Board of Governors of the Federal Reserve System

International Finance Discussion Papers

Number 897

February 2008

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Abstract

Empirical work suggests that oil price increases are associated with protracted oil deficits, but that the effects on the overall trade balance are mitigated by improvements in the nonoil goods balance. We construct a two-country DSGE model that can account for this fact. Differences in wealth effects between the oil-importing and oil-exporting country are key in replicating this finding. Unless, international financial markets are incomplete and the oil price elasticity of demand is sufficiently below unity, the relative wealth effects between the two countries are small and the model fails to generate an improvements in the nonoil goods balance subsequent to an oil price increase.

Keywords: oil-price shocks, trade, DSGE models

JEL Classification: F32, F41

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* The authors thank Roc Armenter, Brett Berger, Chris Carroll, Don Coletti, Luca Dedola, Joe Gagnon, Enrique Mendoza, Andrea Raffo, Trevor Reeve, and seminar participants at the Bank of Canada, the IMF, the Federal Reserve Board, the Federal Reserve Banks of Atlanta, Dallas and New York, Johns Hopkins University, and the CEPR Conference on International Adjustment in Brussels. We are particularly grateful to Christopher Gust, Lutz Kilian, and Eric Swanson for many insightful comments, and to Hilary Croke for excellent research assistance. 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.

1 Introduction

The tripling of world oil prices over the past few years has stimulated renewed interest in the macroeconomic consequences of oil price shocks. Understandably, much attention has focused on the implications of oil price changes for domestic output and prices.[1] However, from an open economy perspective, it is also of interest to identify the channels through which oil price shocks affect trade and the real exchange rate. Such questions seem particularly relevant in recent years, as oil prices have escalated against the backdrop of a large and persistent U.S. trade deficit.

At the end of 2007, the deficit in petroleum and petroleum products equalled half of the overall U.S. goods deficit, according to the National Income and Products Accounts (NIPA). This accounting relationship, however, does not take into account that the oil and the nonoil trade balance react to movements in oil prices through general-equilibrium channels. Following the works of Kilian (2007), Kilian, Rebucci, and Spatafora (2007), and Hamilton (2003), we attempt to disentangle the effects of oil shocks on the trade balance from those of other shocks. Our analysis suggests that oil shocks are associated with protracted oil deficits, but that the effects on the overall trade balance are mitigated by improvements in the nonoil goods balance.

To interpret the results from our statistical analysis, we investigate how a rise in oil prices affects trade and the real exchange rate in the context of a two country DSGE model. In the spirit of a large empirical and theoretical literature, our simulations focus on a permanent rise in the relative price of oil that is induced by an adverse supply shock in the oil-exporting country. However, our key conclusions about trade and the exchange rate are not sensitive to this particular characteri-

[1] A large body of empirical research has attempted to identify the effects of energy supply disruptions on real output and prices; examples include Hamilton (1983), Hamilton (2003), Kilian (2006), and Cavallo and Wu (2006). Bernanke, Gertler, and Watson (1997) argued that the economy's reaction to oil shocks could be heavily influenced by the reaction of monetary policy. See also Hamilton and Herrera (2004).

zation of the oil supply shock, and in fact even hold for a price hike generated by a rise in foreign oil demand,i.e, an oil-specific demand shock in our model.[2] Our general equilibrium framework is useful in identifying structural features of the economy that influence the response of trade and the exchange rate to the oil shock. Moreover, it provides a natural framework for assessing the implications of the two alternative financial market structures of complete and incomplete markets that are often contrasted in the literature.

Our framework builds on the open economy DSGE model of Backus and Crucini (1998). In our model, each country produces a distinct tradable output good that is used as an input into the production of consumption and investment goods both at home and abroad. Oil serves as an input into the production of the domestic tradable good, and also enters directly into the household consumption bundle. One country is an oil-importer, reflecting its relatively low endowment of energy, while the other is an oil-exporter.

We generalize the Backus and Crucini model by allowing for convex costs of adjusting the share of oil used in production and consumption. Adjustment costs provide a tractable way of capturing the putty-clay nature of oil demand (see Atkeson and Kehoe (1999) and Wei (2003)), and allow our model to account for the substantial wedge between the short and long-run elasticity of oil demand that appears to be a robust finding of the empirical literature. Finally, we depart from the complete markets framework of Backus and Crucini by assuming that financial

[2]The assumption that oil price innovations are driven by exogenous changes in supply is typical in the empirical literature, e.g., Hamilton (1983), Hamilton (2003), and Bernanke, Gertler, and Watson (1997), and also has a long tradition in DSGE modeling. Notable examples of the latter include Kim and Loungani (1992), Rotemberg and Woodford (1996), Finn (2000), Leduc and Sill (2004) and Blanchard and Galí (2007). However, recent empirical analysis by Kilian (2006) has challenged the traditional view. In particular, Kilian argues that demand shocks – both specific to the oil market and for industrial commodities generally – have played a much larger role in driving oil price fluctuations than acknowledged in most of the literature. Hence, while our benchmark model follows the usual approach of assuming a supply-driven hike in the oil price, we also consider the implications of one type of demand-driven oil price increase.

markets are incomplete across national borders in our benchmark specification.[3]

In our baseline calibration with incomplete financial markets, we find that a permanent oil price hike has a large negative wealth effect on the oil-importing country relative to the oil-exporting country. In line with the empirical observations the oil-importing country experiences a highly persistent deterioration in the oil component of its trade balance. The only way for the oil-importer to satisfy its intertemporal trade balance condition is for its nonoil component to improve by a sufficient amount, which requires an initial worsening of its nonoil terms of trade (or real exchange rate, as the latter adjusts proportionately).

Two features of our model crucially influence our ability to obtain these results: market completeness and the oil price elasticity. A low oil price elasticity of demand implies that the oil importer runs more persistent deficits on the oil component of its trade balance, while the oil-exporter experiences a more persistent revenue windfall. This magnifies the difference in wealth effects across countries, and hence requires a much larger depreciation of the oil-importer's nonoil terms of trade in order to satisfy the intertemporal current account balance condition. Alternatively, a high oil price elasticity of demand leads to smaller wealth effects and the nonoil trade balance of the oil-importing country may even improve. Similarly, if financial markets are complete oil price increases have essentially no effect on the nonoil terms of trade and the nonoil trade balance irrespective of the oil price elasticity of demand. We employ King's (add to references) "Hicksian" method for decomposing wealth and substitution effects to show formally how the wealth effects depend on the oil price elasticity of demand and market completeness.[4]

[3]Backus and Crucini used their model to explain instability in the time series correlation between output and the terms of trade that they attributed to changes in the relative importance of oil and technology shocks. Given this focus, their results seem likely to hold under either financial market structure.

[4]Since the influential work of Cole and Obstfeld (1991), there has been considerable interest whether differences in financial market structure have pronounced effects. However, the focus has been almost exclusively on technology shocks. Among others Erceg, Gust, and López-Salido (2007) suggest that complete and incomplete

We continue by conducting sensitivity analysis to the particular type of oil price shock assumed. While our benchmark model assumes that the adverse supply shock pushes up the oil price permanently – under the assumption that the foreign exporter reduces supply enough to support the higher price – our conclusions are unchanged under the assumption that the oil price rises endogenously in response to an exogenous contraction in foreign oil supply. Moreover, a taste-driven rise in foreign oil demand that induces a comparable rise in the oil price as the adverse supply shock has similar effects on the trade responses of the home country. Thus, our analysis suggests that only the path of the oil price is relevant to the home country, *provided* that the oil price hike is generated by a foreign supply or demand disturbance that is specific to the oil market.

Finally, we show that although nominal rigidities in prices and wages affect the path of domestic absorption in the short-run, their inclusion has little consequence for the trade and nonoil terms of trade responses that are our principal focus.

The remainder of the paper is organized as follows. Section 2 attempts to isolate the effects of oil shocks on the trade balance. Section 3 describes our benchmark model, and Section 4 the calibration. Section 5 provides simulation results for our benchmark model under incomplete markets, and the sensitivity of our results with respect to the oil price elasticity of demand and the financial markets arrangements. Section 6 considers alternative types of oil price shocks, and Section 7 assesses the role of nominal rigidities. Section 8 concludes.

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markets imply very similar macroeconomic responses to a technology shock when the trade price elasticity is around unity. However, a high trade price elasticity can generate substantial divergence across these alternative financial market structures under certain conditions on labor supply (different preferences over labor supply appear to account for why Baxter and Crucini (1995) found significant disparities, while Schmitt-Grohe and Uribe (2003) did not). Finally, Corsetti, Dedola, and Leduc (2004) showed that very low trade price elasticities can also imply pronounced differences across financial market structures.

2 Oil shocks and the Trade Balance

Figure 1 shows the evolution of the net exports of petroleum and petroleum products (the shaded area), against the movements in the overall goods balance. Over the period from 1970 to 2007, the United States turned from running a surplus in the category of petroleum and related products, to experiencing a large deficit. By the end of 2007, the deficit in petroleum and products was 2.9% of GDP and accounted for almost half of the U.S. goods deficit, amounting to 6.2% of GDP.

In the figure, we highlighted some episodes that are associated with exogenous supply contractions as discussed in Hamilton (2003). There is no obvious relationship between these episodes and movements in the oil and overall trade balance. This observation is linked to the fact that the economy experiences a variety of shocks at any point in time.

To disentangle the movements in the trade balance that can be attributed to events specific to the oil market from movements attributable to other shocks, we follow the econometric approach of Kilian (2007). He distinguishes between supply and demand shocks using a recursively-identified vector auto-regression (VAR), including monthly measures of oil supply, economic activity, and oil price.[5] Kilian, Rebucci, and Spatafora (2007) construct a measure of world-wide economic activity using a shipping index. Here, we replace this index with a monthly measure of industrial activity for the OECD. As in Kilian, Rebucci, and Spatafora (2007) we trace the effects of oil supply and demand shocks on the goods trade balance and its oil and nonoil components. We do so by regressing the measure of interest on the identified shock series from the VAR. Ideally, we would like to include the trade balance and its components in the VAR that produces the identified shocks, rather than running a two step procedure. The recursive identification scheme we exploit

[5] Apart from the recursive scheme, another substantial assumption is that within the horizon of one month, oil demand and supply need to have different price elasticities – if both were vertical, the scheme could not distinguish between demand and supply shocks.

seems sensible at a monthly frequency – because of technological restrictions, supply does take some time to react to changes in prices caused by demand movements – but not at a longer horizons, such as one quarter. Unfortunately, we can only construct measures of the trade balance as a share of GDP at a quarterly frequency.

Unlike Kilian, Rebucci, and Spatafora (2007), who perform an international comparison, we focus on the U.S. only. This allows us to run the second-step regressions at a quarterly frequency rather than an annual frequency.

Our VAR takes the following form:

$$\begin{pmatrix} O \\ A \\ P_O \end{pmatrix}_t = A_1 \begin{pmatrix} O \\ A \\ P_O \end{pmatrix}_{t-1} + \cdots + A_{12} \begin{pmatrix} O \\ A \\ P_O \end{pmatrix}_{t-12} + A_0^{-1} \begin{pmatrix} \epsilon_S \\ \epsilon_A \\ \epsilon_D \end{pmatrix}_t , \qquad (1)$$

where O_t is 100 times the log difference in the world oil supply from the Energy Information Administration; A_t is 100 times a linearly detrended measure of industrial activity for the OECD from the OECD Statistical Compendium; P_Ot is the U.S. refiners acquisition cost for imported crude oil from the Energy Information administration, deflated by the U.S. consumer price index from the Bureau of Labor Statistics. Imposing that A_0 is triangular, we interpret ϵ_{St} as an oil supply shock, ϵ_{At} as an activity shock, and ϵ_{Dt} as an oil-demand shock. For these series, we used data from the first quarter of 1974 till the second quarter of 2007.

Despite the replacement of Kilian's (2007) shipping index with the OECD industrial production index as a measure of economic activity, our first-step results are remarkably close to Kilian's. The demand shock emerges as the major contributor to variation in the price of oil. Indeed, the other shocks do not affect the real oil price in a statistically significant way. We discuss these results and their sensitivity analysis to an appendix. Here, we concentrate on our regressions of the identified oil-demand shocks on the goods trade balance and its oil and nonoil components. To run these regressions, we averaged the estimate of ϵ_{Dt} to transform the series from monthly to quarterly frequency. We then regressed our measure of interest on 3 of its own lags and 6 lags of the oil-demand shock series.[6] Figure 2 shows responses to a demand shock that raises the price of oil by 10% at peak (approximately a one-standard deviation shock). The reaction of the oil real price comes from our first-step regression; we show the monthly response over eight quarters and its one- and two-standard deviation confidence bands. The oil trade balance as a share of GDP deteriorates persistently by about 0.2 percentage point. The deterioration of the overall goods trade balance is smaller. It is moderated by the fact that the nonoil goods balance moves into surplus in reaction to the shock.

