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Oil supply shocks and the U.S. economy: An estimated DSGE model☆

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ABSTRACT

We develop and use a medium-sized DSGE model of the U.S. economy to evaluate how U.S. real GDP responds to oil price movements that originate from global oil supply shocks. The core of the model is a standard macroeconomic DSGE framework that includes nominal and real frictions. The model includes oil as an input in multiple domestic sectors (consumption, intermediate goods, and transportation services). We include a domestic oil production sector for the United States to reflect the recent development in shale oil technology. The model also captures international trade in goods and oil. The model parameters are set through a combination of calibration and Bayesian estimation using quarterly data for 1991 through 2015. Baseline estimation of the model finds the elasticity of U.S. real GDP with respect to an oil price shock of − 0.015, which is among the less elastic estimates in the literature. Using the model to conduct counterfactual analysis, we find that decreasing steady state U.S. oil consumption substantially reduces the response of real GDP to oil prices. Increasing U.S. domestic oil production only modestly reduces the response of real GDP to oil prices.

1. Introduction

Since the early 1970s, economic research has focused on how the U.S. economy has responded to world oil price shocks. As surveyed by Brown and Yücel (2002), Jones et al. (2004), and Kilian (2008c), the aggregate economic effects were interpreted as the consequences of unfavorable oil supply shocks—with the consequences being rising oil prices, slower real GDP growth (possibly recession), higher unemployment rates, and higher price levels. As oil prices have fluctuated throughout the 2000s, however, they seem to have yielded a much smaller response in U.S. real GDP.

Some of the explanations for a weaker response have included increased global financial integration, greater flexibility of the U.S. economy (including labor and financial markets), the reduced oil intensity of the U.S. economy, increased experience with oil price shocks, better monetary policy, and smaller and less frequent shocks. Contributions include Huntington (2003), Stock and Watson (2003), Nakov and Pescatori (2009), Blanchard and Gali (2010), Edelstein and Kilian (2007), Herrera and Pesavento (2009) and Kilian and Lewis (2011).

A growing literature examines the implications of distinguishing the effects of oil price movements that arise from demand or supply shocks in the oil market. That is, oil supply and demand shocks can have different implications for aggregate economic activity. The newer efforts include Kilian (2008 a,b, 2009, 2014), Balke et al. (2010), Baumeister and Hamilton (2015), and Baumeister and Kilian (2016). According to Kilian (2008b), Balke et al., and Baumeister and Hamilton, the differing sources of oil price shocks can explain some of the apparent changes in the relationship between oil price movements and aggregate economic activity. Nonetheless, the newer empirical literature, such as Kilian and Vigfusson (2011 a,b), Kilian (2014), Baumeister and Hamilton, and Baumeister and Kilian, suggest that oil price increases arising from supply shocks in the oil market have a much smaller effects on aggregate economic activity than is found in the earlier literature.

Dynamic stochastic general equilibrium (DSGE) modeling is an approach that allows for identification of the various sources of oil price shocks and at the same time can capture alternative explanations of why the economy has become less sensitive to oil price shocks. Although DSGE models are widely used to examine aggregate economic activity and macroeconomic policy, few empirical exercises involving DSGE models have been used to examine the effect of oil supply shocks on world oil prices and aggregate economic activity. Notable exceptions include Bodenstein et al. (2011), Bodenstein and Guerrieri (2011), and Balke et al. (2010). Although these efforts identified various sources of

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oil price shocks, the efforts represented U.S. oil consumption rather broadly, and none of these efforts allowed for the frictions that are now typically found in DSGE models.

In the present analysis, we expand inquiry by using a medium-sized DSGE model of the U.S. economy that also represents the world oil market, U.S. international trade, and aggregate economic activity in the rest of the world (ROW). The model provides a mapping from structural shocks—such as those in technology and preferences—to observables such as oil prices, oil production, and other measures of economic activity. We use a combination of calibration and Bayesian methods to determine the model's parameters and to assess the stochastic process generating the exogenous shocks. The latter allows us to identify oil supply shocks and to estimate their effects on world oil prices and U.S. real GDP.

The core of the model is essentially a standard macroeconomic DSGE framework that includes nominal frictions (prices) and real frictions (real wages and capital and labor adjustment costs). To this model, we introduce oil as an additional input to production (and consumption), multiple sectors (consumption, final goods, intermediate goods, transportation services and oil production). The transportation sector captures an important channel through which oil prices can affect aggregate economic activity. In addition, the domestic (U.S.) economy interacts with the ROW through the world oil market and final goods market, which provides channels through which U.S. economic activity and these markets affect each other.

The model is used to examine how U.S. real GDP responds to oil price movements that are the result of an oil supply shock originating in the ROW. As a summary measure of this effect, we calculate the elasticity of U.S. real GDP with respect to oil price changes due to a ROW oil supply shock. We estimated the mean (median) of the posterior distribution of the GDP/oil price elasticity to be − 0.015 (− 0.017). That is, if oil prices increase by 10% due to oil supply shock originating in the ROW, U.S. real GDP falls by 0.15% over the subsequent year.

