



## Oil shocks and external adjustment

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### ARTICLE INFO

#### Article history:

Received 22 July 2008

Received in revised form 27 September 2010

Accepted 24 October 2010

Available online 6 November 2010

#### JEL classification:

F32

F41

#### Keywords:

Oil shocks

Trade

DSGE models

### ABSTRACT

We examine the effects of endogenously determined oil price fluctuations in a two-country DSGE model. Under incomplete financial markets, an oil market-specific shock that boosts the oil price results in a wealth transfer toward oil exporters, depresses the oil importer's consumption, and causes the oil importer's real exchange rate to depreciate. Although the oil importer experiences a deterioration in the oil component of its trade balance, an improvement in the nonoil balance substantially dampens the effects on the overall trade balance.

Published by Elsevier B.V.

### 1. Introduction

In reaction to the oil crises of the 1970s and early 1980s, as well as the more recent runup in oil prices that started in 2003, the oil component of the U.S. trade balance consistently deteriorated, as can be seen in Fig. 1. However, the link between oil prices and the overall goods trade balance appears more elusive. For example, although the overall trade deficit has expanded as oil prices have risen in recent years, it showed some improvement after both the first and second OPEC oil price shocks.

It is difficult to uncover a precise relationship between oil prices and the trade balance from Fig. 1. This difficulty may stem from several factors: other shocks have occurred simultaneously with oil shocks, oil shocks markedly affect the nonoil balance through general equilibrium channels, and correlations may vary at different frequencies. Using a dynamic stochastic general equilibrium model, we show that all of these explanations turn out to be important in accounting for the weak observed correlation between oil prices and the overall trade balance.

Our model builds on the work of Backus and Crucini (1998). Each of the two countries in our model produces a distinct good that is used as an input into the production of consumption and investment both at home and abroad. Oil serves as an input into the production of the domestic good, and also enters directly into the household consumption bundle. One country is an oil importer, while the other is an oil exporter. However, the model differs importantly from that of Backus and Crucini (1998) along two dimensions. To emphasize the role of both differential wealth effects across countries and substitution effects in the transmission of oil

shocks, we depart from their complete markets framework by assuming that only one non state-contingent bond is traded across countries. In addition, while Backus and Crucini (1998) focused on oil supply and technology shocks as drivers of oil price fluctuations, in line with recent empirical evidence by Kilian (2009) and Kilian et al. (2009), we include oil demand shocks.<sup>1</sup>

We gauge the relative importance of the various shocks by matching key moments in the model to corresponding moments in U.S. data. At medium-run frequencies, oil demand and supply shocks account for half of the variation in the nonoil balance.<sup>2</sup> However, these shocks account for only one sixth of the variation in the overall goods trade balance, pointing towards sizable general equilibrium effects.

As documented in the next section, the literature that modeled the effects of oil shocks can be divided into two broad categories, depending on whether the focus was on a closed or an open economy setting. The closed economy treatment of the subject has abstracted from the fact that many economies import oil from abroad in order to emphasize either the allocative effects on different industries or the intertemporal production choices involved when the price of the oil input changes exogenously. By contrast, much of the open economy work has focused on differential

<sup>1</sup> Kilian et al. (2009) used the identified VAR approach of Kilian (2009) to estimate fundamental oil demand, supply, and activity shocks. They uncover the response of several measures of the external balance for oil importers and exporters by regressing them on the identified shocks.

<sup>2</sup> By "medium-run frequencies" we mean oscillations of amplitude between 6 and 200 quarters as suggested by Comin and Gertler (2006). Filtering the data at business cycle frequencies, typically 6 to 32 quarters, would exclude near permanent movements or slow-moving adjustments that are important ingredients in understanding fluctuations in the trade balance.

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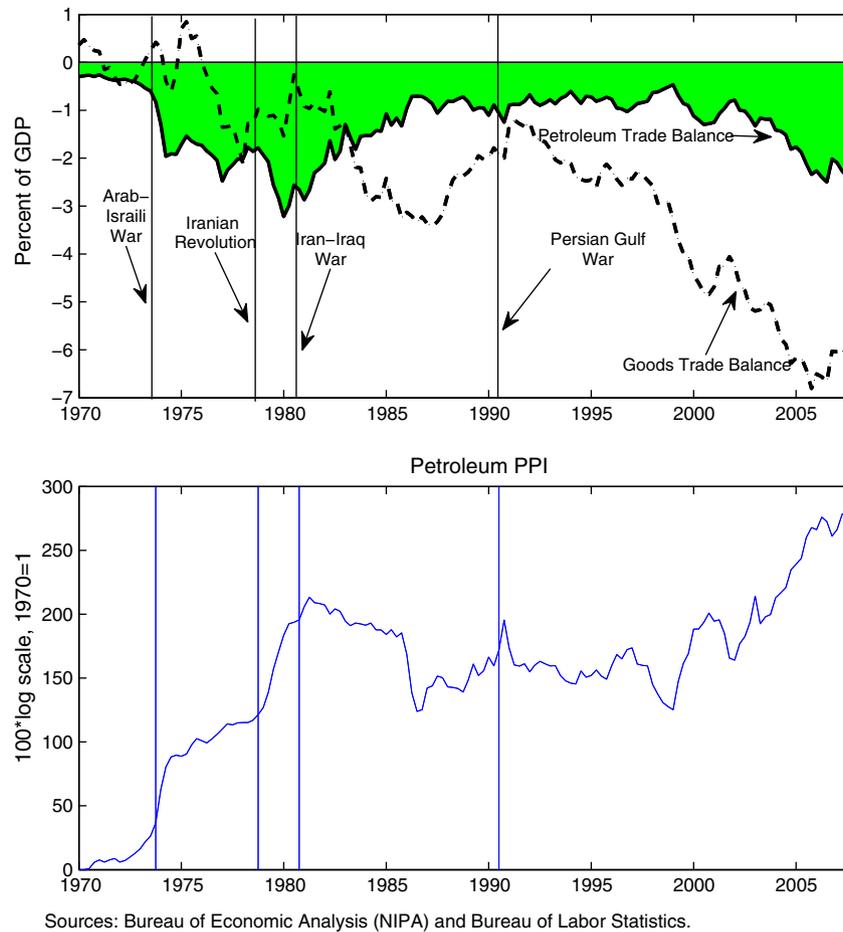


Fig. 1. The U.S. goods trade balance and some key indicators for oil trade.

cross-country wealth effects and has modeled oil price shocks as changes in transfer payments across countries.

The model in this paper bridges the gap between the open and closed economy strands of the literature. Following the closed economy approach, the model links the dynamic investment and saving decisions to the choice of factor inputs in production explicitly. Moreover, following the open economy literature, the model keeps track of relative wealth effects across countries.

We illustrate the general equilibrium repercussions of a change in the price of oil by focusing first on a contraction in foreign oil supply. For an oil importer, such as the United States, producers and households substitute away from oil. Nonetheless, the oil component of the trade balance deteriorates but the nonoil component of the trade balance improves. This improvement in the nonoil component is attributable to a negative wealth effect on the oil importer *relative* to the oil exporter, which induces the former's nonoil terms of trade to worsen, and its nonoil imports to contract. Accordingly, the response of the overall goods trade balance is dampened.

Key features that impact the relative wealth effects across countries are the degree of substitutability between oil and other production factors, the relative oil endowment, and the degree of international risk-sharing. A lower oil price elasticity of demand implies that an oil importer runs a larger deficit on the oil component of its trade balance. In turn, the larger oil deficit requires a larger nonoil trade surplus, and a further worsening of the nonoil terms of trade. Similarly, with a smaller oil endowment, the oil importer experiences a larger deterioration in the terms of trade. Finally, enhanced international risk-sharing reduces the need to counterbalance oil deficits with nonoil trade surpluses and dampens the associated

fluctuations in the terms of trade, but amplifies the fluctuation in the overall goods trade balance.

For oil shocks, the responses derived in our framework under complete financial markets, incomplete markets, and financial autarky are distinct from each other. This result stands in contrast with the typical finding for technology shocks when traded goods are sufficiently substitutable.<sup>3</sup> In that case, as noted by Cole and Obstfeld (1991), movements in the terms of trade are a powerful source of insurance against technology shocks independently of the available set of assets. Under a low elasticity of substitution between traded goods, as pointed out by Corsetti et al. (2008), a positive technology shock abroad causes the home country's terms of trade to *worsen*. In our model, the home country's terms of trade also worsen (and the real exchange rate depreciates) after a contractionary shock to foreign oil supply. With a low oil elasticity, the home country runs a persistent oil deficit that is offset by an expansion in goods exports spurred by a worsening in the terms of trade. Hence, in both Corsetti et al. (2008) and our contribution, the terms of trade fail to provide insurance and pronounced differences between the complete markets case and the incomplete markets setting can occur.

Our work also bridges the gap between the latest empirical evidence on the sources of oil price movements and DSGE models (which have typically taken oil prices as exogenous). With an endogenous oil price, we

<sup>3</sup> For instance, Baxter and Crucini (1995) showed that, for technology shocks, the equilibrium allocations in models where agents trade only one non state-contingent international bond are very close to those derived in an economy with complete international financial markets, provided that the technology shock is not permanent.

highlight commonalities and differences across several sources of fluctuation: oil supply shocks, oil demand shocks, and technology shocks.

Foreign oil demand shocks, modeled as shocks that affect the efficiency of oil inputs in consumption, eventually induce similar effects to those of foreign oil supply disturbances. However, their initial dynamics differ substantially. The moment matching exercise calls for a strong growth component for the shocks (as well as a slow-reverting error-correction component for the level) that induces rising oil prices over an extended period when efficiency contracts and oil demand expands. Since the shock lowers foreign activity disproportionately, the improvement in the nonoil balance is delayed.

In the case of technology shocks, the increase in the oil bill is not the main force influencing external adjustment. The typical effects of a technology shock dominate oil market channels. With a trade elasticity close to one, the increase in foreign production stimulates home export demand in spite of an appreciation of the home exchange rate. An improvement in the nonoil goods balance more than offsets the deterioration in the oil balance.

The rest of the paper proceeds as follows: Section 2 reviews the literature on oil shocks, Section 3 describes the model, Section 4 outlines the calibration and moment matching exercise, Sections 5 and 6 illustrate the model through numerical simulations, and Section 7 concludes.

## 2. Literature review

Since the large fluctuations in the relative price of oil in the 1970s, a vast and growing literature has examined the macroeconomic effects of oil shocks and the channels through which oil shocks operate. One strand of the literature tackled the question with econometric models and the principal aim to size the oil-price/GDP elasticity. Another strand of the literature interpreted the empirical findings that pointed to large macroeconomic effects of oil shocks through the lens of structural models.<sup>4</sup>

Early empirical studies such as Rasche and Tatom (1977) regressed GDP on oil prices and other control variables. Subsequent work, starting with Hamilton (1983), addressed potential endogeneity issues, settling on a censored measure of oil price increases, and singling out episodes of rapidly rising prices.<sup>5</sup>

Barsky and Kilian (2004) reviewed the arguments linking oil price increases to lower economic growth and provided arguments in favor of reverse causality from macroeconomic variables to oil prices. Kilian (2009) pioneered a way to decompose oil price movements into three components driven by shocks to oil supply, global activity, and oil demand.<sup>6</sup> Cavallo and Wu (2009) proposed a novel method of measuring oil price shocks that relies on narrative evidence from oil industry publications.