A long literature has emphasized that there might be non-linearities in the response of macro aggregates to shocks in the oil market, which our linear regression framework could not capture. Hamilton (2003) reviews this literature and builds on it by suggesting that oil price increases following long periods of stable prices have a bigger effect than those that simply correct previous decreases. We followed Hamilton (2003) in constructing a 3-year net increase price series. For each monthly observation, we checked whether the real oil price was higher than in the preceding three years. If so, we recorded the price increase relative to the previous peak for the preceding 3-year window in the net increase series, otherwise we set the net increase to zero. We turned the series from monthly to quarterly by setting the quarterly increase at the highest value of the monthly observations within each quarter. We then regressed the quarterly real price, the trade balance and its oil and nonoil components on this quarterly net increase series. The regressions included 3 lags of the variables of interest and 6 lags of the net increase series. The response to a net increase that pushes real oil prices up by 10 percent is shown in Figure 3. Again, the oil trade balance deteriorates persistently and the deterioration in the overall goods trade balance is moderated by an improvement in the nonoil goods balance.

[6]The form of the regressions in Kilian, Rebucci, and Spatafora (2007) differ from ours as they do not include lags of the dependent variable. Both regressions produce consistent estimates, but have different small-sample properties. In order to justify this form for our second-step regression we require that the identified shocks are strongly exogenous.

We find it remarkable that very different approaches such as the one in Kilian, Rebucci, and Spatafora (2007) and Hamilton (2003) produce the same qualitative results and that even the point estimates are not significantly different. While Kilian, Rebucci, and Spatafora (2007) points to oil demand shocks as having an important impact on the macroeconomy, Hamilton (2003) shows that the results from his regressions on the series for net increases in oil prices are also consistent with a linear framework where exogenous supply shocks are used as instruments. In the remainder of the paper we illustrate the structure of a general equilibrium model which can produce an interaction between the oil and the nonoil trade balance in response to increases in oil prices such as the one documented here. At first, we link the oil price increases to supply movements, but we show that our results obtain also if the oil price movements we consider stem from oil demand shocks.

3 Model Description

3.1 Model Overview

Our model is comprised of two countries, a home country (calibrated based on U.S. data) and a foreign country (rest-of-the-world). The structure of each country block is symmetric, 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 consumption bundle entering the household utility function depends on consumption of the domestically-produced good, on imports of the foreign good, and oil. However, it is convenient for expositional purposes to assume that this composite consumption bundle is simply 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, we assume that asset markets are incomplete internationally.

Finally, both the United States and foreign country are endowed with a non-storable flow supply of oil each period.

3.2 Households

The utility functional of a typical member of household h is

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

where the discount factor β satisfies $0 < \beta < 1$. The period utility function depends on an individual's current consumption $C_t(h)$ and leisure $1 - N_t(h)$.

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

$$\begin{aligned} & P_{Ct} C_t(h) + P_{It} I_t(h) + e_t P^*_{Bt} B_{Ft+1}(h) - e_t B_{Ft}(h) \\ & \quad = W_t(h) N_t(h) + R_{Kt} K_t(h) + \Gamma_t(h) + T_t(h). \end{aligned} \tag{2}$$

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 δ is the depreciation rate of capital.

Households accumulate financial assets by purchasing state-contingent domestic bonds, and a non state-contingent foreign bond (given the representative agent structure, we omit terms involving the former from the household's budget constraint). The term $B_{Ft+1}(h)$ 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 the foreign unit of account in the subsequent period, P^*_{Bt} is the price of the bond in the foreign unit of account, and e_t is the exchange rate expressed in terms of the home unit of account relative to the foreign unit of account.

Each member of household h earns labor income $W_t(h)\,N_t(h)$ and capital income $R_{Kt}K_t(h)$. Each member also receives an aliquot share $\Gamma_t(h)$ of firm profits, and receives net transfers of $T_t(h)$.

In every period t, household h maximizes the utility functional (2) with respect to its 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, a household takes as given prices, wages, net transfers, and aggregate quantities such as lagged aggregate consumption.

3.3 Firms and Production

Each country produces a single distinct nonoil output good. Focusing on the home country, this output 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 (CES) specification of the form:

$$V_t = \left(\omega_k^{\frac{\rho_v}{1+\rho_v}} K_t^{\frac{1}{1+\rho_v}} + L_t^{\frac{1}{1+\rho_v}} \right)^{1+\rho_v}, \tag{4}$$

$$Y_t = \left((1-\omega_{oy})^{\frac{\rho_{oy}}{1+\rho_{oy}}} V_t^{\frac{1}{1+\rho_{oy}}} + \omega_{oy}{}^{\frac{\rho_{oy}}{1+\rho_{oy}}} (\varphi_{OYt} O_{Yt})^{\frac{1}{1+\rho_{oy}}} \right)^{1+\rho_{oy}}. \tag{5}$$

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 O_{Yt} to produce the domestic output good Y_t. The factor φ_{OYt} reflects costs of adjusting the oil intensity of the final output good, and is assumed to take the following quadratic form:

$$\varphi_{OYt} = \left[1 - \frac{\varphi_{oy}}{2} \left(\frac{\frac{O_{Yt}}{V_t}}{\frac{O_{Yt-1}^A}{V_{t-1}^A}} - 1 \right)^2 \right], \tag{6}$$

where O^A_{Yt-1} and V^A_{t-1} denote oil inputs and value added aggregated over all firms. From an aggregate perspective, this specification allows for oil use to respond quickly to gross domestic output, while potentially allowing for very slow adjustment to relative price changes. This form of adjustment cost implies a time-varying elasticity of substitution for oil, an important feature of putty-clay models such as in Atkeson and Kehoe (1999) and Wei (2003). In their setting, a large variety of types of capital goods are combined with energy in different fixed proportions. Thus the short-run elasticity of substitution for oil is low. In the long run, the elasticity is higher, as firms can invest in capital goods with different fixed energy intensities.

Given the presence of adjustment costs, the representative producer can be regarded as choosing a contingency plan for K_t, L_t, and O_{Yt} that minimizes the discounted expected cost of producing the domestic output good subject to equations (4)-(6). In solving this problem, the producer takes as given the rental price of capital R_{Kt}, the wage W_t, and the price of oil P_{Ot}. The representative firm sells its output to households and firms at a price P_{Dt}, which is the Lagrange multiplier from the cost-minimization problem.

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. These distributors purchase a nonoil consumption good C_{Nt} (described below) and oil O_{Ct} as inputs in perfectly competitive input markets, and produce the composite consumption good according to a CES production function:

$$C_t = \left((1-\omega_{oc})^{\frac{\rho_{oc}}{1+\rho_{oc}}} C_{Nt}^{\frac{1}{1+\rho_{oc}}} + \omega_{oc}^{\frac{\rho_{oc}}{1+\rho_{oc}}} (\varphi_{OCt} O_{Ct})^{\frac{1}{1+\rho_{oc}}} \right)^{1+\rho_{oc}}, \tag{7}$$

where the quasi-share parameter ω_{oc} determines the importance of oil purchases in the household's composite consumption bundle, and the parameter ρ_{oc} determines the long-run price elasticity of demand for oil. The form of the production function mirrors the preferences of households over consumption of nonoil goods and oil. The term φ_{OCt} captures costs of adjusting oil consumption at the household level, and is assumed to have the quadratic form:

$$\varphi_{OCt} = \left[1 - \frac{\varphi_{oc}}{2} \left(\frac{\frac{O_{Ct}}{C_{Nt}}}{\frac{O^A_{Ct-1}}{C^A_{Nt-1}}} - 1 \right)^2 \right], \tag{8}$$

where O^A_{Ct-1} and C^A_{Nt-1} denote oil consumption and nonoil consumption aggregated over all households, respectively.

Thus, households are similar to firms in that they adjust their oil demand slowly in response to changes in the relative price of oil. As in the case of firms, the presence of adjustment costs implies that the consumption distributors must solve a dynamic problem of choosing a contingency path for their inputs C_{Nt} and O_{Ct} so as to minimize their discounted expected costs of producing the consumption bundle, taking as given input prices P_{CNt} and P_{Ot}, respectively. The Lagrangian multiplier from this cost-minimization problem determines the price of the consumption bundle they charge to households, i.e., P_{Ct} in the household's budget constraint given in equation (2).

Similarly, it is also convenient to regard the nonoil consumption good C_{Nt} and investment good I_t as produced by perfectly competitive distributors. Both the domestically-produced 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. Thus, the production function for the nonoil consumption good C_{Nt} is given by:

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

where C_{Dt} denotes the quantity of domestically-produced goods used as inputs by the representative nonoil consumption distributor (purchased at a price of P_{Dt}), M_{Ct} denotes imports of the foreign good (purchased at a price of P_{Mt}). 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 equation (9), though allowing for possible differences in the import intensity of investment goods (determined by ω_{mi}, akin to ω_{mc} in equation (9)), the degree of substitutibility between nonoil imports and domestically-produced goods in producing investment goods (determined by ρ_i). 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.[7]

3.4 The Oil Market

We assume that the home country is endowed with a constant exogenous supply of oil each period of Y_O. In our benchmark analysis, the price of oil relative to the domestic output good ψ_t follows an exogenous stochastic process. With both domestic oil supply and the oil price determined exogenously, foreign oil production Y^*_{Ot} adjusts endogenously to clear the world oil market:

$$Y_O + Y^*_{Ot} = O_{Yt} + O_{Ct} + O^*_{Yt} + O^*_{Ct}. \tag{10}$$

Thus, the sum of the home and foreign oil production equals the sum of home and foreign consumption by firms and households. The relative price of oil is assumed to follow a simple AR(1) of the form:

$$log(\psi_t) = \rho log(\psi_{t-1}) + \epsilon_t. \tag{11}$$

The persistence parameter ρ is set arbitrarily close to one, so that the log of the relative price of oil effectively follows a random walk.

In Section 6, we explore a framework in which the oil price is determined endogenously to equate supply and demand in the world oil market. In this case,

[7]As discussed in Erceg, Guerrieri, and Gust (2006), 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 in U.S. trade. The paper also provides empirical support in favor of this specification over a more standard specification in which the real activity variable driving trade is total absorption.

the foreign production level Y_{Ot}^{*} in equation (10) is assumed to follow an exogenous stochastic process.

3.5 Fiscal Policy

We assume that a fixed share g of the domestic output good Y_t is purchased by the government implying that the import content of government purchases is zero. These government purchases G_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:

$$P_{Dt}G_t + T_t = 0. \tag{12}$$

3.6 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:

$$Y_t = C_{Dt} + I_{Dt} + G_t + M_t^{*}, \tag{13}$$

recalling that M_t^{*} denotes the home country's exports.

The evolution of net foreign assets can be expressed as:

$$e_t P_{Bt}^{*} B_{Ft+1} = e_t B_{Ft} + e_t P_{Mt} M_t^{*} - P_{Mt} M_t + P_{Ot}\left(O_{Yt} + O_{Ct} - Y_{Ot}\right). \tag{14}$$

This expression can be derived from the budget constraint of the households after imposing the government budget constraint and the definition of firm profits.

4 Solution Method and Calibration

We solve the model by log-linearizing the equations around the model's steady state. 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) (see also Anderson (1997)).[8] To ensure a unique steady state and stationarity of net foreign assets, we follow Turnovsky (1985) and assume that an intermediation cost is paid by households in the home country for purchases of foreign bonds.[9]

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 trade share parameters which are determined by balanced trade given relative population sizes.

The discount factor β is 0.99. The parameter σ in the subutility function over consumption is set equal to 1 (implying a logarithmic form). We set $\chi = 10$, implying a Frisch elasticity of labor supply of 0.2, which is considerably lower than if preferences were logarithmic in leisure, but well within the range of most empirical estimates. The utility parameter χ_0 is set so that employment comprises one-third of the household's time endowment. The population size parameter ζ is set so that U.S. nonoil output comprises one fourth of world nonoil output.

The production function parameter ρ_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 percent. We set the government share of output to 18 percent, and the quasi-capital share parameter ω_k to 1.61, so that the investment share of output equals an empirically-realistic value

[8]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.

