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BUSINESS CYCLES IN AN OIL ECONOMY[*]

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Abstract

The recent oil price fall has created concern among policy makers regarding the consequences of terms of trade shocks for resource-rich countries. This concern is not a minor one – the world's commodity exporters combined are responsible for 15–20% of global value added. We develop and estimate a two-country New Keynesian model in order to quantify the importance of oil price shocks for Norway – a large, prototype petroleum exporter. Domestic supply chains link mainland (non-oil) Norway to the off-shore oil industry, while fiscal authorities accumulate income in a sovereign wealth fund. Oil prices and the international business cycle are jointly determined abroad. These features allow us to disentangle the structural sources of oil price fluctuations, and how they affect mainland Norway. The estimated model provides three key results. First, oil price movements represent an important source of macroeconomic volatility in mainland Norway. Second, while no two shocks cause the same dynamics, conventional trade channels make an economically less significant difference for the transmission of global shocks to the oil exporter than to oil importers. Third, the domestic oil industry's supply chain is an important transmission mechanism for oil price movements, while the prevailing fiscal regime provides substantial protection against external shocks.

Keywords: *DSGE, small open economy, oil and macro, Bayesian estimation.*

JEL Classification: *C11, E30, F41, F44.*

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1 INTRODUCTION

What drives the business cycle in commodity economies? How are shocks related to resource extraction propagated? How should policymakers respond to them? Recent volatility in commodity prices, in particular the dramatic fall in oil prices, have sparked renewed interest in these questions. The concern is not a minor one. According to the IMF (2015), 17% of world GDP stems from countries with more than 20% of exports from non-renewable commodities. Understanding interactions between commodity prices and the business cycle of commodity exporters is important for all countries with a stake in international trade. Still, our knowledge about these interactions is limited. Most business cycle research either abstracts from the role of commodities all together, or focuses on commodity users rather than commodity producers. The absence of commodities is particularly evident in the dynamic stochastic general equilibrium (DSGE) models often used for projections and policy analysis.[1]

In this paper, we develop a medium-scale DSGE model of a commodity-exporting economy, where commodity exports and other economic activities are jointly determined. Compared to most of the existing DSGE literature, we present a substantially richer description of macroeconomic dynamics in commodity-exporting economies. We estimate the model using Norwegian and international data, and we quantify the importance of oil price movements for business cycle dynamics in Norway. We believe the Norwegian economy is a particularly interesting case study for three reasons. First, Norway is a highly specialized commodity exporter, with petroleum accounting for 20–25% of GDP and almost 50% of total exports. Second, Norway's non-oil economy is highly developed, resulting in intricate intersectoral dynamics. Third, the economic policy framework in Norway has attracted significant international interest, in particular the management of petroleum revenues through the Government Pension Fund Global, a sovereign wealth fund which invests solely in international assets.[2] One contribution of this paper is to evaluate, within the DSGE framework, whether that particular policy has been able to absorb global oil price fluctuations.

The core of our structural framework is similar to conventional small open-economy DSGE models, see e.g. Adolfson et al. (2007, 2008). As our focus is on business cycle dynamics, we abstract from some interesting long-run issues, including the optimal depletion problem studied by Hotelling (1931) and Pindyck (1978), amongst others. But we extend the familiar business cycle framework along several dimensions to facilitate the analysis of resource extraction and sectoral reallocations in the domestic economy. First, we derive dynamics in a competitive oil export industry from first principles. Oil com-

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[1] Prominent examples without any role for commodities include Adolfson, Laséen, Lindé, and Villani (2007, 2008), Justiniano, Primiceri, and Tambalotti (2010, 2011), and Smets and Wouters (2003, 2007), while Bodenstein and Guerrieri (2012), Kormilitsina (2011) and Nakov and Pescatori (2010) estimate the effects of oil price shocks on the U.S. economy (which, up until recently, was a large net oil importer).