General equilibrium models are ideally suited to control for reverse causality. The literature that used structural models can be divided into two categories, depending on whether the focus was on a closed or open economy setting. The closed economy treatment has emphasized either the allocative effects on different industries or on the intertemporal production choices of a sudden change in the price of an input, but at the cost of abstracting from the fact that many economies import oil from abroad. By contrast, much of the open economy work focused on wealth

effects associated with the redistribution of income between oil importers and exporters after oil price changes.

Early contributions with a closed economy focus include Pierce et al. (1974) who used the MPS (MIT-Penn-SSRC) econometric model to obtain quantitative estimates on individual sectors of the U.S. economy for the effects of a permanent rise in the price of oil.<sup>7</sup> While the early models were rich in sectoral detail, they did not link the optimal choice of factor inputs in production to intertemporal saving and consumption decisions. Kim and Loungani (1992) solved this shortcoming by extending the real business cycle model of Kydland and Prescott (1982) to include oil inputs in the production function.<sup>8</sup> Leduc and Sill (2004) augmented the model of Kim and Loungani (1992) to tackle the question originally raised in the VAR study by Bernanke et al. (1997) of how alternative monetary policy specifications influence the transmission of oil shocks.<sup>9</sup>

Early open economy contributions include Schmid (1976), Findlay and Rodriguez (1977), and Buitert (1978). None of these contributions tackled the intertemporal decision on savings and investment. Svensson (1984) examined the welfare effects and the trade balance response to changes in the world oil prices for a small oil-importing economy with optimal saving and investment decisions in the context of a two-period model.

In the related literature on the wealth effects of a domestic resource discovery, or “Dutch Disease”, Bruno and Sachs (1982a) used a dynamic model with infinitely lived agents, while taking the world rate of interest, foreign prices, and foreign wealth as exogenous. The model extended the principally static analysis of earlier contributions by allowing for short-run capital specificity and long-run capital mobility, international capital flows, and far-sighted intertemporal optimizing behavior of households and firms.<sup>10</sup>

Building on the Dutch disease literature, Wijnbergen (1984) and Krugman (1987) developed dynamic open economy models of endogenous growth. However, the production function only incorporated labor. Both Wijnbergen (1984) and Krugman (1987) modeled oil price shocks as transfer payments across countries, capturing country-specific wealth effects, but not the substitution effects for factor inputs, a key feature of the closed economy studies.

The model in this paper bridges the gap between the open and closed economy strands of the literature. Following the closed economy approach, the model links the dynamic investment and saving decisions to the choice of factor inputs in production explicitly. Moreover, following the open economy approach, the model keeps track of changes in wealth across countries.<sup>11</sup>

## 3. Model description

There are two countries, a home country (calibrated based on U.S. data) and a foreign country (rest-of-the-world). Because the structure of

<sup>7</sup> A related study, Bruno and Sachs (1982b) also set up a macro econometric model in the style of the MPS but with a focus on the United Kingdom and found that autonomous increases in commodity prices contributed to a long-run slowdown in productivity.

<sup>8</sup> Rotemberg and Woodford (1996) extended the model of Kim and Loungani (1992) to allow for imperfect competition and found that departures from competitive behavior in the product market can amplify the effect of oil price fluctuations. Finn (2000) argued that such departures from perfect competition are not a necessary ingredient to generate substantial aggregate output effects from oil price increases. Instead, she introduced variable capacity utilization and assumed that capital utilization requires energy.

<sup>9</sup> A separate strand of the closed economy literature has focused on putty-clay models in which the choice of capital is linked with a specific energy intensity at installation. See Atkeson and Kehoe (1999) and Wei (2003).

<sup>10</sup> Earlier contributions on the Dutch disease that developed a static framework include: Bruno (1982), Corden and Neary (1982), Forsyth and Kay (1980), Neary and Purvis (1983). Further references can be obtained from the overview article by Corden (1984).

<sup>11</sup> While Backus and Crucini (1998) had a similar focus on the consistent treatment of oil inputs in production in an international setting, their model dampened the importance of country specific wealth effects through the assumption of complete markets. We assume that financial markets are incomplete.

<sup>4</sup> Jones et al. (2004) offers a helpful overview of this literature. In our review we add more recent contributions and place greater emphasis on papers that model the international nature of the oil trade.

<sup>5</sup> Hamilton (1983) used Granger causality tests and historical details of the oil industry to argue that exogenous price hikes preceded every U.S. postwar recession. Mork (1989) found it important to distinguish between increases and decreases in oil prices. Hamilton (2003) focused on the relative magnitude of increases.

<sup>6</sup> Kilian et al. (2009) extended the analysis in Kilian (2009) to encompass the reaction of open economy variables to oil shocks, also differentiating between oil importers and exporters.

the country blocs is symmetric, we focus on the home country, although our calibration allows for differences in population size and in the per capita oil endowment. Each country specializes in the production of a final good that is an imperfect substitute for the final good produced in the other country. Production requires capital, labor, and oil. The investment bundle is a composite of the domestically produced good and inputs of the foreign good. The consumption bundle is a composite of the domestically produced good, imports of the foreign good, and oil. For expositional purposes, the consumption bundle is assumed to be produced by a competitive distribution sector with a productive structure that mirrors household preferences over the three goods. While asset markets are complete at the country level, asset markets are incomplete internationally. Finally, both the home and foreign country are endowed with a non-storable supply of oil each period.

3.1. Households

The utility functional of a typical member of household  $h$  is

$$\mathbb{E}_t \sum_{j=0}^{\infty} \beta^j \frac{1}{1-\sigma} \left( C_{t+j}(h) - \kappa \frac{C_{t+j-1}}{\zeta} \right)^{1-\sigma} + \frac{\chi_0}{1-\chi} \left( 1 - N_{t+j}(h) \right)^{1-\chi}, \tag{1}$$

where the discount factor  $\beta$  satisfies  $0 < \beta < 1$ . The period utility function depends on an individual's current and lagged consumption, where  $\kappa$  parameterizes the extent of external habit persistence in consumption. The period utility function also depends on leisure,  $1 - N_t(h)$ . Population differences across countries are captured by  $\zeta$ , the household size in the home country, while we normalize household size in the foreign country to unity.

Each member of household  $h$  faces a budget constraint in period  $t$  which states that the combined expenditure on goods and the net accumulation of financial assets must equal disposable income:

$$P_{Ct} C_t(h) + P_{It} I_t(h) + e_t P_{Bt}^* B_{t+1}(h) - e_t B_{Bt}(h) = W_t(h) N_t(h) + R_{Kt} K_t(h) + \Gamma_t(h) + T_t(h) - P_{Dt} \phi_{It}(h). \tag{2}$$

Final consumption goods are purchased at the price  $P_{Ct}$ , and final investment goods at the price  $P_{It}$ . Investment in physical capital augments the per capita capital stock  $K_{t+1}(h)$  according to a linear transition law of the form:

$$K_{t+1}(h) = (1-\delta) K_t(h) + I_t(h), \tag{3}$$

where  $\delta$  is the depreciation rate of capital.

Individuals accumulate financial assets by purchasing state-contingent domestic bonds, and a non state-contingent foreign bond. Given the representative agent structure at the country level, we omit terms involving the former from the budget constraint. The term  $B_{t+1}(h)$  in the budget constraint represents the quantity of the non state-contingent bond purchased by a typical member of household  $h$  at time  $t$  that pays one unit of foreign currency in the subsequent period,  $P_{Bt}^*$  is the foreign currency price of the bond, and  $e_t$  is the exchange rate expressed in units of home currency per unit of foreign currency. To ensure that net foreign assets are stationary, we follow Turnovsky (1985) and assume there is an intermediation cost  $\phi_{Bt}$  paid by households in the home country for purchases of foreign bonds. Specifically, the intermediation costs depend on the ratio of economy-wide holdings of net foreign assets to nominal output ( $P_{Dt} Y_t$ , defined below):

$$\phi_{Bt} = \exp\left(-\phi_b \left(\frac{e_t B_{t+1}}{P_{Dt} Y_t}\right)\right). \tag{4}$$

If the home economy has an overall net lender position, a household will earn a lower return on any holdings of foreign bonds. By contrast, if

the economy has a net debtor position, a household will pay a higher return on any foreign debt.

Each member of household  $h$  earns labor income  $W_t(h) N_t(h)$  and capital income  $R_{Kt} K_t(h)$ . The member also receives an aliquot share  $\Gamma_t(h)$  of the sum of firm profits and the sale of oil, and receives net transfers of  $T_t(h)$ . Finally, as in Christiano et al. (2005), it is costly to change the level of gross investment from the previous period, so that the acceleration in the capital stock is penalized:

$$\phi_{It} = \frac{1}{2} \phi_i \frac{(I_t(h) - I_{t-1}(h))^2}{I_{t-1}(h)}. \tag{5}$$

In every period  $t$ , a typical member of household  $h$  maximizes the utility functional (1) with respect to consumption, labor supply, investment, end-of-period capital stock, and holdings of foreign bonds, subject to its budget constraint (2), and the transition equation for capital (3). In doing so, prices, wages, and net transfers are taken as given.

3.2. Firms and production

Each country produces a single distinct nonoil good. Focusing on the home country, this nonoil good is produced by perfectly competitive firms according to a constant-returns-to-scale technology. The representative firm's technology can be characterized as a nested constant-elasticity of substitution specification of the form:

$$V_t = \left( \omega_k^{\frac{\rho_v}{1+\rho_v}} K_t^{\frac{1}{1+\rho_v}} + (Z_t L_t)^{\frac{1}{1+\rho_v}} \right)^{1+\rho_v}, \tag{6}$$

$$Y_t = \left( (1-\omega_{oy})^{\frac{\rho_o}{1+\rho_o}} V_t^{\frac{1}{1+\rho_o}} + \omega_{oy}^{\frac{1}{1+\rho_o}} O_{Yt}^{\frac{1}{1+\rho_o}} \right)^{1+\rho_o}, \tag{7}$$

where the quasi-share parameter  $\omega_{oy}$  determines the importance of oil purchases in the firm's gross output, and the parameter  $\rho_o$  determines the price elasticity of demand for oil.

Each producer utilizes capital and labor services,  $K_t$  and  $L_t$ , to make a "value-added" input  $V_t$ . This composite input is combined with oil services  $O_{Yt}$  to produce the domestic nonoil good  $Y_t$ . The term  $Z_t$  represents a stochastic process for the evolution of technology. Producers choose a contingency plan for  $K_t$ ,  $L_t$ , and  $O_{Yt}$  that minimizes the cost of producing the domestic output good subject to Eqs. (6) and (7). In solving this problem, producers take as given the rental price of capital  $R_{Kt}$ , the wage  $W_t$ , and the price of oil  $P_{Ot}$ . Firms sell their output for inclusion in final consumption and investment at a price  $P_{Dt}$ , which is the Lagrange multiplier from the cost-minimization problem.