[9]Specifically, the intermediation cost depends on the ratio of economy-wide holdings of net foreign assets to nominal output and is given by:

$$\phi_{Bt} = \exp\left(-\phi_b\left(\frac{e_t B_{Ft+1}}{P_{Dt} Y_t}\right)\right). \tag{15}$$

In practice we set ϕ_b to a very small number (0.0001).

of 20 percent.

Our calibration of ω_{oy} and ω_{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, the overall oil share of the domestic economy is set to 3 percent, with one-third of total oil usage accounted for by households, and two-thirds by firms.[10] To determine the local production share of oil in the steady state the level of oil imports for the home country is set at 50% of total demand. This estimate is based on 2003 data for the United States obtained from British Petroleum and includes oil and natural gas.

Our choices for the parameters that determine the short- and long-run elasticity of substitution for oil (ρ_{oy}, ρ_{oc}, φ_{oy} and φ_{oc}) are motivated by the regression results described in Appendix A. Based on our regression estimates, the parameter ρ_{oy} is set to imply a long-run elasticity of substitution between oil and the other factors of production of 0.5, while the adjustment cost parameter φ_{oy} implies that the half life of the response of oil demand to a permanent rise in the oil price is 10 years. Thus, as in most other studies, we find that the short-run elasticity of oil demand is very small relative to the long-run elasticity. Moreover, the implied time path of the price elasticity of demand for oil is within the wide range of estimates for energy's own price elasticities reported in surveys such as Dahl and Sterner (1991) or Atkins and Jazayeri (2004), which range between 0 to 0.11 (in absolute value) for the short-run elasticity, and between 0 and 3.44 for the long-run elasticity.[11] Our regression analysis constrains the time path of the elasticity of oil demand to be the

[10] In calibrating our model, we adopt a more inclusive interpretation of the oil sector that also incorporates natural gas. Our inclusion of natural gas reflects the close substitutability between oil and natural gas as energy inputs, and the high correlation between movements in oil prices and natural gas prices. Over the period 1970-2005, the correlation between crude oil prices and natural gas prices was 0.9 (using data from NYMEX).

[11] Some of the variation in the elasticity estimates depends on the specific energy aggregate being used. Cooper (2003) estimated the long-run price elasticity of the demand for crude oil – the same energy aggregate we examine – and found a very similar value of 0.45.

same for households as for firms (so $\rho_{oc} = \rho_{oy}$ and $\varphi_{oc} = \varphi_{oy}$).

Turning to the parameters determining trade flows, the parameter ω_{mc} is chosen to match the estimated average share of imports in total U.S. consumption of about 6 percent using NIPA data, while the parameter ω_{mi} is chosen to match the average share of imports in total U.S. investment of about 43 percent. This calibration implies a nonoil-goods import-to-GDP ratio for the home country of about 12 percent. Given that trade is balanced in steady state, and that the oil import share for the home country is 1.5 percent of GDP, the goods export share is 13.5 percent of GDP. We assume that $\rho_c = \rho_i = 2$, consistent with a long-run price elasticity of demand for imported consumption and investment goods of 1.5.[12]

5 Model Simulations

5.1 Benchmark Calibration

Figure 4 shows responses of the home country (the United States) to a 50 percent permanent rise in the relative price of oil under our benchmark calibration. While this is a substantial rise, Blanchard and Galí (2007) have documented how the oil price rose over 100 percent in logarithmic percentage terms on four occasions since the first OPEC shock in 1973.

The oil price shock induces a progressive fall in U.S. oil demand as both households and firms substitute away from this more costly input (upper left panel). With an oil elasticity of demand of one half, oil demand drops roughly 20 percent in the long run.[13] As noted above, our calibration implies that the half-life of the adjustment to this new long-run level is about 10 years.

[12] Hooper, Johnson, and Marquez (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.

[13] While the fall in energy demand due to the direct effect of higher prices is amplified by an endogenous decline in output and consumption, the latter effect is small.

The progressive decline in oil use has effects on output, the expenditure components, and the real interest rate that are qualitatively similar to those of a persistent decline in productivity growth. Thus, gross output declines gradually in response to lower oil use and a falling capital stock, while consumption contracts due to a reduction in household permanent income (however, in contrast to the case of a productivity shock, the long-run consumption decline exceeds that of gross output, since energy imports rise when expressed in units of the domestic good). Investment spending falls, reflecting that a lower path of oil usage pushes down the current and future marginal product of capital. The decline in the marginal productivity of capital induces a modest fall in domestic real interest rates.

Turning to the implications for the external sector, the rise in oil prices causes a sharp and immediate deterioration of the overall (nominal) trade balance equal to about 1-1/4 percentage points of GDP. In the short run, this shift in the overall balance mainly reflects a deterioration in the oil component due to higher oil prices (as the volume of oil imports is nearly fixed). In the longer term, the overall trade deficit narrows and even shifts into surplus roughly fifteen years after the occurrence of the shock. These results are consistent with our empirical analysis, both qualitatively and quantitatively.

Several forces provide a catalyst for eventual trade balance improvement. First, oil import volumes gradually decline. Importantly, because the United States produces half of its oil demand in the pre-shock steady state and U.S. oil supply is assumed to be price inelastic, the decline in oil imports is much larger than the fall in total oil demand in percentage terms: thus, while oil demand falls around 20 percent in the long run, oil imports fall about 40 percent. Second, a decline in the nonoil terms of trade spurs an improvement in U.S. real nonoil exports, while retarding nonoil imports as the relative price of imports rises, and exports fall. Finally, the fall in domestic consumption and investment also compresses real nonoil imports although the effect on net exports is somewhat muted due to a decline in foreign investment spending.

From an accounting perspective, adjustments in both the oil and nonoil components of the nominal trade balance play a quantitatively important role in contributing to the eventual improvement in the overall balance. As indicated by Figure 4, the overall trade balance improves about 1-1/2 percentage points of GDP between the immediate aftermath of the shock and the end of the thirty year horizon shown, and more than half of this improvement is attributable to the oil balance. Nevertheless, given our benchmark calibration of the elasticity of oil demand of 1/2, the oil balance remains in substantial deficit even in the long run. Thus, intertemporal balance requires that adjustment in the nonoil balance also play a sizeable role, which is achieved largely through the worsening of the nonoil terms of trade.

5.2 The Oil Elasticity of Substitution and the Discount Factor

The magnitude of the effects of the oil price shock on the nonoil terms of trade and on the composition of trade adjustment depends critically on the elasticity of substitution between oil and other factor inputs. To illustrate this sensitivity, Figure 5 contrasts responses under our benchmark calibration to the 50 percent oil price hike with responses derived under two alternative calibrations of this *long-run* elasticity. One alternative imposes a long-run elasticity of unity, consistent with a Cobb-Douglas production function over the factor inputs. A second alternative imposes a long-run elasticity of 0.05, much lower than our benchmark, and close to a Leontief specification. In each case, the adjustment cost parameter on oil is changed so that the half life of adjustment to a permanent shock remains 10 years while other parameters are unchanged.

The upper left panel compares the response of total oil demand under the three specifications. Unsurprisingly, oil demand eventually shows a much larger decline under the Cobb-Douglas specification than under the benchmark. With an oil elasticity of demand of unity, oil demand drops roughly 40 percent in the long run. Under the near-Leontief specification, oil demand shows a fairly small contraction, even in the long run. Conversely, the contractionary effects on domestic demand are larger when it is difficult to substitute away from oil, reflecting the larger reduction in permanent income, and a greater decline in investment since the marginal product of capital falls by a more substantial magnitude.

Turning to the implications for the trade balance, the responses under the near-Leontief case are qualitatively the same as under our benchmark. However, from a quantitative perspective, the much smaller decline in oil use translates into a smaller fall in oil imports, accounting for the much larger deterioration of the nominal oil balance apparent in Figure 5. Given the requirement of intertemporal balance, the permanent deterioration of the oil component of the trade balance in turn requires a larger offsetting improvement of the nonoil component than under our benchmark calibration; thus, the nonoil balance improves 1-1/2 percentage point of GDP after 30 years, roughly twice as much as under the benchmark. This greater improvement of the nonoil balance is brought about by a decline of the nonoil terms of trade that is twice as large as under the benchmark. The larger nonoil terms of trade decline reflects the interplay of the greater shortfall on the domestic oil balance, and the correspondingly greater wealth effects.

The responses under the Cobb-Douglas specification exhibit some striking differences from specifications with lower long-run oil elasticities. The 40 percent fall in oil demand in the long run produces a much larger percentage decline in oil imports (since the United States meets a substantial fraction of its oil demand with domestic production), implying an eventual improvement in the nominal oil balance. This in turn allows the nonoil balance and the terms of trade to remain essentially unchanged. Clearly, the high ability to substitute away from oil mitigates the negative wealth effect on the United States, and implies a smaller positive wealth effect abroad.

5.3 Complete vs. Incomplete Markets

In our benchmark model with incomplete markets, oil price shocks have substantial wealth effects that diverge across countries. It is helpful to contrast these results with an alternative financial structure of complete markets in order to emphasize the pivotal role that such cross-country changes in the distribution of relative wealth play in driving the dynamics of the terms of trade and nonoil trade balance.

Figure 6 contrasts responses to the permanent oil price shock in our benchmark model with incomplete markets to responses derived from a variant that allows for complete financial markets. The results are strikingly different: in particular, the nonoil terms of trade remain unchanged from baseline under complete markets, and the nonoil trade balance is essentially unaffected.

These disparities reflect that ownership of the profit flow associated with oil production is effectively shared across countries in the complete markets case through insurance transfers. Although oil price hikes still have a contractionary effect on consumption, the effect is mitigated in the home country and the nonoil terms of trade remain essentially unchanged. While the oil-importing country runs an overall trade deficit under complete markets, the insurance payments offset the higher nominal oil expenditures: these transfers allow it to avoid having to accrue a surplus on its nonoil balance (as was necessary to achieve intertemporal current account balance in the incomplete markets case).

As a corollary, the structural factors highlighted in Section 5 as influencing the magnitude of the nonoil terms of trade and nonoil trade balance responses operate on these variables only insofar as the shock has differential wealth effects across countries. But this hinges on the incomplete market structure. Hence, with these differential wealth effects (virtually) eliminated under complete markets, variations in these structural factors – including the elasticity of substitution between oil and other inputs, the steady state real interest rate, and the magnitude of domestic oil production of the oil importer – have essentially no effect on the nonoil terms of trade or nonoil balance. This is illustrated in Figure 6, which also shows the complete markets response for the case of an extremely low long-run substitution elasticity between oil and other inputs of 0.05, compared with 0.5 in our benchmark. Under complete markets, the response of the nonoil terms of trade and the nonoil trade balance are indistinguishable for these very different substitution elasticities; this contrasts sharply with the large divergence in the incomplete markets case that was highlighted in our discussion of Figure 5.

5.4 Wealth and Substitution Effects

In the two previous sections, we have argued that our model can replicate the empirical observations about the nonoil trade balance if the wealth effects for the two countries are sufficiently different in response to the shock. Both in the model with complete markets and the model with an oil price elasticity of one, we fail to generate an improvement in the nonoil trade balance subsequent to an oil price increase, since the wealth effects across countries are virtually identical.

To gain more formal insights on how these wealth effects differ across parameterizations and financial market structure we employ King's (1990) "Hicksian" method for decomposing 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 oil price shock. As preferences are time-separable, the 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 Figures 7 and 8 we plot the wealth and substitution effects for consumption and labor in the home country for our benchmark calibration, the model with complete markets, and the model with a low oil price elasticity of 0.05 and incomplete financial markets. We chose to omit the case of an oil price elasticity of one (and incomplete markets) since the quantitative results are very similar to the case of complete markets (and an oil price elasticity of 0.5).

In principal, the wealth effects in the two countries arise as follows. The oil-importing home country faces a higher oil bill, which are transferred to the oil-exporting foreign country. However, given our implementation of the oil price shock, the foreign country also faces a smaller oil endowment.

Under our benchmark calibration (solid line), the home country experiences a large negative wealth effect relative to the foreign country. In the home country, the wealth effect on consumption is large and negative, and positive on labor, whereas there is almost no wealth effect on these variables in the foreign country.[14] If international financial markets are complete (dashed line), the home country is insured against the oil price increase and receives transfer payments. Both countries experience a negative wealth effect of similar impact on consumption and labor. With a low oil price elasticity, a given oil price hike 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 0.05 (dotted line) relative to our baseline calibration. In the foreign country, the oil price 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 interest rate. In all three scenarios, real interest rates and wages fall in both countries. The real wage decline (not shown) and leads households to substitute from consumption towards leisure (and

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

away from labor). In the home country, this decline is largest under the low oil price elasticity and smallest under complete markets. Thus, the wage substitution effects are largest under the low elasticity and smallest under complete markets. In the foreign country these orderings are reversed. [15] As the real interest rate shows a similar decline across scenarios and countries, the interest rate substitution effects are very much alike. Lower interest rates imply a lower the price of current consumption and leisure relative to future consumption and leisure. Therefore, the interest rate substitution effect is positive on consumption and negative 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.

