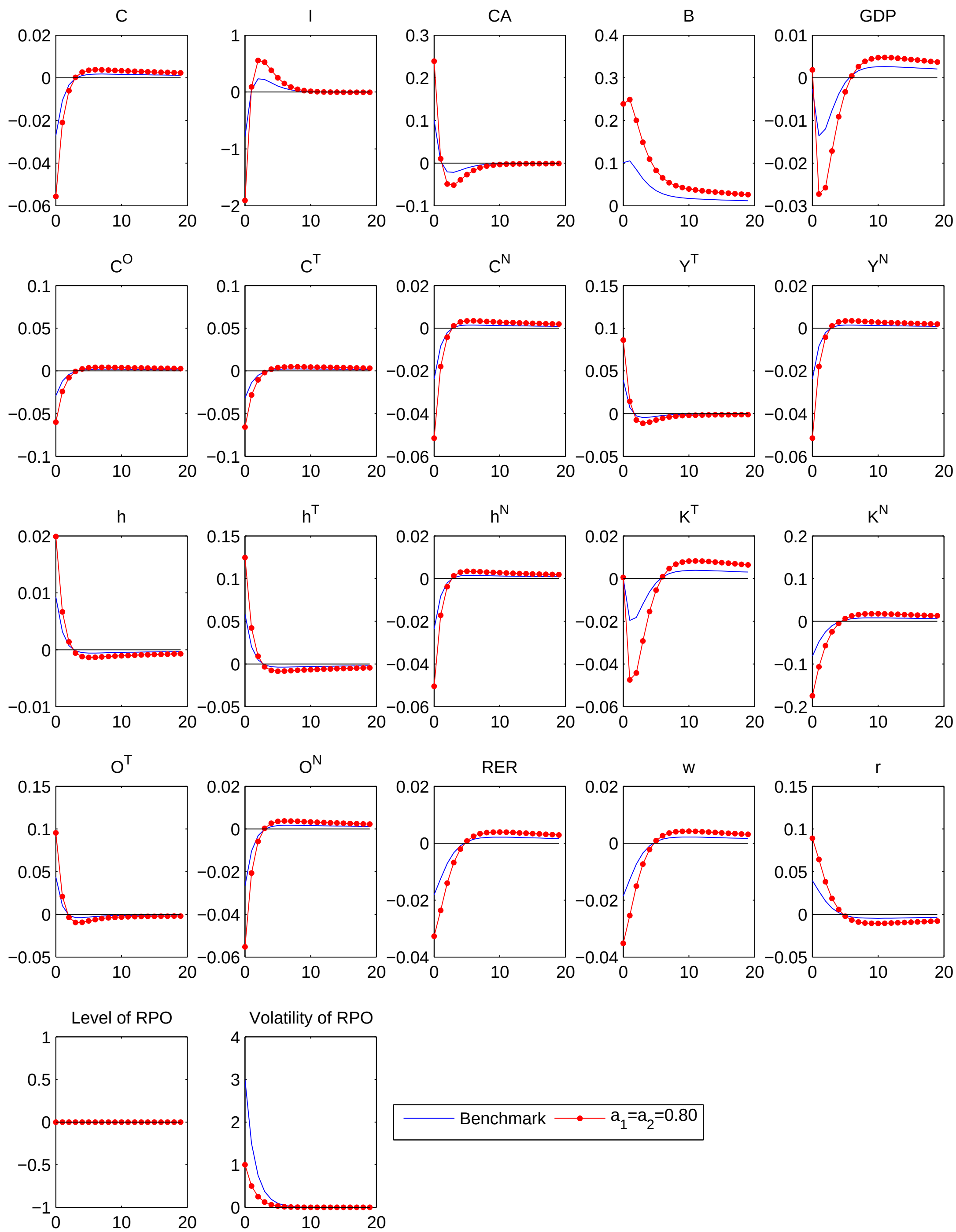


Figure 9: Impulse Responses to One S.D. Adverse Shocks to Volatilities of Oil Price, Tradable TFP and Non-Tradable TFP with Higher Weight of Oil in Production