3.2.1. Production of consumption and investment goods

The consumption basket  $C_t$  that enters the household's budget constraint can be regarded as produced by perfectly competitive consumption distributors. The form of the production function mirrors the preferences of households over consumption of nonoil goods and oil. These distributors purchase a nonoil consumption good  $C_{Nt}$  and oil services  $O_{Ct}$  as inputs in perfectly competitive input markets, and produce a composite consumption good according to a CES production function:

$$C_t = \left( (1-\omega_{oc})^{\frac{\rho_o}{1+\rho_o}} C_{Nt}^{\frac{1}{1+\rho_o}} + \omega_{oc}^{\frac{1}{1+\rho_o}} \left( \frac{O_{Ct}}{\mu_{O_{Ct}}} \right)^{\frac{1}{1+\rho_o}} \right)^{1+\rho_o}, \tag{8}$$

where the quasi-share parameter  $\omega_{oc}$  determines the importance of oil purchases in the household's composite consumption bundle, and the parameter  $\rho_o$  determines the price elasticity of demand for oil (assumed equal for households and firms). The term  $\mu_{O_{Ct}}$  represents a stochastic process for the oil intensity in the production of the consumption bundle. This shock could capture changes in oil demand coming from external

factors, such as unusually cold winters, or a shift towards consuming goods that are more energy intensive.

Consumption distributors choose a contingency path for their inputs  $C_{Nt}$  and  $O_{Ct}$  to minimize the costs of producing the consumption bundle, taking as given input prices  $P_{CNt}$  and  $P_{Ob}$ , respectively. The Lagrangian multiplier from this cost-minimization problem determines the price of the consumption bundle charged to households, i.e.,  $P_{Ct}$  in the household's budget constraint given in Eq. (2).

Similarly, the nonoil consumption good  $C_{Nt}$  and investment good  $I_t$  are produced by perfectly competitive distributors. Both the domestically produced nonoil good and the foreign nonoil good are utilized as inputs, though we allow for the proportion of each input to differ between nonoil consumption and investment goods. The production function for the nonoil consumption good  $C_{Nt}$  is given by:

$$C_{Nt} = \left( (1 - \omega_{mc})^{\frac{\rho_c}{1 + \rho_c}} C_{Dt}^{\frac{1}{1 + \rho_c}} + (\omega_{mc} \mu_{Mt})^{\frac{\rho_c}{1 + \rho_c}} (M_{Ct})^{\frac{1}{1 + \rho_c}} \right)^{1 + \rho_c}, \quad (9)$$

where  $C_{Dt}$  denotes the quantity of the domestically-produced nonoil good purchased at a price of  $P_{Dt}$ , and used as an input by the representative nonoil consumption distributor. The term  $M_{Ct}$  denotes imports of the foreign nonoil good purchased at a price of  $P_{Mt}$ . The term  $\mu_{Mt}$  captures an import preference shock. In the moment matching exercise that follows, this shock helps account the volatility of nonoil goods trade not explained by the remaining shocks. The Lagrangian multiplier from the cost minimization problem for the distributors determines the price of the nonoil consumption good,  $P_{CNt}$ .

Finally, the production function for investment goods is isomorphic to that given in Eq. (9), though allowing for possible differences in the import intensity of investment goods (determined by  $\omega_{mi}$ , akin to  $\omega_{mc}$  in Eq. (9)), and the degree of substitutability between nonoil imports and domestically-produced goods in producing investment goods (determined by  $\rho_i$ ). The same import preference shock  $\mu_{Mt}$  also affects investment imports. The Lagrangian from the problem that investment distributors face determines the price of new investment goods,  $P_{It}$ , that appears in the household's budget constraint.<sup>12</sup>

### 3.3. The oil market

Each period the home and foreign countries are endowed with exogenous supplies of oil  $Y_{Ot}$  and  $Y_{O^*t}$ , respectively. The two endowments are governed by distinct stochastic processes.

With both domestic and foreign oil supply determined exogenously, the oil price  $P_{Ot}$  adjusts endogenously to clear the world oil market:

$$Y_{Ot} + \frac{1}{\zeta} Y_{O^*t} = O_{Yt} + O_{Ct} + \frac{1}{\zeta} (O_{Y^*t} + O_{C^*t}). \quad (10)$$

To clear the oil market, the sum of home and foreign oil production must equal the sum of home and foreign oil consumption by firms and households. Because all variables are expressed in per capita terms, foreign variables are scaled by the relative population size of the home country  $\frac{1}{\zeta}$ .

### 3.4. Fiscal policy

The government purchases a fixed share  $g$  of the domestic nonoil good  $Y_t$  but the import content of government purchases is zero. Government

purchases  $G_t = gY_t$  have no direct effect on household utility. Given the Ricardian structure of our model, we assume that net lump-sum transfers  $T_t$  are adjusted each period to balance the government receipts and revenues, so that:

$$P_{Dt} G_t + T_t = 0. \quad (11)$$

### 3.5. Resource constraints for nonoil goods, and net foreign assets

The resource constraint for the nonoil goods sector of the home economy can be written as:

$$Y_t = C_{Dt} + I_{Dt} + G_t + \frac{1}{\zeta} M_t^* + \phi_{It}, \quad (12)$$

where  $M_t^*$  denotes foreign imports – again expressed in per capita terms, which accounts for the population scaling factor  $\frac{1}{\zeta}$ . The term  $\phi_{It}$  denotes the resources that are lost due to costs of adjusting investment.

The evolution of net foreign assets can be expressed as:

$$e_t P_{Bt}^* B_{Ft+1} = e_t B_{Ft} + e_t P_{Mt}^* \frac{1}{\zeta} M_t^* - P_{Mt} M_t + P_{Ot} (Y_{Ot} - O_{Yt} - O_{Ct}). \quad (13)$$

This expression can be derived by combining the budget constraint for households, the government budget constraint, and the definition of firm profits.

## 4. Solution method and calibration

The model is log-linearized around its steady state.<sup>13</sup> To obtain the reduced-form solution of the model, we use the numerical algorithm of Anderson and Moore (1985), which provides an efficient implementation of the method proposed by Blanchard and Kahn (1980).<sup>14</sup>

The model is calibrated at a quarterly frequency. The parameter values for the home economy under our benchmark calibration are listed in Table 1. Parameters for the foreign economy are identical except for the parameters determining the intensity of oil use, the capital share of production, and the trade shares. The latter are determined by the assumption that trade is balanced in the steady state and that the relative population size,  $\zeta$ , is scaled so that the home economy accounts for one third of world GDP.

The discount factor  $\beta$  is 0.99. The parameter  $\sigma$  in the subutility function over consumption is set equal to 1.5. We set  $\chi = 10$ , implying a Frisch elasticity of labor supply of 0.2. The utility parameter  $\chi_0$  is set so that employment comprises one-third of the household's time endowment. In line with Smets and Wouters (2007), the real rigidities affecting consumption,  $\kappa$ , and investment,  $\phi_i$ , are 0.8 and 3, respectively.

The production function parameter  $\rho_v$  is set to  $-2$ , implying an elasticity of substitution between capital and labor of 0.5. The depreciation rate of capital  $\delta = 0.025$  is consistent with an annual depreciation rate of 10%. We set the government share of output to 18%, and adjust the quasi-capital share parameter  $\omega_k$ , so that the investment share of output equals an empirically-realistic value of 20%.

<sup>13</sup> A linear framework might appear at odds with the empirical work that has stressed asymmetries in the propagation of oil shocks to the macroeconomy. However, the recent analysis of Kilian and Vigfusson (2009) found little support for asymmetries in the response of U.S. GDP, unemployment, and gasoline consumption to energy price shocks.

<sup>14</sup> The steady state around which we linearize depends on the relative level of technology in each country, which we initialize to unity. We evaluated the robustness of our solution procedure by using a nonlinear Newton–Raphson algorithm that does not rely on linearization around an initial steady state, and found that the results were nearly identical to those reported.

<sup>12</sup> As discussed in Erceg et al. (2008), our trade specification implies that the activity variable driving (nonoil) import and export demand can be regarded as a weighted average of consumption and investment, with the latter receiving a large weight consistent with the high weight of investment goods in U.S. trade. The paper also provides empirical support in favor of this specification over a specification in which the real activity variable driving trade is total absorption. See also Engel and Wang (2008).

**Table 1**  
Benchmark calibration.

| Parameter                                     | Used to determine                       | Parameter   | Used to determine                            |
|---|---|---|--|
| <i>Parameters common across countries</i>     |   |   |  |
| $\beta = 0.99$                                | Discount factor                         | $\sigma = 1.5$  | Intertemporal consumption elasticity         |
| $\chi = 10$                                   | Labor supply elasticity (0.2)           | $N_{ss} = 0.33$   | Steady state labor share to fix $\chi_0$     |
| $\kappa = 0.8$                                | Habit persistence                       | $\phi_i = 3$  | Investment adj. cost                         |
| $\delta = 0.025$                              | Depreciation rate of capital            | $\rho_v = -2$   | K–L sub. elasticity (0.5)                    |
| $\rho_o = -1.65$                              | Oil sub. elasticity (0.40)*             | $\rho_c = \rho_i = 13$                                  | Cons./inv. import sub. elasticity (1.1)*     |
| $g = 0.18$                                    | Steady state gov. cons. share of GDP    |   |  |
| <i>Parameters not common across countries</i> |   |   |  |
| $\omega_k = 1.54$                             | Parameter on K in value added (home)    | $\omega_k^* = 1.60$                                     | Parameter on K in value added (foreign)      |
| $\omega_{oy} = 0.028$                         | Weight on oil in production (home)      | $\omega_{oy}^* = 0.057$                                 | Weight on oil in production (foreign)        |
| $\omega_{oc} = 0.023$                         | Weight on oil in consumption (home)     | $\omega_{oc} = 0.041$                                   | Weight on oil in consumption (foreign)       |
| $\omega_{mc} = 0.068$                         | Weight on imports in consumption (home) | $\omega_{mc}^* = 0.039$                                 | Weight on imports in consumption (foreign)   |
| $\omega_{mi} = 0.40$                          | Weight on imports in investment (home)  | $\omega_{mi} = 0.25$                                    | Weight on imports in investment (foreign)    |
| <i>Parameters specific to home country</i>    |   |   |  |
| $\zeta = 1/2$                                 | Relative size of home country           | $\frac{y_{obs}^1}{\theta_{ss}^1 + \theta_{cs}^1} = 0.3$ | Steady state ratio oil prod. to cons. (home) |
| $\phi_b = 0.0001$                             | Curvature of bond intermed. cost        |   |  |

\*Values determined using simulated method of moments. See also Table 2.

Our calibration of  $\omega_{oy}$  and  $\omega_{oc}$  is determined by the overall oil share of output, and the end-use ratios of oil in consumption and production. Based on data from the Energy Information Administration of the U.S. Department of Energy for 2008, the overall oil share of the domestic economy is set to 4.2%, with one-third of total oil usage accounted for by households, and two-thirds by firms. The oil imports of the home country are set to 70% of total demand in the steady state, implying that 30% of oil demand is satisfied by domestic production. This estimate is based on 2008 data from the National Income and Product Accounts. In the foreign block, the overall oil share is set to 8.2%. The oil endowment abroad is 9.5% of foreign GDP, based on oil supply data from the Energy Information Administration.

Turning to the parameters determining trade flows, the parameter  $\omega_{mc}$  is chosen to match the estimated average share of non-oil imports in total U.S. non-oil consumption of about 7% using NIPA data, while the parameter  $\omega_{mi}$  is chosen to match the average share of imports in total U.S. investment of about 40%. This calibration implies a ratio of nonoil goods imports relative to GDP for the home country of about 12%. Given that trade is balanced in steady state, and that the oil import share for the home country is 3% of GDP, the goods export share is 15% of GDP. Following Erceg et al. (2008), we also set  $\omega_{mc}^*$  and  $\omega_{mi}^*$  to reflect the split in U.S. exports between consumption and investment in the BEA International Accounts.