5.5 Other Key Factors

In light of our discussion about wealth effects in the previous section, it is straightforward to comment on the role of the size of the domestic oil production in our analysis. The lower the oil endowment of the oil-importing country the larger is the increase in the oil bill subsequent to the shock. This implies a larger difference in the wealth effects between countries and hence a more pronounced deterioration of terms of trade and the stronger improvement of the nonoil trade balance. We find this observation noteworthy since the model predicts that the contractionary impact of an oil shock should be larger for countries like Japan and the Euro Area compared to the U.S.[16]

[15]The wage substitution effect on consumption is constant since our utility function is additive separable in consumption and leisure, and time separable.

[16]The empirical analysis of Kilian (2006) seems consistent with these implications. In particular, Kilian found that an exogenous oil price increase would lead to a depreciation relative to the dollar for Italy, France, Germany, and Japan, all countries whose level of per capita domestic oil production is lower than for the United States. Moreover, he found the Canadian dollar appreciated, which is also in line with our model given that Canada is a major energy exporter.

Changes in the discount factor β primarily affect the analysis through the wealth effect in the foreign country. As the home country reduces its oil imports over time in response to the price hike a low discount factor implies that the foreign country places a larger weight on periods when oil revenues are relatively high. The lower discount factor, the larger is the (positive) wealth effect in the foreign country, which amplifying the differences in the wealth effect between the two countries. Consequently, a lower discount factor leads to a sharper deterioration of the nonoil terms of trade for the home country and a stronger improvement of the nonoil trade balance.

6 An Endogenous Oil Price

We have thus far assumed that the relative price of oil is determined exogenously, and assessed the effects of permanent oil price shocks. This approach has a long precedent in the literature, as it appeared to capture key features of the dramatic OPEC-driven oil price hikes of the 1970s. However, our analysis of the effects of oil shocks on the external balance does not hinge on specifying the relative price of oil as an exogenous process. In this section, we show that similar results obtain in a framework in which the oil price responds endogenously to shocks either to the quantity of oil supplied by the foreign sector, or to foreign oil demand in response to a taste-shock.

Figure 9 shows responses to an adverse supply shock that induces a gradual reduction in the foreign flow endowment of oil Y^*_{Ot}. In this framework, the foreign endowment is assumed to follow an AR(1) in the growth rate with an autoregressive parameter of 0.9, and the innovation is scaled so that the relative price of oil rises 50 percent above baseline at its peak under our benchmark calibration. Although the peak effect is identical to that analyzed earlier, the figure shows that the oil price declines considerably over the long simulation horizon. The gradual decline in the oil price is due to falling world oil demand as households and firms substitute away from oil.

Focusing on our benchmark calibration, it is clear from figure 9 that the qualitative effects of the oil supply shock are identical to those derived under an exogenous shock to the oil price (recalling Figure 4). The higher oil price shifts the trade balance of the oil-importer into persistent deficit. This deficit must be offset by an improvement in the nonoil balance, which is achieved through a deterioration in the nonoil terms of trade. The notable difference between the responses in Figure 9 and those in Figure 4 is that the former are quantitatively smaller. This simply reflects that the oil price hike is less persistent, and the wealth transfer to the oil-importer correspondingly smaller.

Key structural parameters affect the response of the nonoil terms of trade and the trade balance (figures 4-6) in the same way under an endogenous price response. The divergence in responses across alternative calibrations of the elasticity of substitution parameter and the domestic production share parameter tends to be even larger than in simulations with an exogenous oil price. To illustrate this, figure 9 compares the effects of the oil quantity shock under our benchmark calibration in which the oil elasticity of demand is set to 0.5 with alternatives in which the elasticity is set equal to unity and 0.05 just as in figure 5. Given that the fall in world oil supply is identical across simulations, the oil price shows a larger and more persistent increase as the long-run oil price elasticity of substitution declines. Accordingly, the terms of trade deteriorate by more and the nonoil balance improves by more if the oil price elasticity of demand is low, which mirrors the qualitative pattern in Figure 5. However, because the oil price response is now much larger under the low-elasticity calibration, the magnitude of the nonoil terms of trade deterioration and nonoil trade balance response is greatly amplified. By comparison, under a high elasticity of substitution the oil price remains only slightly above its pre-shock baseline in the long-run, so that the terms of trade and nonoil balance remain nearly unchanged.

We next compare the effects of an oil price rise generated by the supply shock with a similar-sized price increase induced by a demand shock that is specific to the oil market. To model the latter in our framework, we modify the foreign consumption demand equation to allow for a preference shock μ^*_{ot} to the foreign demand for oil:

$$C^*_t = \left((1-\omega^*_{oc})^{\frac{\rho_{oc}}{1+\rho_{oc}}} C^*_{Nt}{}^{\frac{1}{1+\rho_{oc}}} + \omega^*_{oc}{}^{\frac{\rho_{oc}}{1+\rho_{oc}}} (\varphi^*_{OCt} \frac{O^*_{Ct}}{\mu^*_{ot}})^{\frac{1}{1+\rho_{oc}}} \right)^{1+\rho_{oc}}. \quad (16)$$

Thus, a rise in μ^*_{ot} raises the marginal productivity of oil abroad, and hence raises household oil demand at constant relative prices.[17] As in the case of the supply shock, we assume that the demand shock follows an autoregressive process in the growth rate (the autoregressive parameter is 0.88).

Figure 10 compares the responses of the home country to the supply and the demand shock in the oil market. The latter is scaled so that the peak response of the oil price is roughly the same as for the supply shock. The two shocks affect the home country through similar channels, and have comparable effects on the trade balance and nonoil terms of trade, as well as on other domestic variables. Thus, either shock causes the oil component of the trade balance to shift into persistent deficit, which in turn induces the nonoil terms of trade to depreciate.

Our results suggest that only the path of the oil price is relevant to the home country, provided that the oil price hike is generated by a foreign supply or demand disturbance that is specific to the oil market. From a practical perspective, it is immaterial to the United States whether oil prices rise because of a supply contraction in the Middle East, or because of cold weather in China, so long as the oil price responds commensurately.

But in interpreting our results, two important caveats are important. First, insofar as we designed our comparison to elicit similar oil price paths, our analysis should *not* be taken to imply that reasonably calibrated oil-specific demand and

[17]The increase in the marginal product reflects that oil and nonoil consumption goods are complements in the household consumption bundle under our baseline calibration.

supply shocks generate similar oil price responses. Clearly, these shocks may have different effects on the dynamic response of the oil price, depending on the size of underlying innovations, and on the time path of the elasticities of the supply and demand for oil.[18] The second caveat is that there are many other types of shocks that affect world oil demand primarily through their effects on aggregate expenditure. For example, a rise in foreign productivity growth raises oil demand through its stimulative effect on foreign absorption. The effects on the home country of a given-sized oil price hike induced by this latter type of foreign demand shock could diverge markedly from that caused by an oil supply shock, reflecting the different channels through which the shock would affect the foreign economy; roughly speaking, the differences arise through channels that would remain operative even if the oil share of the world economy declined toward zero. As there are a myriad of different shocks that affect aggregate demand, oil price increases associated with different underlying shocks (e.g., productivity growth vs. consumption taste shock) could be associated with quite different responses of the home economy.

7 Allowing for Nominal Rigidities

This section examines the sensitivity of our results to the inclusion of nominal rigidities in both price- and wage-setting. In particular, we consider an alternative version of our model that modifies our flexible price framework along several dimensions that have become standard in the literature on dynamic New-Keynesian models. First, we account for stickiness in the aggregate price of the domestically produced nonoil good P_{Dt} by assuming that it is produced by a continuum of monopolistically-competitive firms that set prices for an extended duration in overlapping staggered

[18] Thus, even if only the path of the oil price response matters for oil-market specific shocks, it is still of interest to understand the transmission process from various oil demand and supply shocks to oil prices. For example, colder weather in China would presumably have smaller and shorter-lived effects on oil prices than a rise in oil demand associated with a greater use of motorized vehicles.

contracts. In this framework, the domestically produced nonoil good in equation (5) effectively serves as the factor input to the monopolistic producers. Thus, all producers have the same marginal cost. These monopolistically-competitive firms set prices in their domestic currency in Calvo-style contracts ("producer currency pricing" in the export market), with a mean contract duration of four quarters, and full indexation to past prices as in the model of Christiano, Eichenbaum, and Evans 2005. Second, we allow for nominal wage stickiness by assuming that wages are set in staggered contracts by a continuum of households with differentiated labor inputs. Wages are also set in Calvo-style staggered contracts with a mean duration of four quarters, with full indexation to past wage inflation. Finally, we assume that monetary policy is determined by an estimated interest rate reaction function of the form:

$$i_t = (1 - \gamma_i)(\overline{r} + \overline{\pi}) + \gamma_i i_{t-1} + \gamma_\pi(\pi_t^{(4)} - \overline{\pi}) + \gamma_y(y_t - y_{t-1}) + \epsilon_{it}. \tag{17}$$

In the above, i_t is the annualized nominal interest rate, $\pi_t^{(4)}$ is the four-quarter inflation rate of the aggregate output deflator (i.e., $\pi_t^{(4)} = \sum_{j=0}^{3} \pi_{t-j}$), $\bar{r}$ and $\bar{\pi}$ are the steady-state real interest rate and the central bank's constant inflation target, respectively (both expressed at annual rate), and $y_t - y_{t-1}$ is the annualized quarterly growth rate of aggregate output. We estimated the parameters of the monetary policy rule using U.S. data from 1983:1-2003:4.[19] Our estimates implied $\gamma_\pi = 0.6$, $\gamma_y = 0.28$, and $\gamma_i = 0.8$.

As seen in Figure 11, the response of the trade balance and its components in the model with nominal rigidities is virtually identical to that in the model with flexible prices and wages, and the response of the nonoil terms of trade is also very similar. This similarity reflects that the response of oil demand is mainly driven by the large change in the relative price of energy. Given the similar response of the oil component of the trade balance across the two models, the required adjustment in the nonoil balance and nonoil terms of trade turns out to be similar. The requisite

[19]We estimated the rule using instrumental variables with lags of inflation and output growth as instruments.

nonoil terms of trade adjustment can occur even in the model with nominal rigidities because the exchange rate is flexible to adjust. As Figure 11 shows an alternative monetary policy that responds to inflation only would yield only minor differences in the responses of the oil and nonoil trade balance relative to our estimated policy rule.[20]

8 Conclusion

This paper has investigated how a rise in oil prices affects the U.S. trade balance and the nonoil terms of trade. We present a DSGE model that is in line with the documented empirical evidence: oil shocks that lead to an increase in the price of oil are associated with protracted oil deficits, but the effects on the overall trade balance are mitigated by the improvement in the nonoil goods balance. Our ability to replicate these empirical findings with our model hinges on two elements about which there is considerable debate. First, we require a sufficiently low oil price elasticity of demand. Second, international financial markets need to be incomplete. It is only under these two assumptions that the oil price hike induces large enough differential wealth effects between countries that lead to a subsequent improvement of the nonoil trade balance through the requirement of intertemporal trade balance. In future work, we intend to estimate the impact of alternative types of demand and supply shocks using the restrictions of a theoretical model, including shocks that are specific to the oil market, and other shocks that affect oil prices through their influence on aggregate demand. Such analysis would provide a model-based complement to the recent empirical work by Kilian, Rebucci, and Spatafora (2007)

[20]Leduc and Sill (2004) emphasized that alternative monetary policy rules can lead to markedly different responses of output to oil price increases. In our setup, increasing the long-run elasticity would increase the differences brought about by alternative monetary rules for the response of output and absorption. However, varying the policy rule has a negligible impact on the oil and nonoil trade balance response, because of offsetting movements in the nonoil terms of trade.

and our own VAR analysis performed in this paper.