[2] The fund has not, despite its name, any formal pension liabilities. It was established in order to smooth the use of petroleum revenues over time, safeguard Norways' wealth for future generations, and provide room for fiscal policy in periods of economic contraction (http://www.nbim.no/en/the-fund/about-the-fund/).

panies make production plans to maximize profits in response to domestic and foreign shocks, taking the world price of oil as given. In the short run, costly factor adjustments imply that the oil supply is relatively inelastic, in line with empirical evidence (Baumeister and Peersman, 2013a; Hamilton, 2009; Kilian, 2009). At longer horizons, however, capacity depends on the development of new fields, and investments are determined by the entire expected path of break-even points. Second, the oil industry is linked to the rest of the economy through a supply chain. Both maintenance of existing fields and the development of future production capacity require inputs from suppliers. This supply chain gives rise to substantial spillovers from the oil industry to the mainland economy. Third, to understand sectoral non-oil dynamics, we distinguish between firms in manufacturing and service sectors, which differ in terms of technologies and trade intensities as in Bouakez, Cardia, and Ruge-Murcia (2009) and Bergholt (2015). This multi-sector structure allows for a rich transmission of various disturbances related to the extraction and export of oil, including resource movement effects of the kind emphasized by Corden and Neary (1982).[3] Fourth, the model includes a sovereign wealth fund and a fiscal policy regime, accounting for the fact that a large share of oil revenues accrue to governments. Fifth, we model the global economy explicitly. This allows us to identify domestic responses to a range of international shocks that drive the oil price, as emphasized by Kilian (2009) and others.

Using Bayesian techniques, we fit the model to data for Norway and its main trading partner, the European Union. The estimated model is used to address three related questions of relevance for macroeconomic policy. First, how important are oil price fluctuations for business cycles in mainland Norway? Second, are all oil shocks alike, or do the effects depend on the source of oil price volatility? Third, what are the main transmission channels that account for spillovers to the domestic economy? Regarding the first question, our results support the view that oil shocks, and movements in the oil price more generally, are important factors behind macroeconomic fluctuations in mainland Norway. Foreign disturbances explain a sizeable share of business cycle fluctuations, particularly at longer horizons. Our answer to the second question is that shocks that raise the oil price increases activity on the Norwegian mainland in all but a few exceptional cases. The conclusion from Bodenstein, Guerrieri, and Kilian (2012) must be modified for oil exporters: while no shocks are the same and responses differ quantitatively, conventional trade channels make an economically less significant difference for the transmission of global shocks to the oil-exporting economy. Finally, the model puts forward domestic supply chains as the main channel for spillovers to mainland Norway. That is, higher activity in the oil industry transmits mainly because of the associated rise in factor demand. Fiscal policy, in contrast, protects the Norwegian economy against even larger fluctuations. Our model suggests that a spend-as-you-go fiscal rule would lead to much stronger responses of GDP to oil price movements.

Our work speaks to the literature on connections between oil price fluctuations and macroeconomic activity. Several empirical studies document systematic oil price re-

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[3] See also Charnavoki and Dolado (2014) and Bjørnland and Thorsrud (2016) for recent empirical evidence.

sponses to international shocks, and emphasize the importance of taking the two-way causality into account (Baumeister and Peersman, 2013b; Kilian, 2009; Kilian and Murphy, 2012). While most theoretical work ignores this view,[4] we acknowledge that oil prices are best seen as endogenous. However, our study complements the VAR literature by obtaining identification through the cross-equation restrictions embedded in a fully specified general equilibrium model. This approach facilitates inference based on a relatively large dataset, and allows us to disentangle an array of different business cycle shocks. A few recent studies estimate DSGE models with endogenous demand and supply in global oil markets (Bodenstein and Guerrieri, 2012; Nakov and Pescatori, 2010; Peersman and Stevens, 2013). While they focus on the oil-macro nexus from the point of view of oil importers (in particular the U.S. economy), our contribution is to quantify the role of oil in a representative oil exporting economy.