4.1. Moment matching

The parameters governing the elasticity of substitution for oil,  $\rho_o$ , the elasticity of substitution between domestic and foreign goods,  $\rho_c = \rho_i$ , and the autoregressive processes for the various shocks in the model are calibrated using the simulated method of moments. Accordingly, the model incorporates 4 shock processes in each of the 2 countries: technology shocks, import preference shocks, oil supply shocks, and oil demand shocks. The first three types of shocks are governed by an AR(1) process. However, the oil demand shock is governed by an AR(2) process that captures a growth rate component and imposes an error correction term to ensure stationarity in levels.<sup>15</sup> We constrain the auto-regressive parameters to be identical in the U.S. and the foreign bloc, but left the standard deviations of the innovations unconstrained. We assume that the innovations to all the shock processes are independent of each other. The calibration procedure involves minimizing the square of the distance

between key moments generated from the model and their observed counterparts.

Following Comin and Gertler (2006), we bandpass filtered the data used in estimation to retain only oscillations with amplitude between 6 and 200 quarters.<sup>16</sup> Going beyond business cycle frequencies avoids the exclusion of nearly permanent movements or slow-moving adjustments that are important ingredients in understanding fluctuations in the trade balance. Oil shocks may cause slow interactions between the nonoil balance and oil imports that are of principal interest in this exercise. However, we also report the implications of our calibration for moments at business cycle frequencies.

The distance function for the moment matching exercise includes the standard deviation and the first-order autocorrelation of eight variables: U.S. and foreign GDP, U.S. and foreign oil supply, the relative price of oil, oil imports, nonoil goods imports, and the overall goods trade balance expressed as a share of GDP.<sup>17</sup> In an attempt to normalize the various moments included in the distance function, we scaled them by the size of the corresponding moment in the data. Table 2 reports the parameter values that minimized the distance function. The calibration of the elasticity of substitution for oil, at a value of 0.4, is in line with previous empirical estimates.<sup>18</sup> The value for the goods trade elasticity, at 1.1 is also in line with typical estimates using aggregate data.<sup>19</sup>

The moments underlying the distance function are reported in Tables 3 and 4. The model matches the moments in the data closely. Table 3 shows that oil shocks play essentially no role in accounting for the volatility of U.S. output at medium-run frequencies (encompassing oscillations with amplitude from 6 to 200 quarters). By contrast, at these frequencies, the bulk of the volatility in the oil price and in the oil import share are explained by oil demand and supply shocks, with oil demand shocks playing a larger role. Moreover, about half of the variation in the

<sup>16</sup> We use the implementation of the bandpass filter derived by Christiano and Fitzgerald (2003).

<sup>17</sup> We use quarterly data from 1974 through 2008. Series for U.S. GDP, oil imports, nonoil goods imports, and the overall goods trade balance are from the U.S. National Income and Products Accounts (NIPA). Series for U.S. and foreign oil production are from the Energy Information Administration of the U.S. Department of Energy. The relative price of oil is the ratio of the refiners' acquisition cost for imported crude obtained from the Energy Information Administration and the GDP deflator from NIPA. The series for foreign GDP is an export-weighted average of the GDP of the 26 most important trading partners of the United States. A description of the export weights can be found in Loretan (2005). The countries included account for well over 90% of U.S. exports as well as imports.

<sup>18</sup> For instance, Cooper (2003) estimated the long-run price elasticity of the demand for crude oil to be 0.45.

<sup>19</sup> For instance, Hooper et al. (2000) estimated trade price elasticities using aggregate data for G-7 countries. They reported a long-run export price elasticity of 1.5 for the United States.

<sup>15</sup> We fixed the error correction term at an arbitrary small value. When we allowed for AR(2) processes for technology, import preference shocks, and oil supply shocks, the growth component was rejected by the data in each case.

**Table 2**  
Results of moment matching exercise.<sup>a</sup>

| Home and foreign                           |                    |                                 |
|--|--------------------|---------------------------------|
| Shock type                                 | AR(1) coefficients | AR(2) coefficients <sup>b</sup> |
| Technology                                 | 0.89               | –                               |
| Import preferences                         | 0.98               | –                               |
| Oil supply                                 | 0.99               | –                               |
| Oil demand                                 | 1.90               | 0.91                            |
| Standard deviations of innovations         |                    |                                 |
| Shock type                                 | Home               | Foreign                         |
| Technology                                 | 0.017              | 0.010                           |
| Import preferences                         | 0.0008             | 0.0054                          |
| Oil supply                                 | 0.018              | 0.016                           |
| Oil demand                                 | 0.00018            | 0.038                           |
| Home and foreign substitution elasticities |                    |                                 |
| Nonoil goods imports                       | 1.1                |                                 |
| Oil  | 0.40               |                                 |

<sup>a</sup> The distance function for the moment matching exercise constrained the AR coefficients for the shock processes to be identical in the Home and Foreign country, but not the standard deviations. Similarly, the substitutions elasticity were imposed to be identical across countries.

<sup>b</sup> The oil demand shock has growth and error correction components given by the process:  $\mu_{ot} - \mu_{ot-1} = \rho_{\mu 1}(\mu_{ot} - \mu_{ot-1}) - \rho_{\mu 2}(\mu_{ot-1}) + \epsilon_{\mu_{ot}}$ , where  $\epsilon_{\mu_{ot}}$  is white noise. That process can be mapped into an AR(2) representation for  $\mu_{ot}$  with coefficients given by  $1 + \rho_{\mu 1} - \rho_{\mu 2}$  and  $-\rho_{\mu 1}$ .

nonoil balance is attributed to oil shocks. Because of offsetting effects between the nonoil balance and oil imports, oil shocks account for a more modest fraction of the volatility in the overall goods trade balance.

Finally, Table 5 reports the variance at business cycle frequencies (including oscillations with amplitude from 6 to 32 quarters) for the variables in the distance function, keeping the calibration unvaried. Remarkably, the model still comes close to replicating the observed variances; the only large miss is the variance for the oil price. At business cycle frequencies, productivity shocks explain again most of the variation in GDP and oil shocks explain most of the variation in oil prices. These findings are in line with those reported in Backus and Crucini (1998), notwithstanding their omission of oil demand shocks.

## 5. Model simulations

We start by reporting simulation results for oil supply shocks. This approach is in the spirit of much of the previous literature, which analyzed the effects of oil price fluctuations that were ascribed exclusively to supply shocks. In addition, a focus on supply shocks facilitates the exploration of wealth and substitution effects, as these shocks lead to nearly permanent increases in the price of oil in our

**Table 3**  
Variances of key variables at medium-run frequencies.

| Variable                      | Data | All shocks | Oil shocks only |
|-------------------------------|------|------------|-----------------|
| 1. U.S. GDP                   | 5.1  | 5.1        | 0.2             |
| 2. Foreign GDP                | 2.9  | 2.9        | 1.0             |
| 3. U.S. oil supply            | 26   | 26         | 26              |
| 4. Foreign oil supply         | 20   | 20         | 20              |
| 5. Oil price (in real terms)  | 1622 | 1600       | 1560            |
| 6. Oil balance (GDP share)    | 0.25 | 0.25       | 0.25            |
| 7. Nonoil balance (GDP share) | 0.83 | 0.86       | 0.40            |
| 8. Trade balance (GDP share)  | 0.62 | 0.60       | 0.13            |

Both observed and model data were bandpass filtered choosing oscillations of amplitude ranging from 6 to 200 quarters. “All shocks” refers to model data generated by turning on shocks to technology, import preferences, oil demand, and oil supply both at home and abroad. “Oil shocks only” refers to model data generated by turning on domestic and foreign oil demand and supply shocks, and excluding all other shocks.

calibrated model. In Section 6, we highlight commonalities and differences between oil supply shocks, oil demand shocks, and technology shocks.

Fig. 2 shows responses of the home oil-importing country under our benchmark calibration. The shock reduces foreign oil supply and is scaled at two standard deviations. The resulting 8% persistent rise in the price of oil induces a fall in home oil demand. Both households and firms substitute away from the more costly oil input. Given an elasticity of oil demand equal 0.4, demand drops about 3%.

The decline in oil use has effects on gross nonoil output, the expenditure components, and the real interest rate that resemble those of a highly persistent decline in productivity. Lower oil use leads to a fall in the current and future marginal product of capital, causing investment and gross output to fall. In the long term the capital stock also falls. Consumption contracts due to a reduction in household income. The real interest rate falls, notwithstanding a transient initial increase due to habit formation in preferences.

Turning to the implications for the external sector, the drop in domestic oil demand translates into a 4.5% fall of real oil imports, as the home country imports about two thirds of its oil use in steady state. Given oil imports amount to about 3% of GDP in steady state, and nominal imports rise about 3.5%, the oil balance deteriorates 0.1%age point.

While the responses of consumption output and investment to the oil supply shock resemble those of a persistent contraction in technology, the exchange rate response does not.<sup>20</sup> Since the rational expectations solution requires that the net foreign asset position is bounded away from infinity (conditional on current information), the home country's nonoil balance must improve enough to offset the long-run deterioration in the oil balance, as well as to finance interest payments on the stock of debt accumulated along the transition path. Thus, the consumption-based real exchange rate (the terms of trade track the real exchange rate closely) depreciates, which stimulates home nonoil net exports. As the shock to oil supply leads to a very persistent rise in oil prices, consumption smoothing dictates a quick offset of the deficit from the oil side of the trade balance by a surplus in the nonoil balance. If the offset were delayed, a greater accumulation of debt and related interest rate payments would result in a suboptimal drop in future consumption.

Fig. 3 contrasts the responses of the persistent oil supply contraction under our baseline calibration with those of a shock with lower persistence (the AR(1) coefficient is 0.5). With the less persistent shock, the rise in oil prices would be more transient. Consumption smoothing in concert with a smaller depreciation of the exchange rate imply a smaller improvement in the nonoil balance; hence, the overall trade balance deteriorates almost twice as much on impact.

### 5.1. Key parameters influencing the wealth effect

If oil demand is sufficiently price-inelastic, a reduction in foreign oil supply raises the present value of oil imports. The resulting deterioration in the overall goods trade balance is offset by an improvement in the nonoil balance. This improvement is attributable to a negative wealth effect on the oil-importing country relative to the foreign oil exporter.

Several structural parameters play a key role in determining the relative wealth effects across countries. Fig. 4 contrasts the responses to a foreign oil contraction sized at two standard deviations under our benchmark calibration and under two alternative calibrations of the price elasticity of oil demand. One alternative imposes an elasticity of unity, consistent with a Cobb–Douglas production function over the factor inputs. The other alternative imposes an elasticity of 0.10, close to a Leontief specification.

<sup>20</sup> The benchmark calibration of the trade elasticity around unity implies an appreciation of the real exchange rate in reaction to a persistent contraction in technology.