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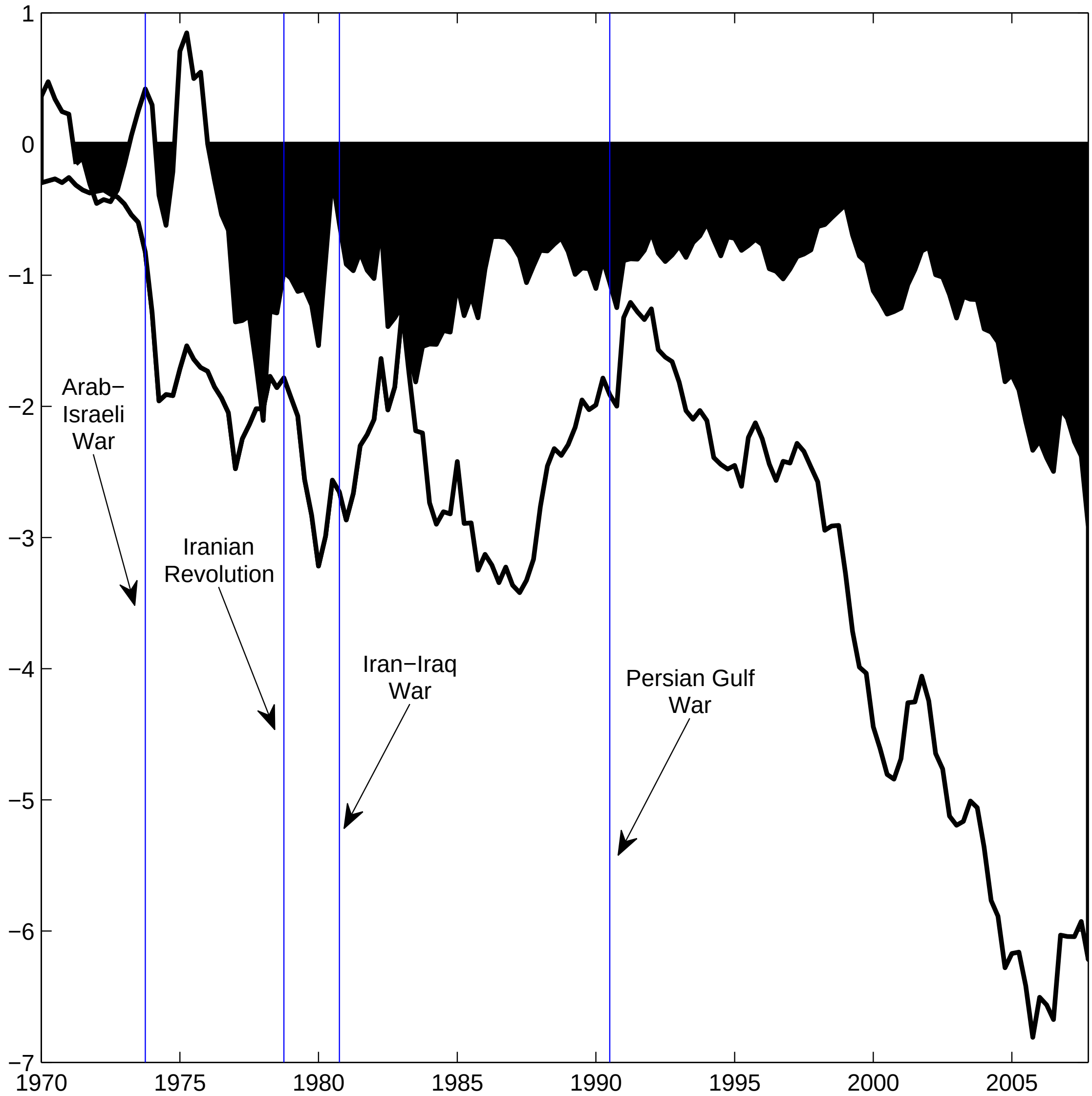
Table 1: Calibration of Baseline Model

Parameter	**Used to Determine**	**Parameter**	**Used to Determine**
Parameters governing households' behavior			
$\beta = 0.99$	discount factor	$\chi = 10$	labor supply elasticity[a]
$\sigma = 1$	intertemporal consumption elasticity	$\omega_{oc} = 0.018$	weight of oil in consumption
$\rho_{oc} = -2$	oil elasticity in consumption (0.5)	$\varphi_{oc} = 142$	oil adj. costs in consumption
Parameters governing firms' behavior			
$\delta = 0.025$	depreciation rate of capital	$\rho_v = -2$	K-L sub. elasticity (0.5)
$\omega_k = 1.61$	parameter on K in value added	$\omega_{oy} = 0.024$	weight of oil in production
$\rho_{oy} = -2$	value-added oil sub. elasticity (0.5)	$\varphi_{oy} = 142$	oil adj. costs in production
Parameters governing international trade			
$\rho_c = -1$	consumption import sub. elasticity (1.5)	$\omega_{mc} = 0.063$	weight of imports in nonoil consumption
$\rho_i = -1$	investment import sub. elasticity (1.5)	$\omega_{mi} = 0.43$	weight of imports in investment

[a] The Frisch elasticity is $2/\chi = 0.2$.

Figure 1: Net Exports of Petroleum and Products and Goods Trade Balance (share of GDP, 1970q1-2007q4)



Source: National Income and Products Accounts.

Figure 2: Effects of An Oil Demand Shock that Drives the Price of Oil Up by 10% – Linear Estimator

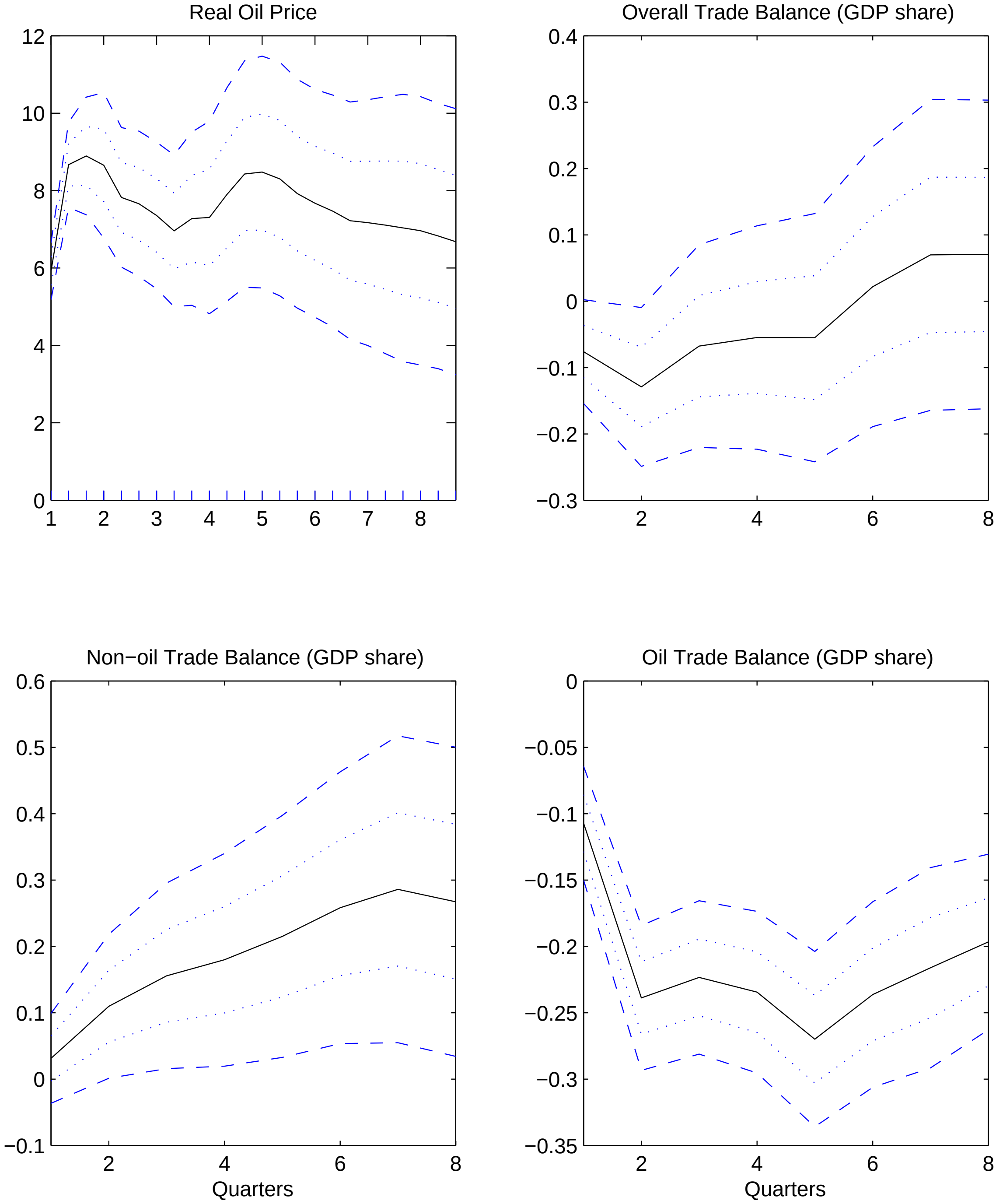


Figure 3: Effects of An Oil Shock that Drives the Price of Oil Up by 10% – Nonlinear Estimator