The rest of the paper is organized as follows. Section 2 reports how the oil exporter is affected by foreign shocks in a simple VAR. The point is to highlight some stylized facts, but also to illustrate the limited scope for structural inference based on VARs. Our benchmark DSGE model is presented in Section 3. Section 4 describes the data, calibration choices and estimation results. The quantitative analysis is presented in Section 5. In Section 6 we analyze a number of counterfactual experiments. Section 7 concludes.

2 SOME STYLIZED FACTS

As a preliminary exercise, we start our analysis with the estimation of a simple VAR for the Norwegian economy. Our goal is to get a first, crude overview of what the data tells us about international shocks and the Norwegian business cycle. To this end we impose only a minimal set of restrictions on the system. The model is summarized below:

$$A_0\tilde{y}_t = A_1\tilde{y}_{t-1} + B\varepsilon_t, \quad \tilde{y}_t = \begin{bmatrix} y_t^* & p_{o,t}^* & q_t & y_{o,t} & y_{m,t} & y_{s,t} \end{bmatrix}', \qquad \varepsilon_t \text{ iid } N(0,1)$$

$\tilde{y}_t$ is a (period t) vector of two foreign variables, real activity y_t^* and the real oil price $p_{o,t}^*$, and four domestic variables: The real exchange rate q_t, value added in oil $y_{o,t}$, value added in manufacturing $y_{m,t}$, and value added in services $y_{s,t}$. We make two assumptions in order to obtain structural inference. First, in order to identify the international shocks, we follow Bjørnland and Thorsrud (2016) and impose a Cholesky decomposition of the impact matrix A_0. That is, we assume that only the first element of ε_t affects y_t^* on impact ($A_{0,12} = 0$). The oil price, in contrast, can be contemporaneously affected by both the first and second element of ε_t. We acknowledge that innovations to the oil price equation might be caused by oil-specific demand disturbances, by oil-specific supply disturbances, or by both. Therefore, we do not interpret oil price innovations as oil supply shocks – they are simply oil price shocks. Second, as in previous literature (Justiniano and Preston, 2010; Zha, 1999) we impose block exogeneity on the system of foreign and domestic variables. In particular, we assume that Norwegian business cycles do not affect y_t^* or

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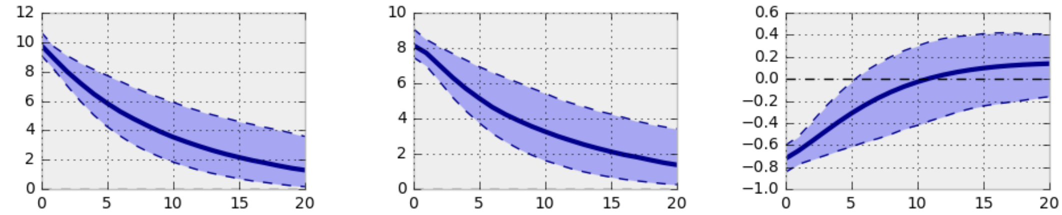
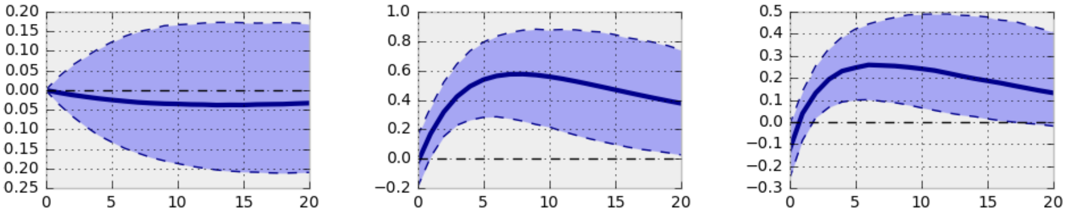
[4] Examples include Kormilitsina (2011), Pieschacon (2012), and Rotemberg and Woodford (1996).