**Table 4**  
Autocorrelations of key variables at medium-run frequencies.

| Variable                      | Data | All shocks | Oil shocks only |
|-------------------------------|------|------------|-----------------|
| 1. U.S. GDP                   | 0.97 | 0.96       | 0.99            |
| 2. Foreign GDP                | 0.97 | 0.97       | 0.99            |
| 3. U.S oil supply             | 0.98 | 0.98       | 0.98            |
| 4. Foreign oil supply         | 0.98 | 0.98       | 0.98            |
| 5. Oil price (in real terms)  | 0.98 | 0.99       | 0.99            |
| 6. Oil balance (GDP share)    | 0.98 | 0.99       | 0.99            |
| 7. Nonoil balance (GDP share) | 0.98 | 0.98       | 0.99            |
| 8. Trade balance (GDP share)  | 0.98 | 0.98       | 0.98            |

Both observed and model data were bandpass filtered choosing oscillations of amplitude ranging from 6 to 200 quarters. “All shocks” refers to model data generated by turning on shocks to technology, import preferences, oil demand, and oil supply both at home and abroad. “Oil shocks only” refers to model data generated by turning on domestic and foreign oil demand and supply shocks, and excluding all other shocks.

With the size of the oil supply disruption kept constant across the cases shown in Fig. 4, the oil price rises about four times as much under the near-Leontief specification as under our baseline calibration. As the oil price elasticity of demand under this alternative calibration is about one fourth as large as under the benchmark calibration, home oil demand falls again

**Table 5**  
Variances of key variables at business cycle frequencies.

| Variable                      | Data | All shocks | Oil shocks only |
|-------------------------------|------|------------|-----------------|
| 1. U.S. GDP                   | 1.6  | 1.4        | 0.01            |
| 2. Foreign GDP                | 0.49 | 0.49       | 0.04            |
| 3. U.S oil supply             | 3.9  | 4.1        | 4.1             |
| 4. Foreign oil supply         | 3.8  | 3.2        | 3.2             |
| 5. Oil price (in real terms)  | 246  | 53         | 48              |
| 6. Oil balance (GDP share)    | 0.03 | 0.01       | 0.01            |
| 7. Nonoil balance (GDP share) | 0.14 | 0.12       | 0.01            |
| 8. Trade balance (GDP Share)  | 0.13 | 0.13       | 0.02            |

Both observed and model data were bandpass filtered choosing oscillations of amplitude ranging from 6 to 32 quarters. “All shocks” refers to model data generated by turning on shocks to technology, import preferences, oil demand, and oil supply both at home and abroad. “Oil shocks only” refers to model data generated by turning on domestic and foreign oil demand and supply shocks, and excluding all other shocks.

about 3%. Accordingly, the larger oil price rise results in a greater deterioration of the oil component of the trade balance. The associated transfer of relative purchasing power further depresses home relative to foreign wealth. To obtain a bigger improvement in the nonoil balance, the real exchange rate depreciates by more.

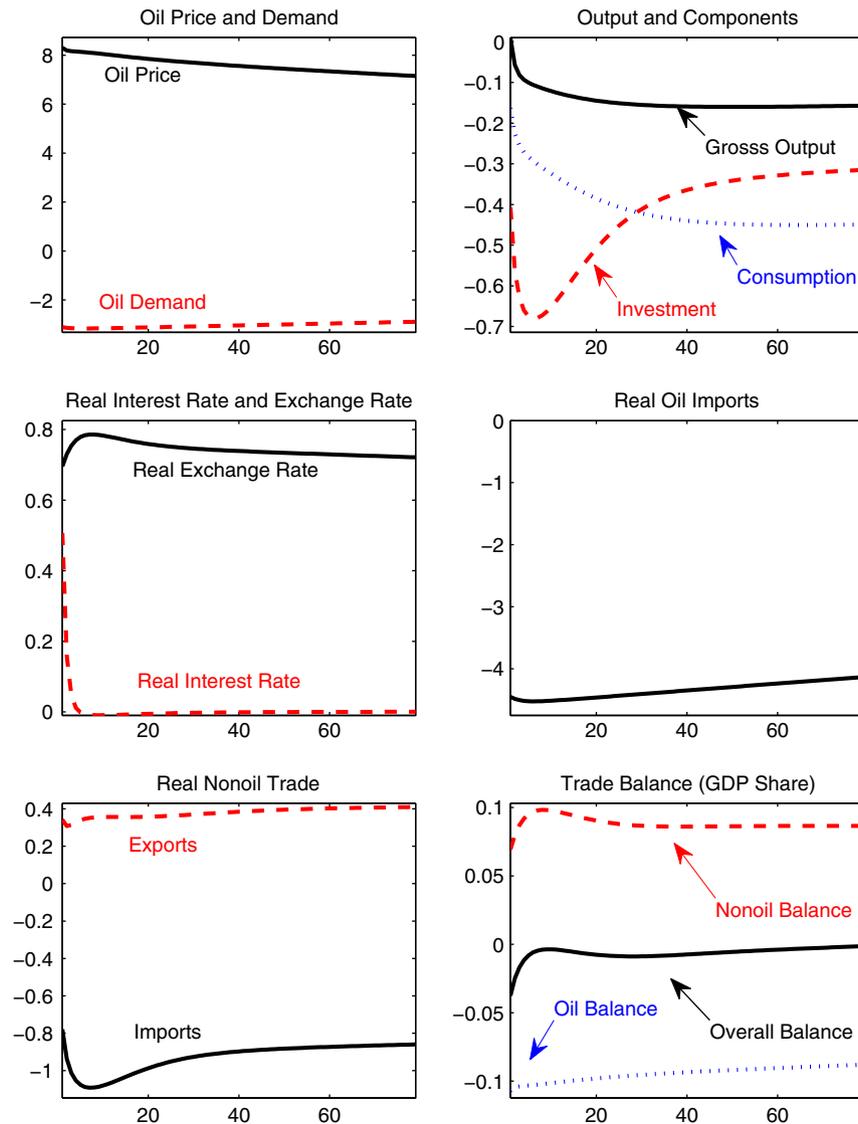


Fig. 2. A foreign oil supply shock (home response).

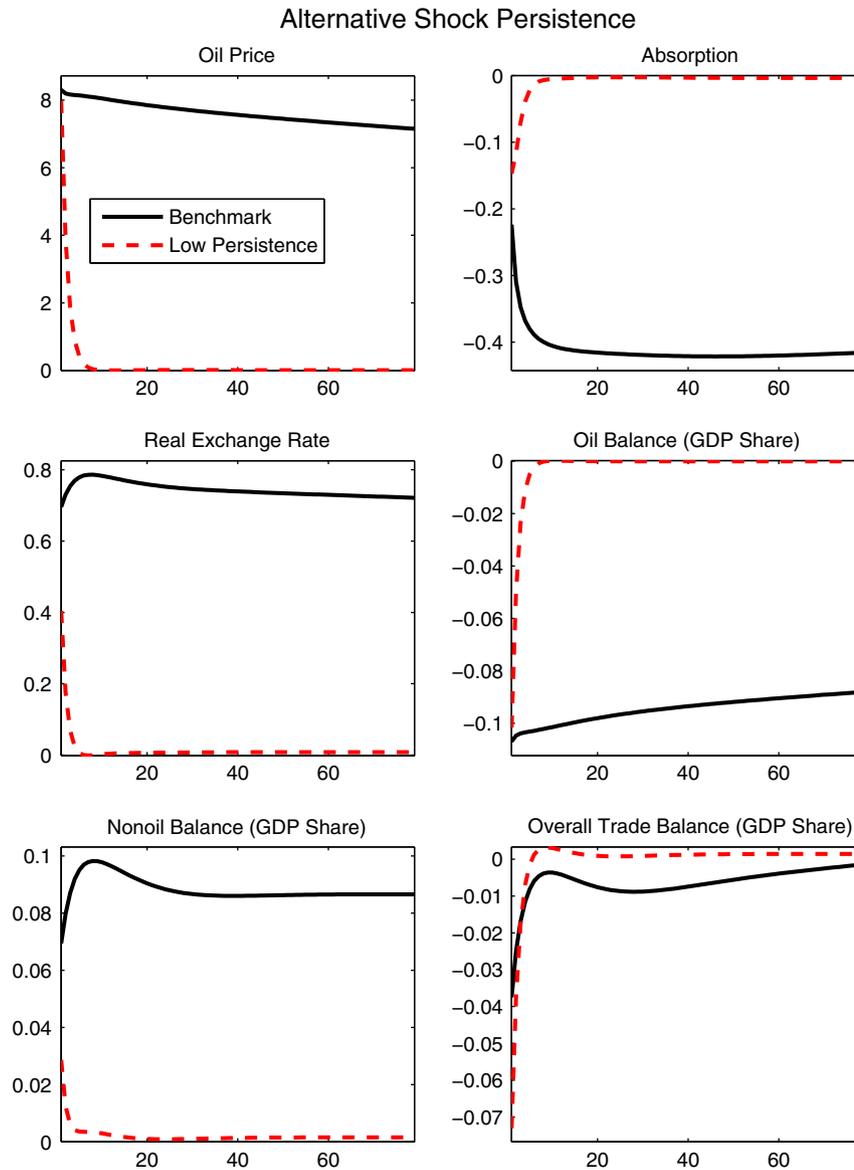


Fig. 3. A foreign oil supply shock (home response).

Under the alternative with a unitary price elasticity of demand, real oil demand falls by exactly the same magnitude as the increase in the oil price. Because the home country produces oil, real imports decline by more than the price rises, implying an improvement in the oil balance. With the oil balance improving, the nonoil balance *deteriorates*.

Fig. 5 compares model responses under our benchmark calibration in which the home country has an oil endowment equal to one third of its steady state oil consumption with an alternative in which it has no oil endowment (“no domestic oil production”).<sup>21</sup> A shock to foreign oil supply sized at two standard deviations induces a larger rise in the price of oil if the home country has to import all of the oil used. Given the larger deficit in the oil component of the trade balance under the case of no domestic oil production, the improvement in the nonoil balance must be larger, which entails a larger depreciation of the real exchange rate.

<sup>21</sup> Local oil endowments differentiate our model further from that of Backus and Crucini (1998). In their framework such a distinction would play no role because of complete financial markets.

## 5.2. Complete vs. incomplete markets

In our model, oil shocks affect the dynamics of nonoil variables through changes in wealth across countries. To elucidate the role of such changes, Fig. 6 contrasts the responses under our benchmark case with incomplete financial markets to those with complete financial markets and financial autarchy. Under either financial market arrangement, the oil price rises about 8% in response to a two-standard-deviation shock that contracts foreign oil supply.

The deterioration in the oil balance is also comparable in magnitude across cases. By contrast, the results for the remaining variables in Fig. 6 are strikingly different: in particular, under complete markets the nonoil balance is virtually unchanged from its steady state level and the depreciation of the real exchange rate is substantially reduced.