We also use the model to conduct counterfactual analyses. In particular, we examine how a decline in the U.S. oil usage intensity and an increase in U.S. oil production affects long-run oil consumption, oil imports, as well as the response of the U.S. economy to oil supply shocks originating in ROW. We find that if the steady state level of U.S. oil consumptions is lower, the U.S. economy becomes substantially less responsive to ROW oil supply shocks. In the model when steady state U.S. oil production is substantially higher (75% higher), there is only a modest reduction of the sensitivity of U.S. economic activity to ROW oil supply shocks. Reducing U.S. oil consumption appears to have more impact in lowering the sensitivity of aggregate U.S. economic activity than an increase in U.S. oil production.

The remainder of the paper is organized as follows. Section 2 describes the DSGE model of the U.S. economy, the world oil market, U.S. international trade and ROW economic activity. Section 3 covers the estimation of the model and the posterior distribution of some of the key parameters in the model. Section 4 provides the key empirical results of the model through impulse response functions and historical decompositions. Section 5 provides estimated elasticities of real GDP with respect to the oil price. Section 6 provides counterfactual analysis of the model whereby we change the steady state oil usage intensity and domestic oil production and examine their effects on the GDP/oil price elasticity. Section 7 offers concluding remarks and policy implications.

2. Model

Our model builds on the work of open economy models of oil such as Backus and Crucini (2000), Balke et al. (2010), Bodenstein et al. (2011), and Bodenstein and Guerrieri (2011). Where we differ is that we allow a specific role for transportation in the use of oil products and for oil efficiency to evolve endogenously. Unlike these other models, we do not model structurally the rest-of-the world because data limitations make estimating the structural parameters for the rest-of-the-world difficult.

The main features of the model are as follows:

1. U.S. Economy
   a. Largely neoclassical, dynamic macroeconomic model with real wage and nominal price rigidities, adjustment costs for capital and labor.
   b. Multi-sector model with emphasis on oil's impact through transportation sector and through consumption.
   c. Endogenous oil efficiency.
2. World oil market
   a. Quasi-structural model of ROW supply and demand for oil
   b. Interacts with U.S. oil supply and demand in world oil market to determine price of oil
3. Non-oil interaction of U.S. with ROW
   a. Reduced form model of trade in non-oil goods between U.S. and ROW. Model allows for feedback from U.S. and oil markets to ROW. In the long-run, an increase in U.S. oil imports must be met by an increase in net exports of the non-oil good to ROW, but that need not hold in the short-run.

2.1. Domestic (U.S.) household sector

Household utility is given by:

$$\sum_{i=0}^{\infty} \beta^i u(c_t, l_t) \tag{1}$$

where in the benchmark model

$$u(c_t, l_t) = \frac{(c_t - x_c h_t)^{1-\sigma}}{1-\sigma} - \chi \frac{l_t^{1+\eta}}{1+\eta} \tag{2}$$

where h_t represents habits (external) that evolve according to $h_t = c_{t-1}{}^{1-\gamma_h} h_{t-1}{}^{\gamma_h}$. Consumption, c_t, is given by:

$$c_t = z_{c,t}(\psi_n n_t{}^{\rho_c} + (1-\psi_n) ks_{c,t}{}^{\rho_c})^{1/\rho_c} \tag{3}$$

and

$$l_t = \left(1+\phi\left(\frac{l_{f,t}}{l_{f,t-1}}\right)\right) l_{f,t} + \left(1+\phi\left(\frac{l_{m,t}}{l_{m,t-1}}\right)\right) l_{m,t} + \left(1+\phi\left(\frac{l_{o,t}}{l_{o,t-1}}\right)\right) l_{o,t} \tag{4}$$

Consumption depends on expenditures on nondurables, n_t, and the service flow from durables, $ks_{c,t}$. Households allocate labor to production of final goods, $l_{f,t}$, intermediate goods, $l_{m,t}$, and oil production, $l_{o,t}$. The $\phi\left(\frac{l_{f,t}}{l_{f,t-1}}\right)$ terms represent adjustment costs to households of reallocating their labor supply. We use the functional form:

$$\phi_l\left(\frac{l_{j,t}}{l_{j,t-1}}\right) = a_{jl} \frac{(l_{j,t}/l_{j,t-1}-1)^2}{2} \tag{5}$$

We assume real wage frictions similar to those in Blanchard and Gali (2010). Here the real wage (in terms of the final good) before adding the adjustment costs of changing labor is given by

$$w_t = \quad (w_{t-1})^{\alpha_w} (\lambda_{l,t})^{1-\alpha_w} \tag{6}$$

where

$$\lambda_{l,t} = \left(\frac{1}{\rho_w}\right) \lambda_{c,t} \left(\frac{-U_l(c_t, l_t)}{U_c(c_t, l_t)}\right) \tag{7}$$

$\lambda_{c,t}$ is the real shadow price of the consumption good, $\left(\frac{-U_l(c_t, l_t)}{U_c(c_t, l_t)}\right)$ is the marginal rate of substitution between leisure and consumption, and $\left(\frac{1}{\rho_w}\right)$ is a markup greater than one.

The service flow from durables depends on the stock of durables, $k_{c,t}$, and oil usage, $o_{c,t}$:

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