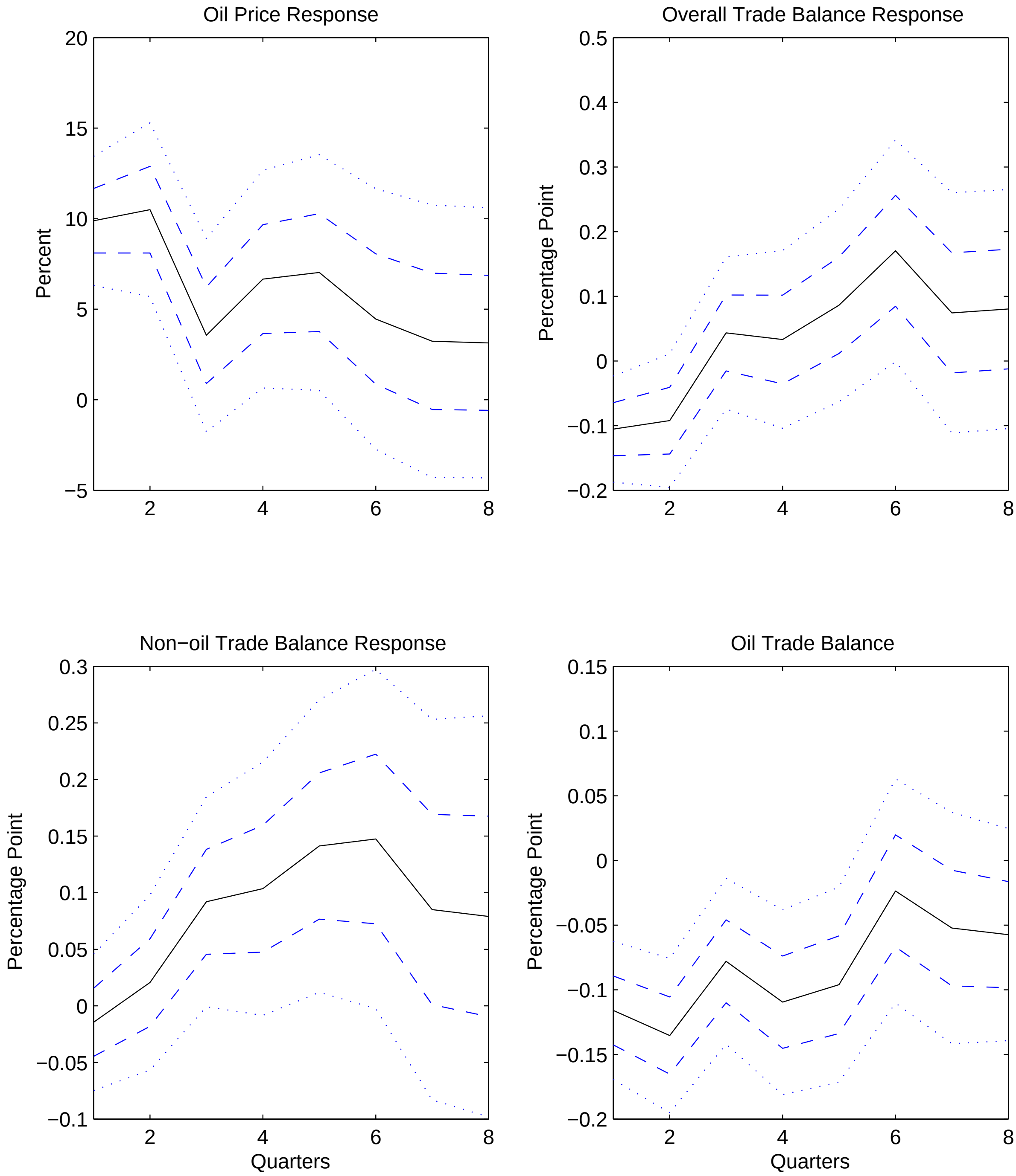


Figure 4: A 50% Increase in the Price of Oil

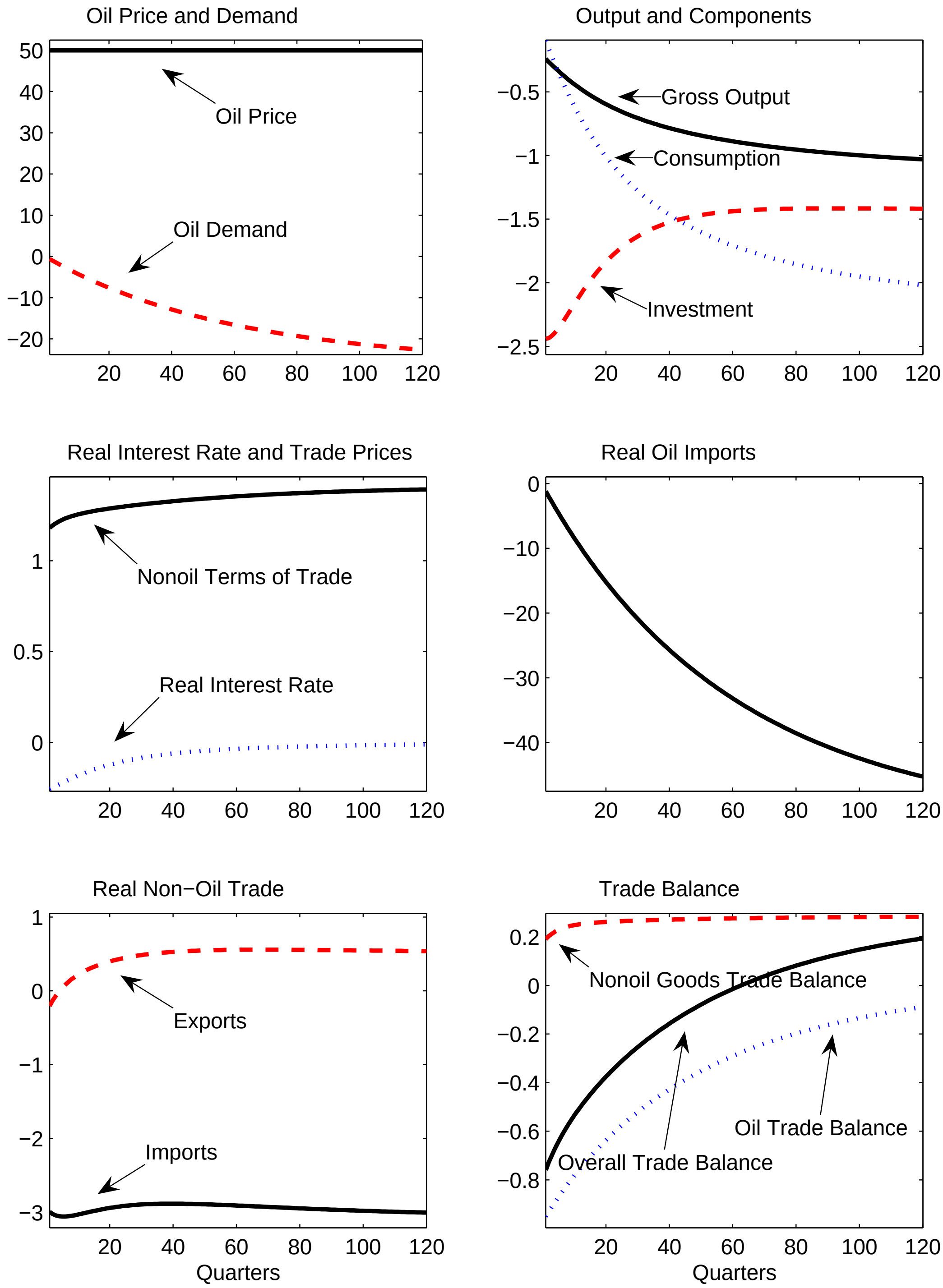


Figure 5: A 50% Rise in the Oil Price: Alternative Price Elasticities of Oil Demand