Figure 1: International oil price shock

(a) Oil price (b) Oil sector (c) Exchange rate



(d) International output (e) Manufacturing (f) Services



Note: Impulse responses to a one standard deviation shock to the real oil price. Calculations are based on 1000 draws from the posterior distribution. Median and 68 % credible bands.

$p^*_{o,t}$, either contemporaneously or with a lag. Block exogeneity is motivated by the fact that Norway is a small open economy with negligible influence on international quantities and prices. As our focus is on the domestic effects of international shocks, we do not make any assumptions regarding the sign and size of domestic responses. For the same reason we do not make any attempt to identify domestic shocks.

Our model is estimated on quarterly data from Norway and EU28, covering the period 1995Q1-2015Q4. EU28 serves as a proxy for the international economy.[5] We use as observables the Brent oil price, the import weighted exchange rate I44, as well as sectoral (aggregate) value added in Norway (EU28). The exact sector division is described in the appendix. Value added is defined in per capita, and all variables are measured in consumption units. The data are HP-filtered.[6] The VAR model is estimated with Bayesian techniques. We aim for parsimony and use a non-informative prior (Jeffreys). For the same reason we include only one lag in the VAR.[7]

Impulse responses to the two identified shocks are reported in Figure 1 and Figure 2, respectively. Consider first the international oil price shock. A one standard deviation shock to the oil price equation raises oil prices by almost 10% on impact, while foreign GDP barely moves at all. These responses are consistent with previous studies (Bjørnland and Thorsrud, 2016; Peersman and Van Robays, 2012), and support the view that oil price shocks play a limited role for international activity.[8] Domestic responses, in contrast, are economically significant. The real exchange rate appreciates by about 0.7% on impact.

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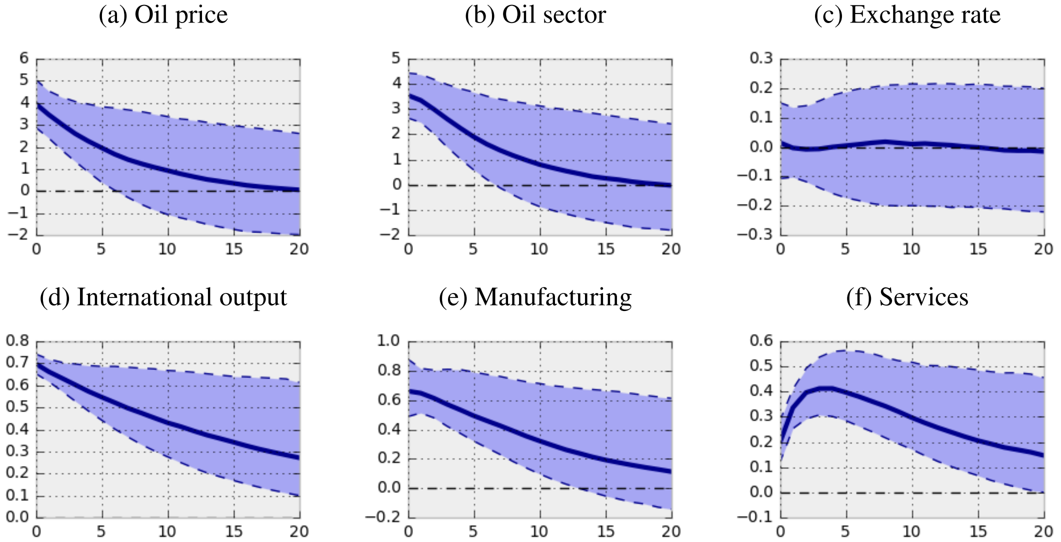
[5] In the appendix, we re-estimate the model using data for the OECD as a proxy for the rest of the world.

[6] We refer to the appendix for further details regarding our dataset.

[7] Results are similar if we use a Normal-Wishart prior or include two lags.

[8] Another plausible explanation is that oil-specific demand and supply disruptions have offsetting effects on international activity. As stated earlier, our oil price shock is likely a mix of the two.