Under complete markets, ownership of the profit flow associated with oil production is effectively shared across countries through insurance transfers. These insurance transfers enable the home country to satisfy the intertemporal budget constraint without having to accrue a surplus on the nonoil balance. Accordingly, the response of the exchange rate is muted relative to the incomplete market case. As

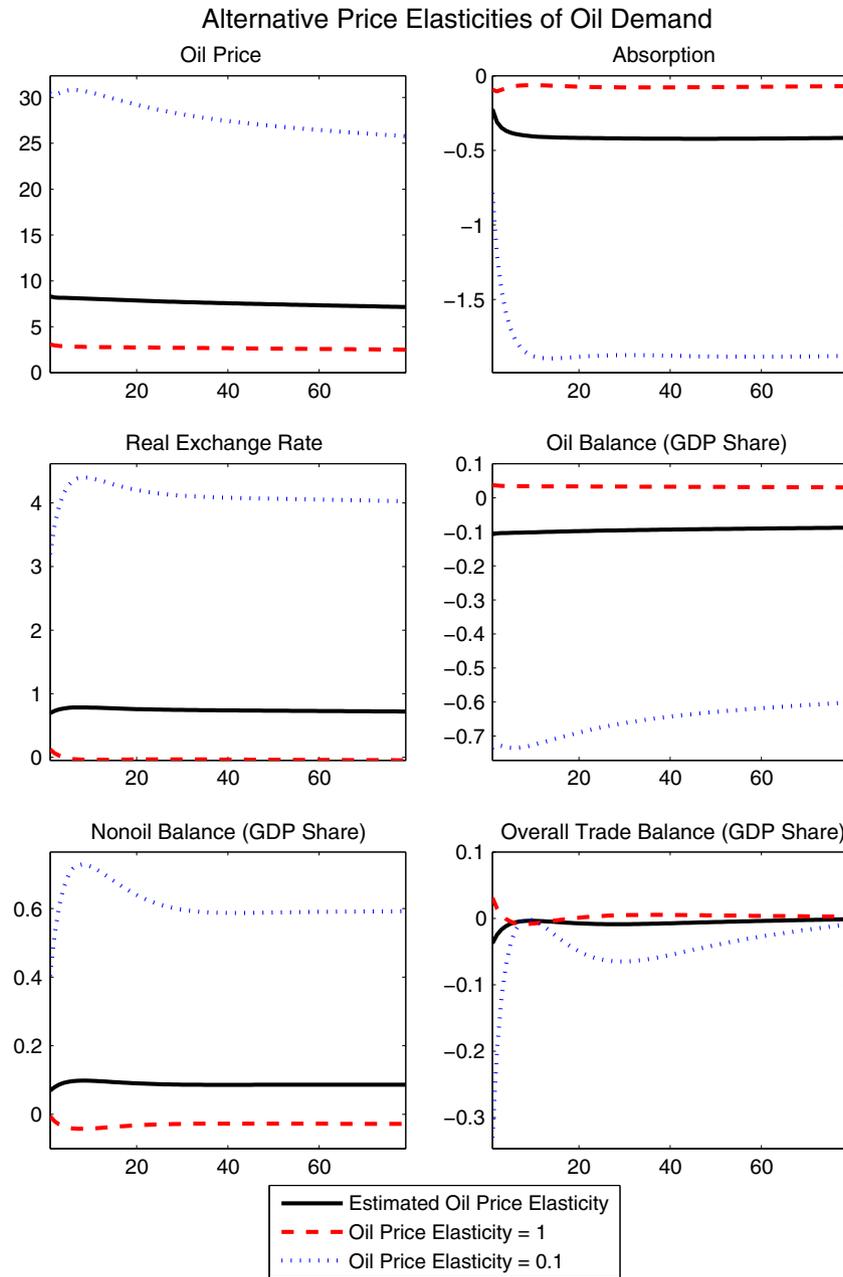


Fig. 4. A foreign oil supply shock (home response).

described above, our benchmark calibration reflects cross-country differences in oil endowments and intensities. With the foreign economy more oil intensive, consumption drops more abroad than at home if markets are complete. Consequently, as the home (consumption-based) real exchange rate equals the ratio of the marginal utility of consumption across countries, it depreciates in that case. Under complete markets, the nonoil balance and the real exchange rate would show no movement if oil endowments and intensities were chosen to be identical in the two countries (implying no oil trade in steady state).

Under financial autarchy, the effects of the shocks cannot be smoothed at all and the real exchange rate depreciates by more so that the deficit in the oil balance can be completely offset by a surplus in the nonoil balance in every period.

The responses under incomplete financial markets resemble those under financial autarchy much more than those under complete markets; this result contrasts sharply with the typical effects of

technology shocks that would also obtain in our model. [Baxter and Crucini \(1995\)](#) showed that for technology shocks the equilibrium allocations in models where agents trade only one non state-contingent international bond are very close to those derived in an economy with complete international financial markets, provided that the technology shock is not permanent. Furthermore, [Cole and Obstfeld \(1991\)](#) pointed out that movements in the terms of trade provide a powerful source of insurance against technology shocks independently of the set of internationally available assets (again, there is little distinction between the real exchange rate and the terms of trade in our model). Thus, in standard models of the international business cycle that focused on technology shocks, the movement in relative prices offsets the wealth effects. A notable exception is [Corsetti et al. \(2008\)](#). These authors showed that under a low elasticity of substitution between traded goods, the movement in relative prices operates to reinforce the wealth effects of the shock. Thus, their model implies pronounced differences between the three

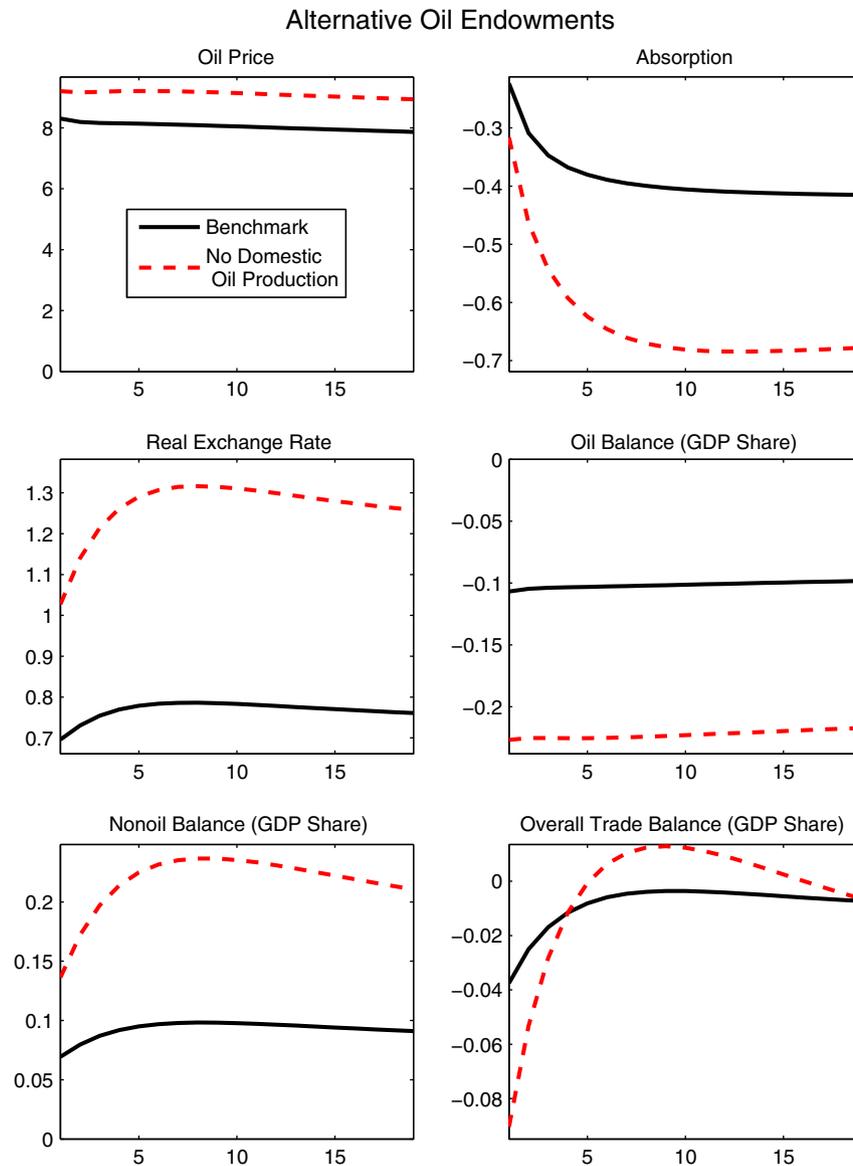


Fig. 5. A foreign oil supply shock (home response).

financial market arrangements (complete markets, one bond economy, and financial autarchy). Corsetti et al. (2008) also show that similar channels are at play with high trade elasticities of substitution, as long as the shocks are sufficiently persistent.

In our model, a contractionary shock to oil supply leads to a much more pronounced depreciation of the real exchange rate for the oil importing country under incomplete markets than under complete markets. Hence, as in Corsetti et al. (2008), the exchange rate does not provide sufficient insurance to the oil importer. The responses to oil supply shocks continue to differ across the three financial market arrangements even for less persistent shocks to oil supply. Similar results obtain for oil efficiency shocks.<sup>22</sup>

Although we do not model the gross holdings of international assets explicitly, our analysis sheds light on the importance of valuation effects. As discussed by Kilian et al. (2009), changes in asset prices and the real

exchange rate affect the international wealth distribution in response to oil shocks. Under optimal portfolio allocations, such valuation effects can be thought as yielding additional insurance. The more diversified a country's portfolio holdings, the more effectively that country can insure itself against movements in the price of oil, implying smoother real exchange rate movement and larger responses of its overall goods trade balance.

### 5.3. Wealth and substitution effects

In the preceding discussion, we have argued heuristically that differences in wealth effects across countries shape the response of the nonoil balance and the real exchange rate. To quantify the wealth effect, and the extent to which it accounts for most of the disparity in the responses of consumption and labor supply across countries, we employ the "Hicksian" decomposition devised by King (1990).

King's method decomposes the consumption and labor supply responses into (i) a wealth effect, (ii) a real wage effect, and (iii) a real interest rate effect. To compute the wealth effects, we first find the change in discounted lifetime utility due to the two-standard deviation oil supply shock. As preferences are time-separable, the

<sup>22</sup> However, for technology shocks the three financial market arrangements imply very similar allocations, as the trade elasticity is parameterized close to unity and the real exchange rate provides substantial insurance against technology shocks in our model.