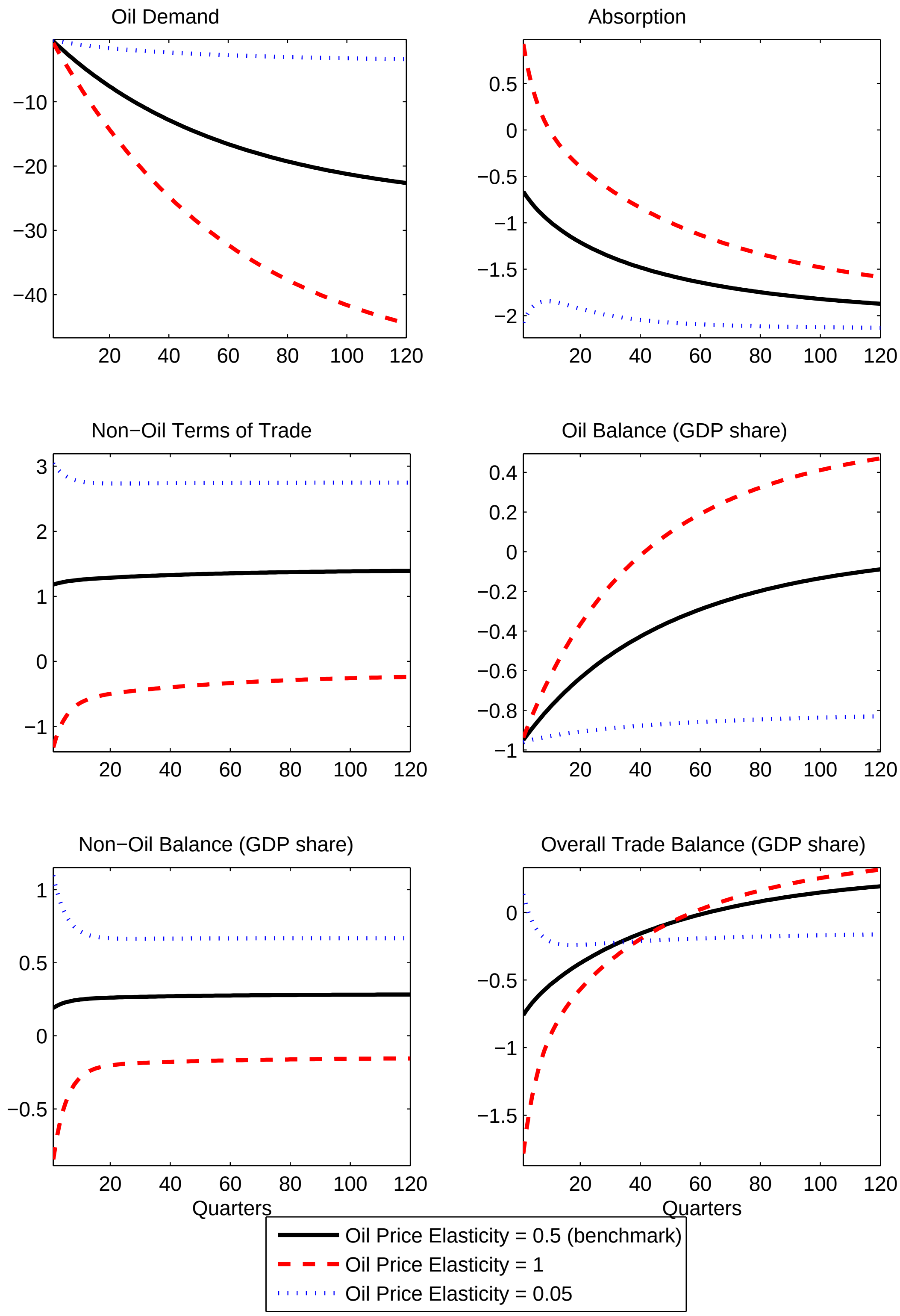


Figure 6: 50% Rise in the Oil Price: Complete and Incomplete Markets

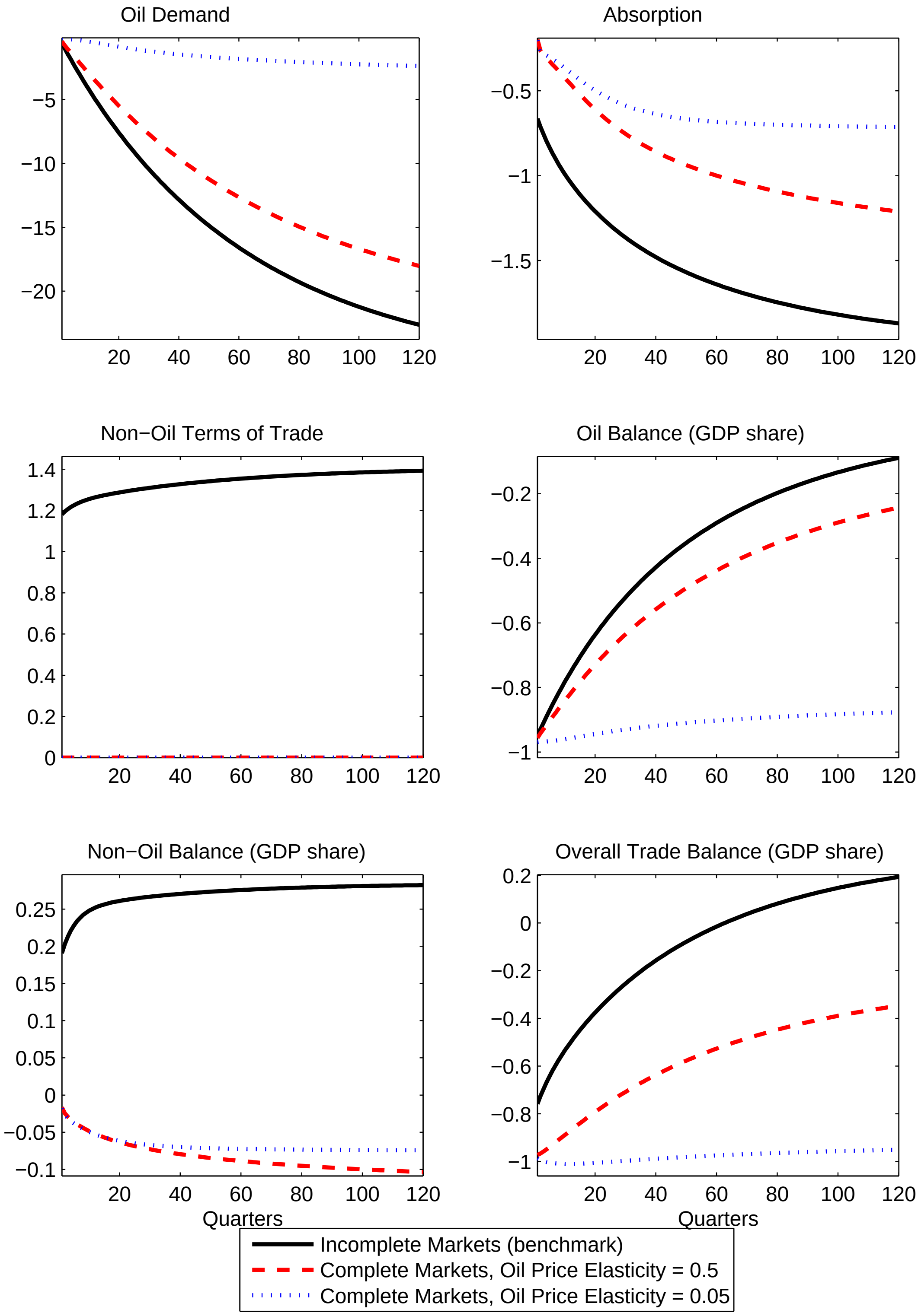


Figure 7: Hicks Decomposition, Home Country

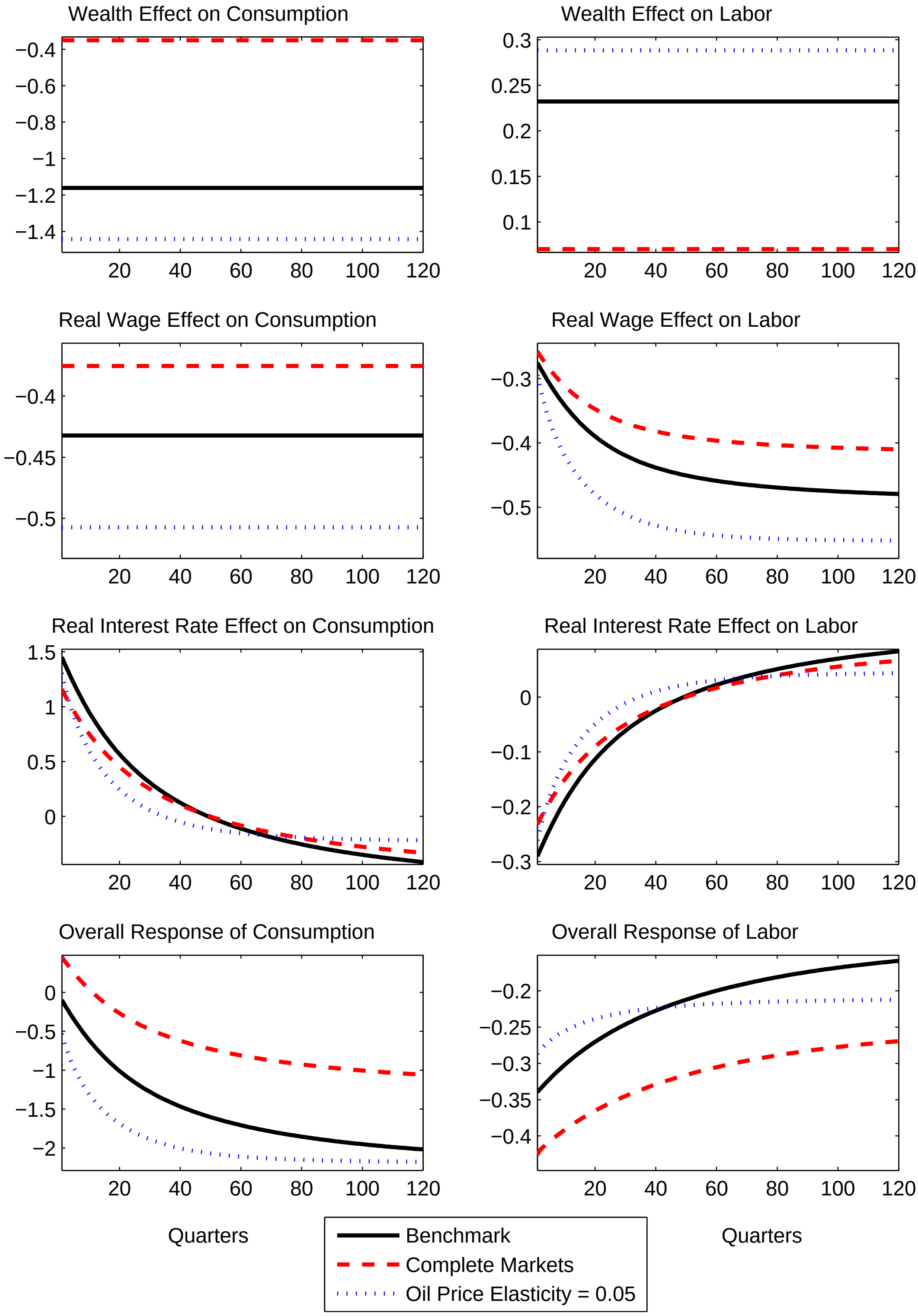


Figure 8: Hicks Decomposition, Foreign Country

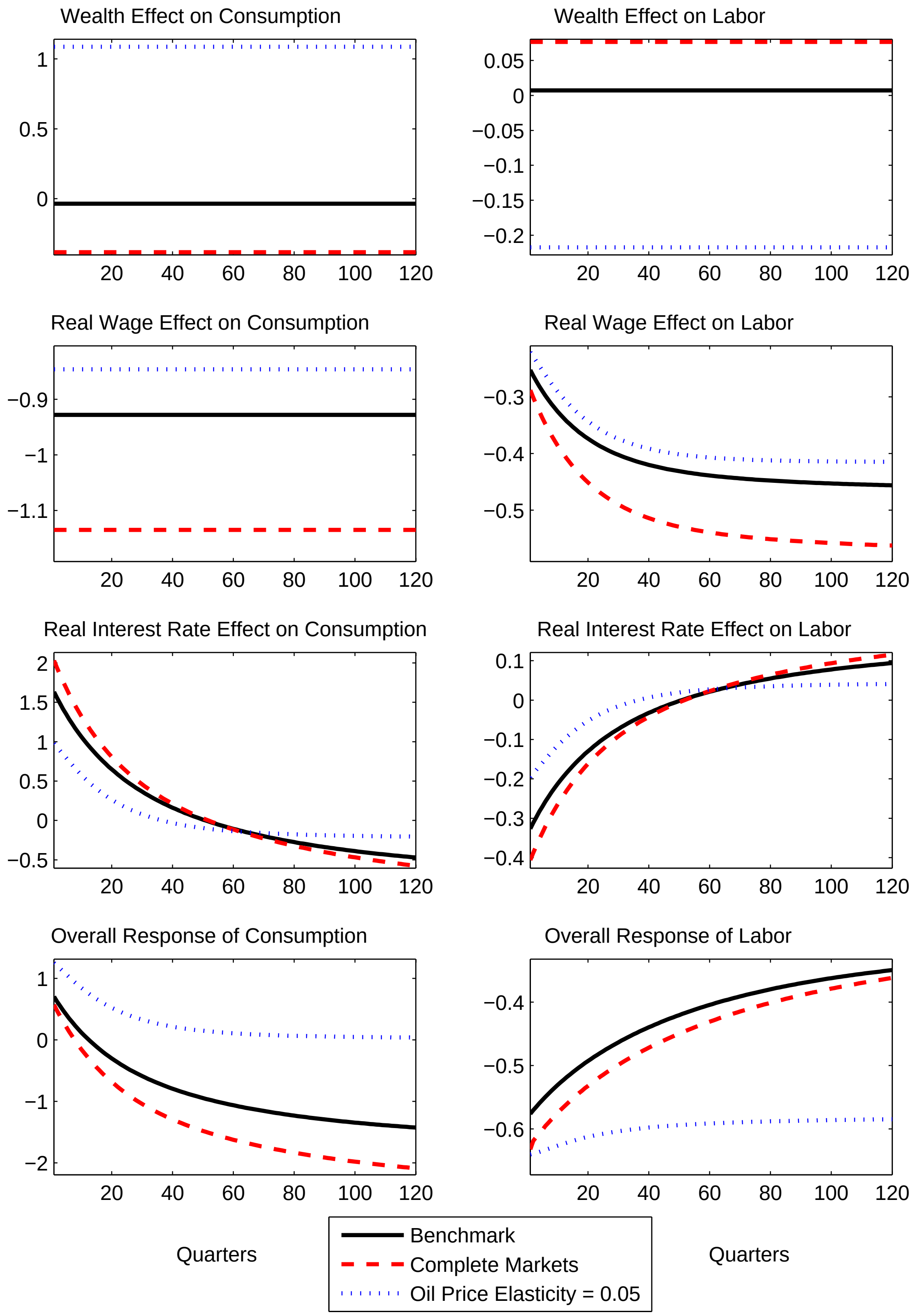


Figure 9: Contraction in Foreign Oil Supply

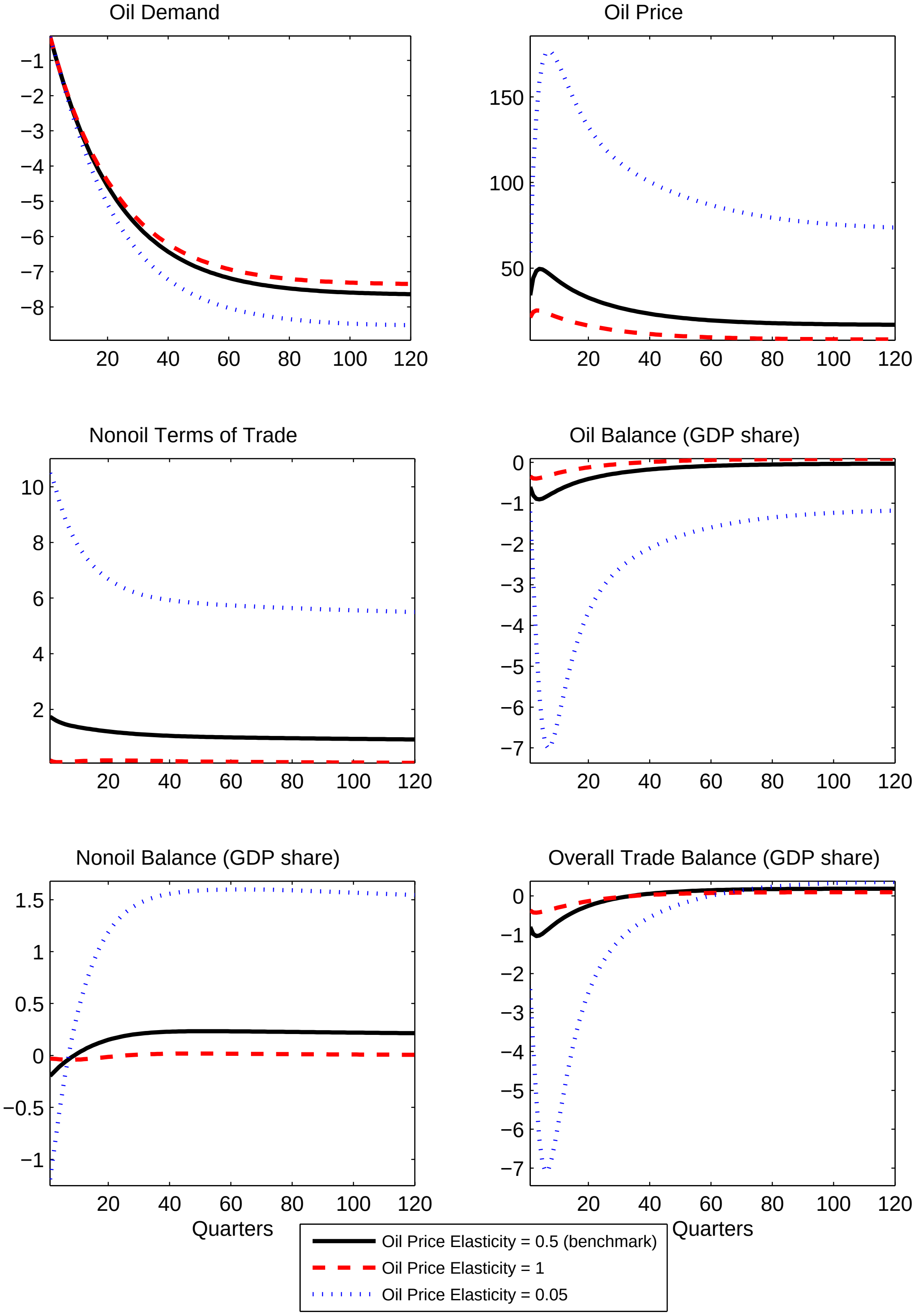


Figure 10: Comparing a Contraction in Foreign Oil Supply with an Expansion in Foreign Oil Demand