Figure 2: International activity shock


(a) Oil price

(b) Oil sector

(c) Exchange rate

(d) International output

(e) Manufacturing

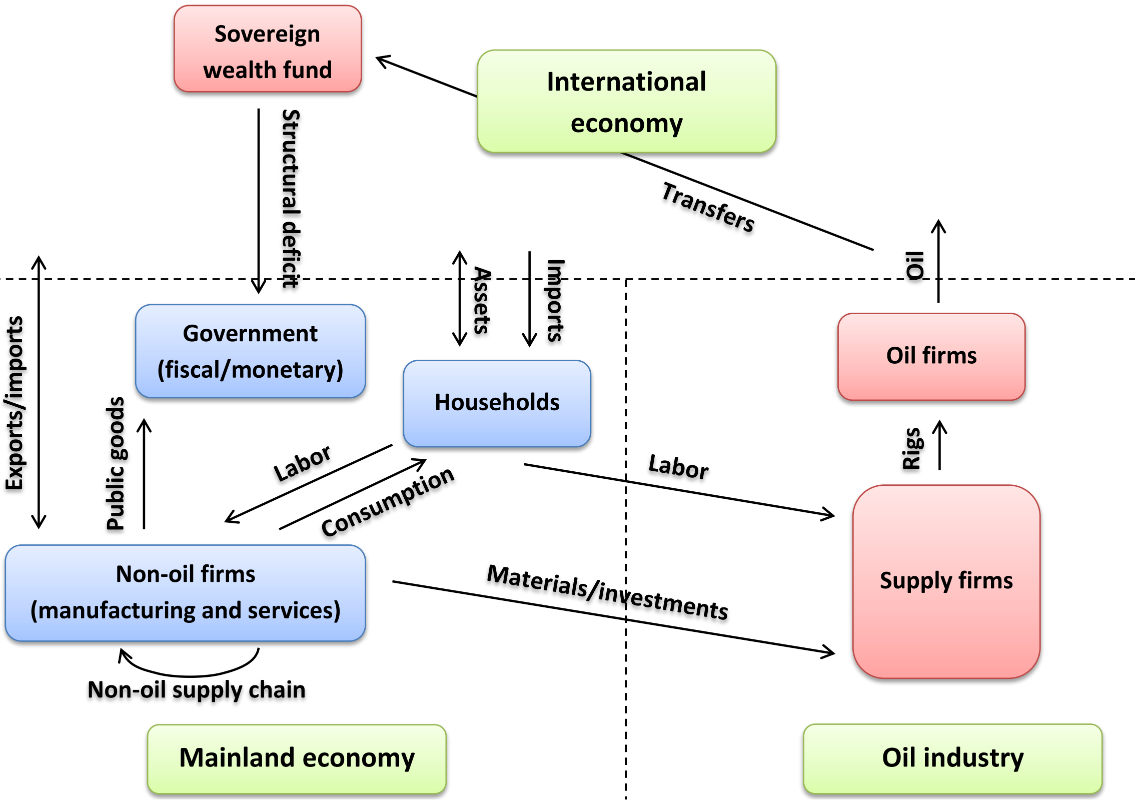
(f) Services

Note: Impulse responses to a one standard deviation shock to international activity. Calculations are based on 1000 draws from the posterior distribution. Median and 68 % credible bands.

Value added displays increases in all domestic sectors for a prolonged period of time, although the impact effect is muted in manufacturing and services (the latter is even slightly negative the first period). Note that activity in the oil sector responds substantially stronger than in mainland Norway, while activity in manufacturing increases more than in services. The latter observation contrasts with the view that windfall shocks crowd out traded industries. Our VAR model does not, however, provide any structural explanation for the large, positive effects on value added in manufacturing. Later we emphasize the importance of factor demand in the oil sector, which stimulates activity among manufacturing firms producing oil inputs (the supply chain channel). Turning to the international activity shock, we note that also this event causes positive spillover to the Norwegian economy. The point estimates for sectoral value added are higher on impact but at the same time less persistent, compared with the oil price shock. This suggests that oil price shocks, in terms of variance decompositions of value added, gain importance at longer horizons.