### Alternative Financial Market Arrangements

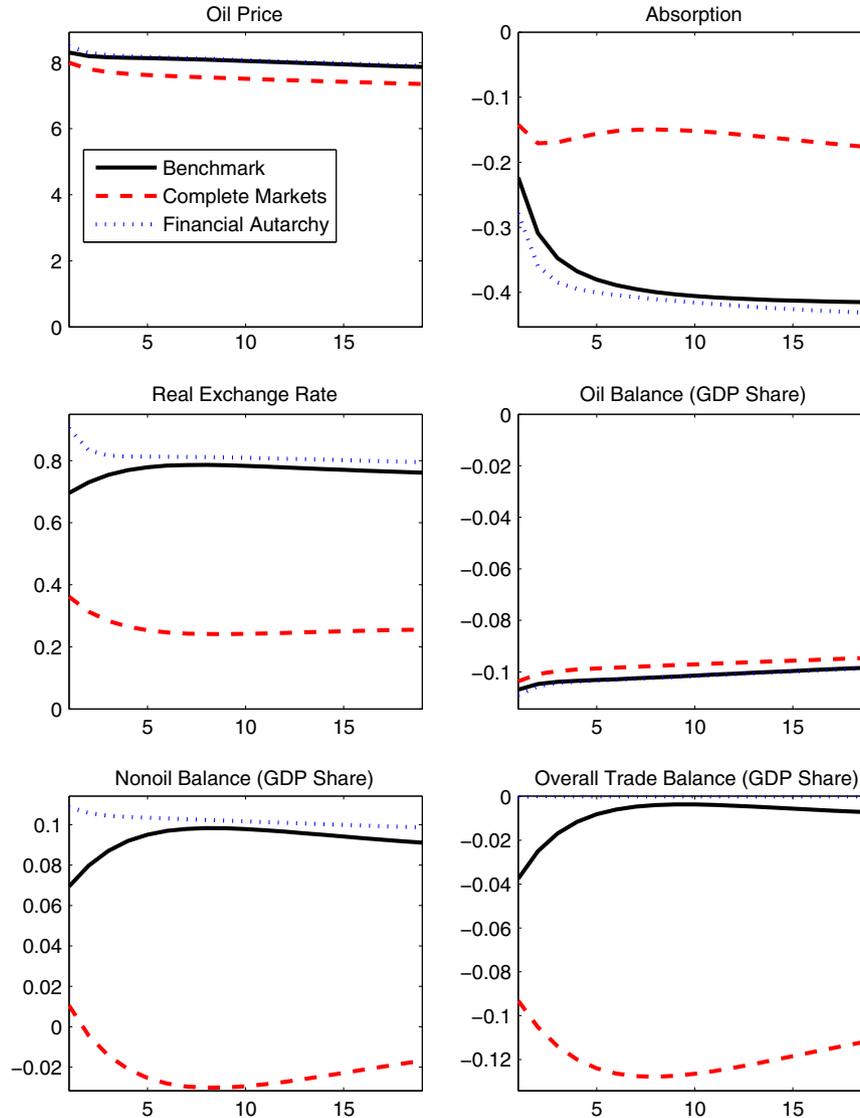


Fig. 6. A foreign oil supply shock (home response).

wealth effects on consumption and labor supply are given by the constant consumption and labor profiles that match the computed change in utility while wages and interest rates are held constant at their steady state values. The real wage effect is the part of the overall response in consumption or labor that is due to changes in the real wage alone, keeping utility at its steady state level. The real interest rate effect is computed analogously.

In Fig. 7 we plot the wealth and the two substitution effects for consumption in the home (left panel) and foreign country (right panel) under our benchmark calibration. To show how wealth effects vary with structural features, we consider an alternative calibration that imposes an elasticity of oil demand of 0.1 (under incomplete markets), as well as a second alternative with complete markets in which case all parameters assume the same values as under the benchmark. Fig. 8 shows the corresponding decomposition for the labor supply response under the same three cases.

Under the benchmark calibration, the home country experiences a negative wealth effect relative to the foreign country. In the home country, the wealth effect reduces consumption, and increases labor

supply, whereas the wealth effect on these variables in the foreign country is close to zero.<sup>23</sup> If international financial markets are complete, the home country is insured against the oil price increase and receives transfer payments. Both countries experience a small negative wealth effect of similar impact on consumption and labor. By contrast, with a low oil price elasticity of 0.1 and incomplete markets, a given oil supply shock has a more pronounced contractionary effect on the home country. This is reflected in the larger wealth effects on consumption and labor under an oil price elasticity of 0.1 relative to our benchmark calibration. In the foreign country, the oil supply shock has a large positive wealth effect that pushes up consumption and leads to a substantial drop in the labor supply.

For completeness, we also report the substitution effects on consumption and labor due to changes in the real wage and the real

<sup>23</sup> The absence of a wealth effect in the foreign country does not imply that consumption and labor are unaffected by the oil supply shock. However, these variables are impacted through the substitution effects caused by a lower real wage and a higher real interest rate.

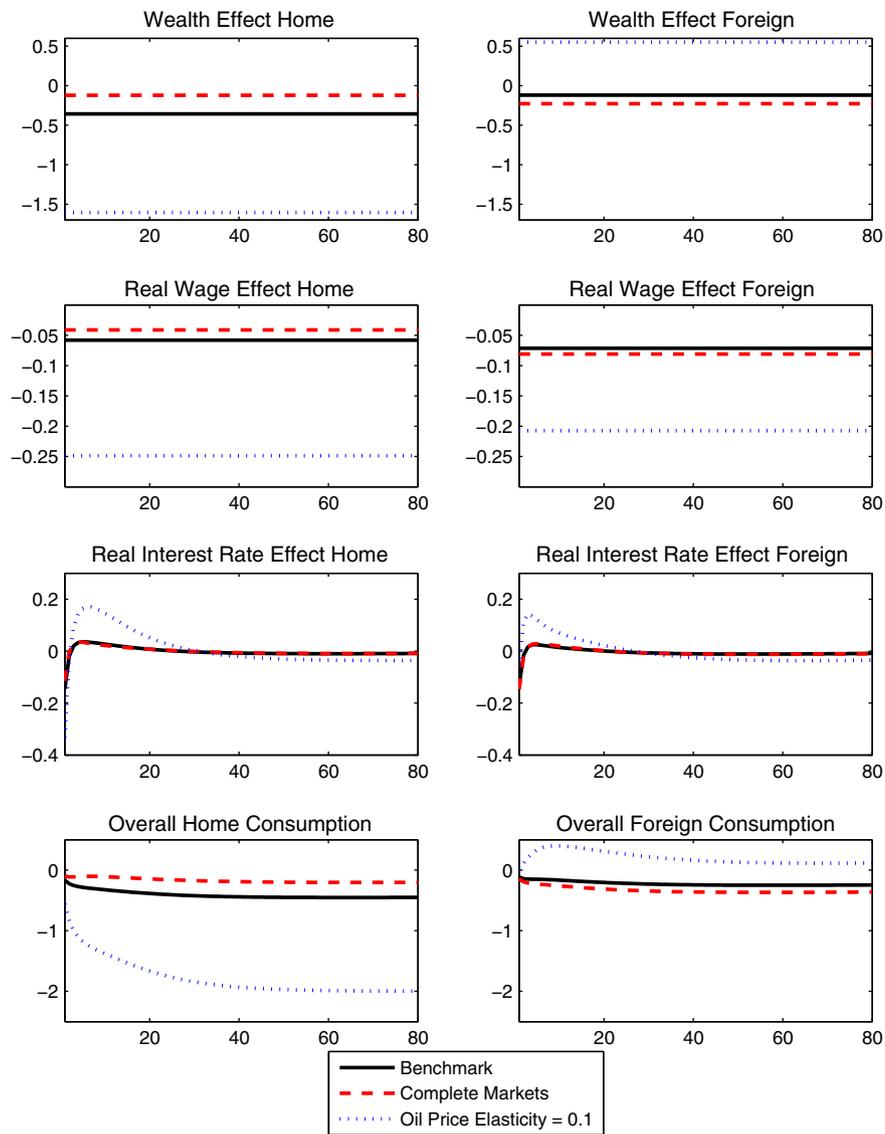


Fig. 7. Hicks decomposition of home and foreign consumption response to an oil supply shock\*.

In our "Benchmark" calibration financial markets are incomplete and the oil price elasticity equals 0.40. For the "Complete Markets" case, the oil elasticity still equals 0.40. The last case shown, "Oil Price Elasticity = 0.1," assumes incomplete financial markets.

interest rate. While these effects are important in explaining the response of consumption, they differ little across countries. In all three scenarios, real interest rates rise on impact and wages fall in both countries. The declines in the real wage lead households to substitute from consumption towards leisure and away from labor.<sup>24</sup> Higher interest rates imply a higher price of current consumption and leisure relative to future consumption and leisure. Therefore, the interest rate substitution effect is negative on consumption and positive on labor.

Overall, the analysis confirms that it is differences in wealth effects between the two countries that explain most of the differences in the consumption and labor response between countries and across scenarios.

## 6. Oil supply, oil demand, and technology shocks

The moment matching exercise reveals the importance of treating oil prices as endogenous. The calibrated processes for each shock is associated

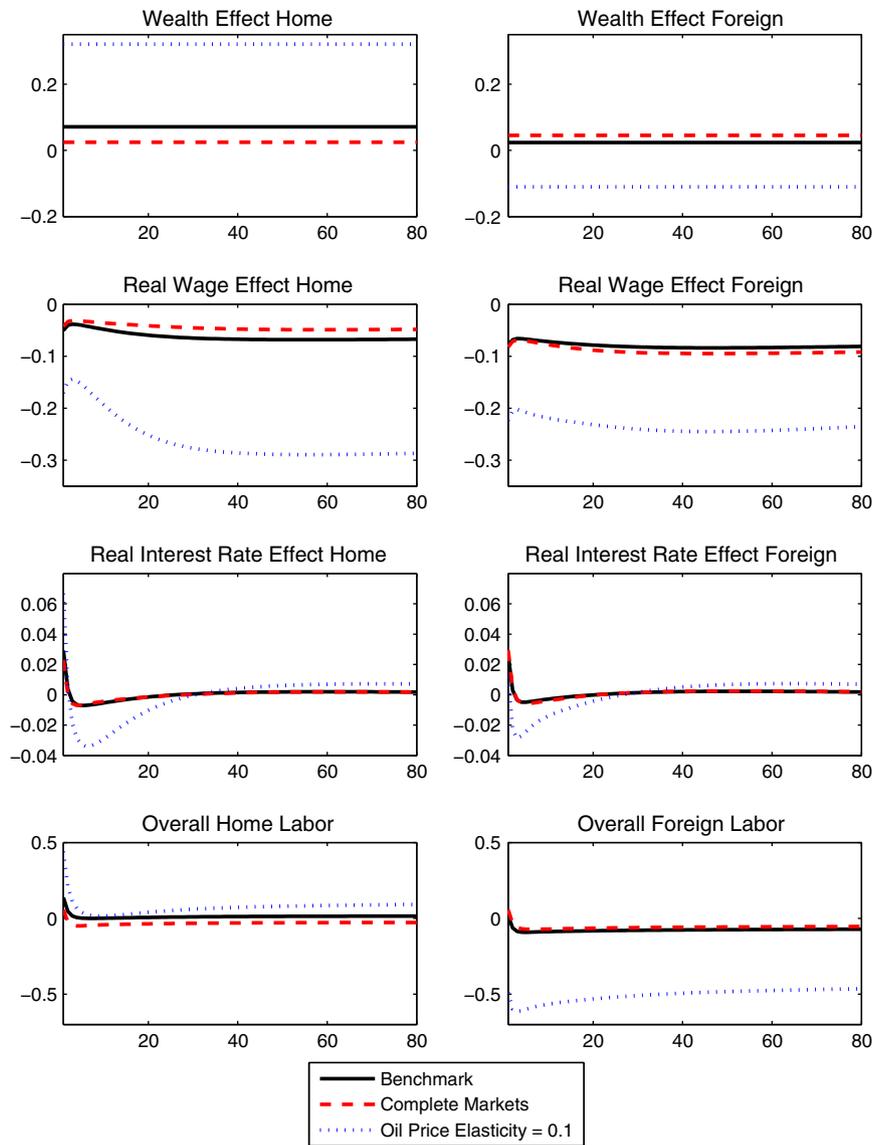
with different price paths for the price of oil. Thus, it is difficult to characterize a typical response for the price of oil.