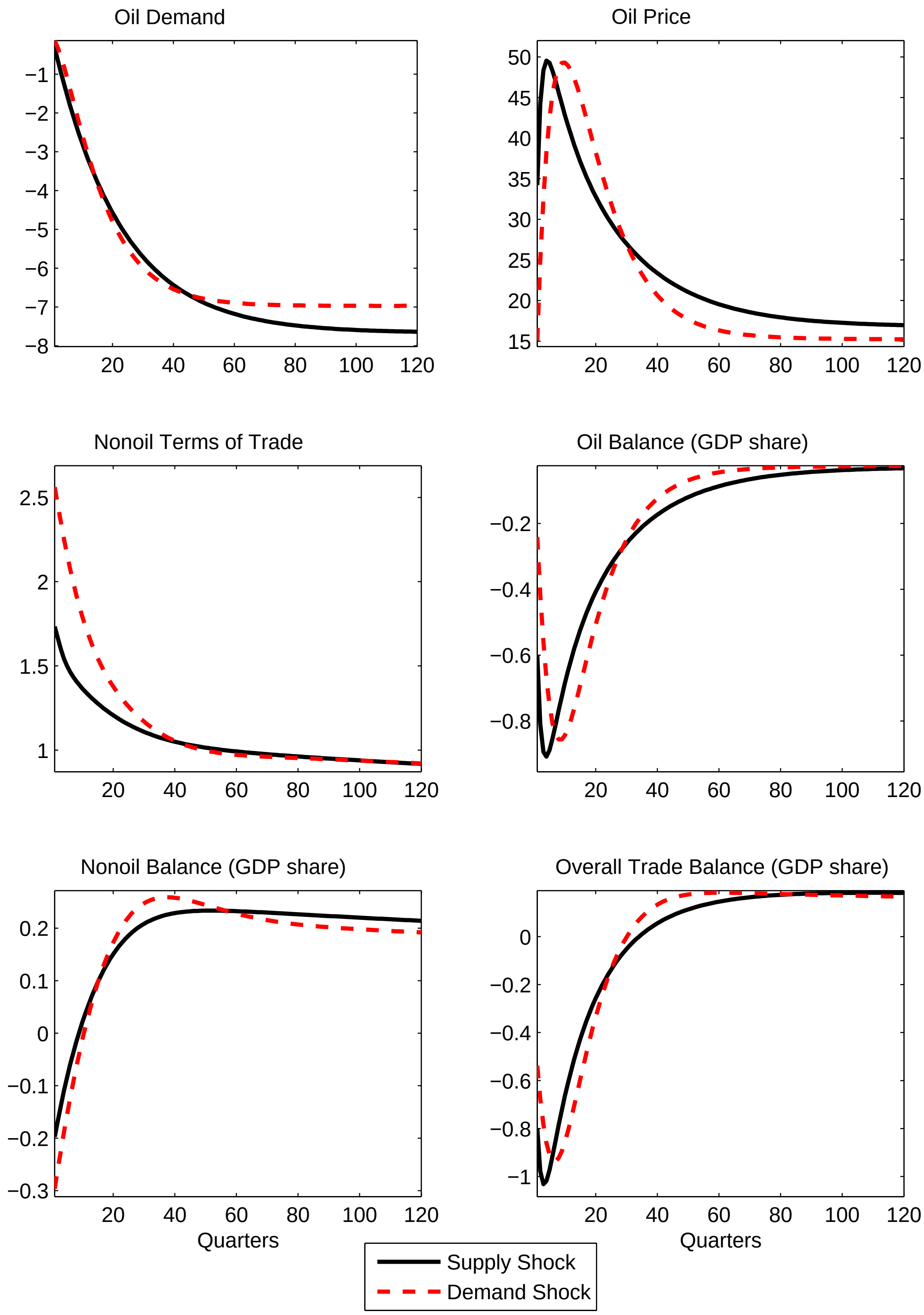
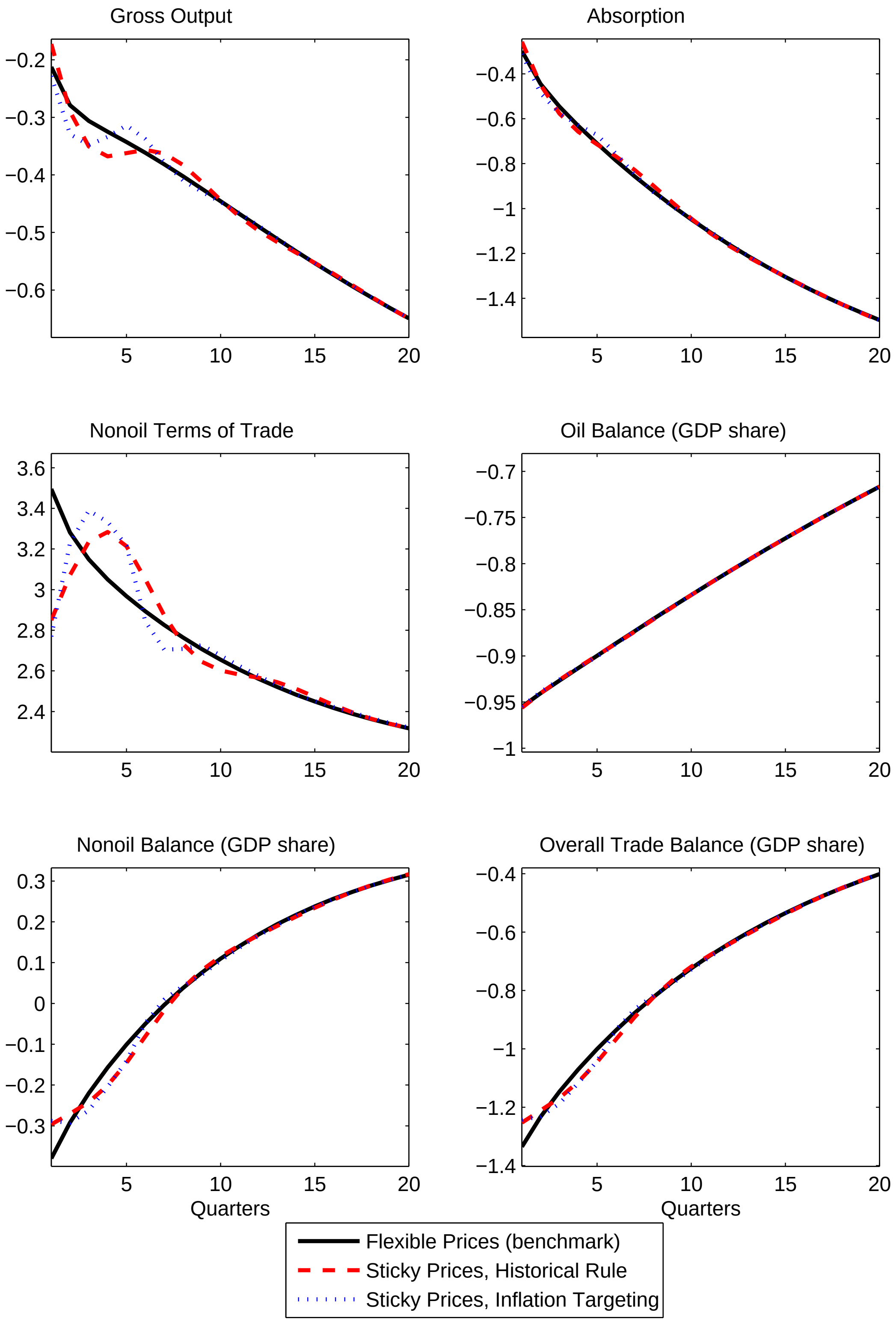


Figure 10. 50% Rise in the Oil Price: Flexible vs. Sticky Prices



A Appendix: Estimation of the Oil Demand Equation

Abstracting from taxes, the log-linearized behavioral equation determining aggregate oil demand can be expressed as:

$$\begin{aligned}\hat{O}_t &= \varepsilon_a \left(\frac{O_Y}{O}\hat{Y}_t + \frac{O_C}{O}\hat{C}_t \right) - \frac{\varepsilon_o}{1+\varepsilon_o\varphi_o}\left(\hat{P}_{O,t} - \frac{O_Y}{O}\hat{P}_{Dt} - \frac{O_C}{O}\hat{P}_{Ct} \right) \\ &\quad - \frac{\varepsilon_o\varphi_o}{1+\varepsilon_o\varphi_o}\left(\frac{O_Y}{O}\hat{Y}_{t-1} + \frac{O_C}{O}\hat{C}_{t-1} - \hat{O}_{t-1} \right) + u_t. \qquad (18)\end{aligned}$$

In equation (18), a "hat" denotes a variable's percentage deviation from its steady state value. Steady state values are distinguished by the omission of a time subscript. To derive the equation above, we imposed the restrictions $\varepsilon_o = \frac{1+\rho_{oy}}{\rho_{oy}} = \frac{1+\rho_{oc}}{\rho_{oc}}$ and $\varphi_o = \varphi_{oy} = \varphi_{oc}$, by which the price elasticity of oil demand is equalized across the two end uses in our model at each point in time. The parameter ε_o is the absolute value of the long-run price elasticity of oil demand. The variable u_t reflects a stochastic shock to oil demand, as discussed in Section 6. Our model imposes that the coefficient ε_a on contemporaneous activity $\left(\frac{O_Y}{O}\hat{Y}_t + \frac{O_C}{O}\hat{C}_t \right)$ equals one, but we estimate it as a free parameter as a test of our specification.

To control for endogeneity, our econometric approach follows Fuhrer and Moore (1995). As a statistical model, we use a three equation VAR(4) that includes oil demand, the activity measure, and the relative price measure.[21] The demand equation (18) replaces the oil equation in that VAR system. We estimate this system using maximum likelihood.

As a measure of oil, demand we take total petroleum consumption (product supplied) from the Energy Information Administration. We construct the activity measure as a weighted average of consumption and GDP from the National Income and Product Accounts (NIPA).[22] For the relative price measure, we use the crude oil producer price index series from the Bureau of Labor Statistics, and the consumption

[21] We chose a lag length of 4 to avoid serial correlation in the residual.

[22] The weights reflect the share of total oil usage devoted to consumption and production under our base-

and GDP deflators from NIPA. We run all regression equations using log linearly detrended quarterly data. The estimation sample covers the period from the second quarter of 1948 to the fourth quarter of 2005.

The regression results for the oil demand equation are summarized in Table 2. The estimated elasticity for the activity measure is not significantly different from 1, which is the value imposed by our theoretical model. The oil price elasticity is estimated at 0.28. Our baseline calibration value of 0.5 is within one standard deviation. The estimated adjustment cost parameter φ_o is 139.2, which implies a half life of 7 years for the response of oil demand to a permanent price increase. Our baseline half life of 10 years lies within one standard deviation of the estimate of φ_o.

The Durbin Watson statistics suggests serial correlation in the regression residuals of the oil demand equation. To address the potential mispecification, we modify the adjustment cost function for oil demand in production (equations 6) as follows:

$$\varphi_{OYt} = \left[1 - \frac{\varphi_{oy1}}{2}\left(\frac{\frac{O_{Yt}}{V_t}}{\frac{O^A_{Yt-1}}{V^A_{t-1}}} - 1\right)^2 - \frac{\varphi_{oy2}}{2}\left(\frac{\frac{O_{Yt-1}}{V_{t-1}}}{\frac{O^A_{Yt-2}}{V^A_{t-2}}} - 1\right)^2\right]. \tag{19}$$

We change the adjustment cost function for oil demand in consumption (equation 8) analogously.

Upon log-linearizing, the aggregate oil demand equation now takes the form:

$$\hat{O}_t = \varepsilon_a\left(\frac{O_Y}{O}\hat{Y}_t + \frac{O_C}{O}\hat{C}_t\right) - \frac{\varepsilon_o}{1+\varepsilon_o(\varphi_{o1}+\varphi_{o2})}\left(\hat{P}_{O,t} - \hat{P}_{D,t}\right) + \tag{20}$$

$$-\frac{\varepsilon_o\varphi_{o1}}{1+\varepsilon_o(\varphi_{o1}+\varphi_{o2})}\left(\frac{O_Y}{O}\hat{Y}_{t-1} + \frac{O_C}{O}\hat{C}_{t-1} - \hat{O}_{t-1}\right)$$

$$-\frac{\varepsilon_o\varphi_{o2}}{1+\varepsilon_o(\varphi_{o1}+\varphi_{o2})}\left(\frac{O_Y}{O}\hat{Y}_{t-2} + \frac{O_C}{O}\hat{C}_{t-2} - \hat{O}_{t-2}\right). \tag{21}$$

line calibration (of 1/3 and 2/3, respectively. Gross output is the theoretically preferred production measure implied by our model. However, because deriving a gross output measure requires estimating the share of oil imports directed towards production, we used GDP in our benchmark specification. As a robustness check, we constructed an alternative proxy for gross output, and found little difference from the results reported below.

Following the same estimation procedure as described above we obtain estimates summarized in Table 3.

This alternative regression specification reduces the residual autocorrelation, as indicated by a lower Durbin-Watson statistic. The coefficient estimates ε_a and ε_o are not significantly different from those in the simpler specification. Again, we fail to reject the restriction imposed by our theoretical model that ε_a is 1. The estimates for the adjustment cost parameters φ_{o1} and φ_{o2} imply a half life of 10 years for the response of oil demand to a permanent price increase, as in our baseline calibration. Given the short length of the time series and the slow adjustment of oil demand, it is difficult to estimate the long-run elasticity precisely. Nonetheless, the regression does very well at capturing the variation in oil demand, as suggested by the high R^2 statistic.

Table 2: Regression results for baseline oil demand equation*

	Coefficient	Std. Error	Prob.
ε_a	1.05	0.05	0.00
ε_o	0.28	0.27	0.30
φ_o	139.2	95.0	0.14
R^2 =0.98	Durbin-Watson stat. = 2.40		

* See equation (18).

Table 3: Regression results for augmented oil demand equation*

	Coefficient	Std. Error	Prob.
ε_a	1.04	0.05	0.00
ε_o	0.45	0.42	0.29
φ_{o1}	81.9	40.3	0.04
φ_{o2}	21.3	11.6	0.07
R^2 =0.98	Durbin-Watson stat. = 2.05		

* See equation (20).