Fig. 9 shows the responses of two-standard-deviation shocks to foreign oil supply, foreign oil demand, and foreign technology, respectively. The direction of the shocks is chosen to induce a rise in the price of oil.<sup>25</sup>

The dashed lines in Fig. 9 report the responses for the oil demand shock. As the moment matching exercise favored an AR(2) process with a persistent growth component (and a small error correction component in the level) for the shock, the price of oil rises over an extended period. Although the initial dynamics differ relative to those of an oil supply shock, some common features eventually show through. As in the case of oil supply shocks, the oil component of the trade balance deteriorates persistently, which triggers an improvement of the nonoil balance and a substantial depreciation of the real exchange rate. Indeed, in the long run, country-specific wealth effects

<sup>24</sup> The wage substitution effect on consumption is constant since our utility function is additive separable in consumption and leisure, and time separable.

<sup>25</sup> The parametrization of the shock processes is determined by the moment matching exercise discussed in Section 4.1 and reported in Table 2.



**Fig. 8.** Hicks decomposition of home and foreign labor response to an oil supply shock<sup>25</sup>. In our "Benchmark" calibration financial markets are incomplete and the oil price elasticity equals 0.40. For the "Complete Markets" case, the oil price elasticity still equals 0.40. The last case shown, "Oil Price Elasticity = 0.1," assumes incomplete financial markets.

are again the dominant force in the transmission of oil demand shocks across countries.

Despite similarities with the oil supply shock, it is clear from Fig. 9 that there are some differences in the short-run responses. At first, the movements in the oil balance and nonoil balance reinforce each other, instead of offsetting each other. The shock reduces the efficiency of foreign oil input in production boosting oil demand. In turn, lower oil efficiency reduces the marginal product of capital, and pushes down investment demand abroad. Given the growth component of the shock, the prospect of further efficiency losses works to amplify the cut in investment. As foreign aggregate demand drops more than home demand, the real interest rate declines more abroad than at home and the home real which dampens the initial depreciation of the home country's exchange rate. Given the decline in foreign activity the home nonoil trade balance deteriorates initially.

The dotted lines in Fig. 9 show responses to a persistent technology shock abroad. The shock leads to a modest increase in the price of oil and worsening of the oil balance for the home country. The increase in the oil bill, in this case, is not the dominant force influencing external adjustment. The typical effects of a technology shock dominate oil

market channels. The increase in foreign production stimulates home export demand in spite of an appreciation of the home exchange rate. Both the nonoil and the overall goods trade balance improve drastically in spite of the deterioration in the oil balance.<sup>26</sup>

### 6.1. Unconditional simulations

Fig. 9 highlights that the nonoil balance and the overall goods trade balance move differently when conditioning on each of the shocks in the model. Table 6 aggregates the responses to individual shocks to report unconditional correlations between the components of the trade balance and the price of oil. As these moments were excluded from the moment matching exercise used to calibrate the model, they are clean yardsticks of model performance.

<sup>26</sup> Foreign consumption preference shocks, or foreign government spending shocks would also influence the price of oil in the model. However, as with technology shocks, the external adjustment mechanism would be dominated by the direct effects of those shocks, rather than oil market considerations.

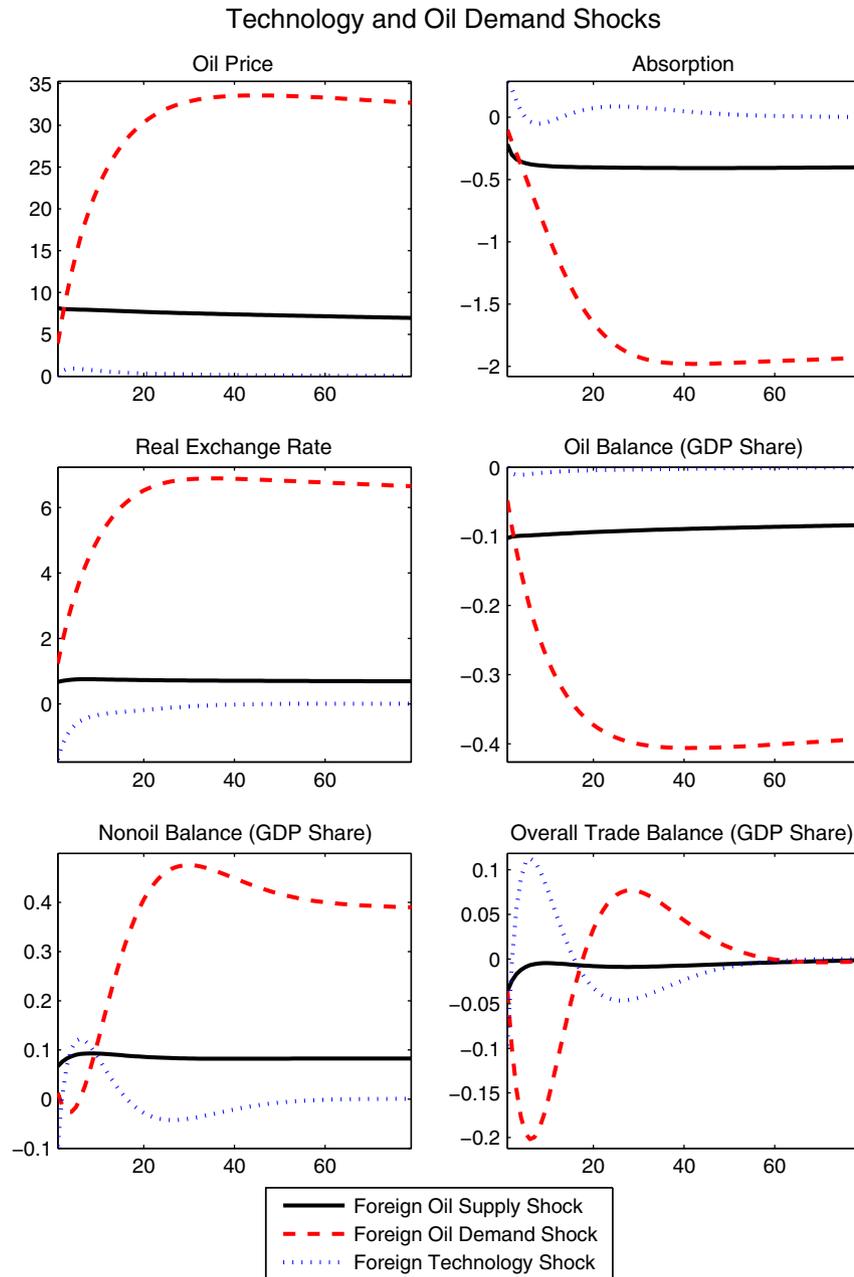


Fig. 9. Technology and oil demand shocks (home response).

At medium-run frequencies, the correlation between oil prices and the overall goods balance in the U.S. data is a modest  $-0.19$ , while the model implies essentially no correlation. The discrepancy between model and data reflects the nearly perfect correlation between oil prices and the oil balance in the model; in the data the latter is not as strong. However, in both the model and the data the movements in the nonoil balance counteract those in the oil balance.

The table also highlights the importance of multiple sources of shocks. Without oil shocks, as can be evinced from our prior discussion of technology shocks, the correlation between oil prices and the nonoil balance would have the wrong sign. The correlation between oil prices and the trade balance at medium-run frequencies is slightly positive for oil demand shocks and negative for oil supply shocks.

The bottom part of the table reports unconditional correlations for the model with complete financial markets. As discussed in Section 5.2, complete markets imply a strong deterioration of the

trade balance after oil price increases which has a prominent influence on the unconditional moment – with oil shocks only the correlation would be  $-0.97$  instead of  $-0.66$  with all shocks.

The incomplete market case captures the offset between the oil and nonoil components in the correlation of the overall the trade balance. The complete market case does not. Taken together, we interpret these findings as favoring the incomplete market framework. However, the results also point to the starkness of our characterization of market incompleteness. We speculate that an intermediate case that expanded the menu of international assets could narrow the distance between model and data.

## 7. Conclusion

Using a DSGE model with an endogenously determined price of oil, we emphasize three reasons that can account for the lack of a close

**Table 6**

Correlations with the price of oil at medium-run frequencies.

| Variable (GDP share)                 | Data  | All shocks | Oil shocks only | Oil demand shocks only | Oil supply shocks only | Without oil shocks |
|--------------------------------------|-------|------------|-----------------|------------------------|------------------------|--------------------|
| <i>Model with incomplete markets</i> |       |            |                 |                        |                        |                    |
| 1. Oil balance                       | −0.83 | −0.99      | −0.99           | −0.99                  | −0.90                  | −0.98              |
| 2. Nonoil balance                    | 0.29  | 0.52       | 0.83            | 0.78                   | 0.86                   | −0.17              |
| 3. Trade balance                     | −0.19 | 0.03       | 0.09            | 0.10                   | −0.60                  | −0.25              |
| <i>Model with complete markets</i>   |       |            |                 |                        |                        |                    |
| 1. Oil balance                       | −0.83 | −0.99      | −0.99           | −0.99                  | −0.88                  | −0.98              |
| 2. Nonoil balance                    | 0.29  | −0.30      | −0.83           | −0.85                  | −0.69                  | −0.04              |
| 3. Trade balance                     | −0.19 | −0.66      | −0.97           | −0.97                  | −0.92                  | −0.16              |

Both observed and model data were bandpass filtered choosing oscillations of amplitude ranging from 6 to 200 quarters. “All shocks” refers to model data generated by turning on shocks to technology, import preferences, oil demand, and oil supply both at home and abroad. “Oil shocks only” refers to model data generated by turning on domestic and foreign oil demand and supply shocks, and excluding all other shocks. “Oil Demand Shocks Only” refers to model data generated by turning on domestic and foreign oil demand shocks only. “Oil Supply Shocks Only” refers to model data generated turning on domestic and foreign oil supply shocks only. “Without Oil shocks” refers to model data generated by turning off domestic and foreign oil demand and supply shocks.

relationship between oil prices and the overall goods trade balance: multiple shocks occur simultaneously, oil shocks affect the nonoil balance in general equilibrium, and different sources of oil price movements are associated with different propagation channels.

To match the variance and autocorrelation of the oil price and global oil supply, our calibration strategy calls for an oil price elasticity well below one. The fact that oil shocks are relatively more important for the variation of the nonoil balance than the variation in the overall goods trade balance reflects a strong interaction between the oil imports and the nonoil balance. With incomplete financial markets, both oil demand and supply shocks that increase the price of oil lead to a deterioration in the oil balance for an oil-importing country such as the United States. With a low oil price elasticity, the increased transfers to the oil exporter are substantial and generate a powerful drag on wealth for the oil importer. This wealth effect is principally responsible for a consumption decline, an exchange rate depreciation, and a surplus in the nonoil balance. A strong consumption-smoothing motive explains why the surplus in the nonoil balance tends to limit the deficit in the overall goods trade balance immediately after the oil price increase.

Although positing only one non state-contingent bond overstates the role of the nonoil balance in counteracting the movements in the oil balance, the assumption of complete markets leads to strongly counterfactual implications in our model. In future work, we plan to investigate whether a broader set of internationally traded assets can align the model more closely with the data.

## Acknowledgements

The authors thank Christopher Gust, Lutz Kilian, Andrea Raffo, Luca Dedola and Eric Swanson for the many insightful comments. We are particularly grateful to Giancarlo Corsetti (the editor) and two anonymous referees whose suggestions have greatly improved this paper. The views expressed in this paper are solely the responsibility of the authors and should not be interpreted as reflecting the views of the Board of Governors of the Federal Reserve System or of any other person associated with the Federal Reserve System.

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