In sum, we draw two conclusions based on the preliminary VAR analysis: First, international oil price and activity shocks, in the way they are defined here, cause positive spillover to the Norwegian economy. Second, we do not find that oil price shocks crowd out manufacturing output, despite a rather strong exchange rate appreciation. Our preliminary conclusions rest upon a minimal set of identifying restrictions. However, these restrictions do not facilitate much economic inference. Important questions remain unanswered, including: (i) what are the structural disturbances underlying our VAR innovations? (ii) what are the main transmission channels at play? These questions are key for our understanding of the interactions between mainland Norway and the international economy. This is why the rest of the paper is devoted to the role of international shocks from the viewpoint of a medium-scale DSGE model.

Figure 3: A bird's eye view of the home economy



3 THE DSGE MODEL

In this section we describe our DSGE model for a resource-rich economy. A bird's eye view is provided in Figure 3. The home economy consists of a non-oil block – the mainland economy – and an oil industry. The mainland economy has two production sectors, manufacturing (subscript m) and services (subscript s). Both sectors provide consumption and investment goods for the home market and exports, and they engage in interindustry trade. The two sectors differ in terms of technologies and trade-intensities. The oil industry is comprised of oil extraction firms operating offshore (subscript o) and oil supply firms on the coast (subscript c). Extraction firms invest in the development of oil fields and sell the oil they produce in the international market. Supply firms combine primary inputs with materials from mainland industries to produce an investment good specific to oil extraction. Households supply labor, consume domestic and foreign goods, and save abroad. They also invest and rent out their capital to firms. The government saves oil tax revenues in a sovereign wealth fund, and it draws on the fund to finance a structural deficit. Several frictions are included in the model. Wage and price setting on the mainland is subject to nominal stickiness, and international trade is invoiced in the buyer's currency implying imperfect exchange rate passthrough. International capital flows are limited by a sovereign risk premium that depends on the net external position. Here we provide a brief summary of the most important model components with emphasis on the industrial structure in the home economy. Full details are given in an online appendix.

3.1 PRODUCTION

Production in sector $j \in \{c, m, s\}$ follows a constant returns to scale production function:

$$Y_{j,t} = Z_{j,t} X_{j,t}^{\phi_j} N_{j,t}^{\psi_j} K_{j,t}^{1-\phi_j-\psi_j}, \tag{1}$$

where $Y_{j,t}$ represents output, $X_{j,t}$ is intermediate inputs, $N_{j,t}$ denotes labor hours, $K_{j,t}$ is capital rented from households, and $Z_{j,t}$ is a sector-specific productivity shifter. Materials are a composite of sectoral goods produced in manufacturing and services, respectively:

$$X_{j,t} = \left[\zeta_j^{\frac{1}{\nu_j}} X_{mj,t}^{\frac{\nu_j - 1}{\nu_j}} + (1 - \zeta_j)^{\frac{1}{\nu_j}} X_{sj,t}^{\frac{\nu_j - 1}{\nu_j}} \right]^{\frac{\nu_j}{\nu_j - 1}} \tag{2}$$

where ζ_j is the share of manufacturing inputs, ν_j represents the elasticity of substitution between manufactured goods and services, and X denotes the use of the sectoral good as an intermediate input to production. In turn, sectoral goods from each sector are composites of domestic and imported goods (with subscripts H and F). For materials in sector j, we have:

$$X_{ij,t} = \left[\alpha_i^{\frac{1}{\eta}} X_{Hi,t}^{\frac{\eta - 1}{\eta}} + (1 - \alpha_i)^{\frac{1}{\eta}} X_{Fi,t}^{\frac{\eta - 1}{\eta}} \right]^{\frac{\eta}{\eta - 1}} \tag{3}$$

for $i \in \{m, s\}$, where α_i is the share of domestic goods, and η is the international elasticity of substitution. Thus, the aggregate import share of inputs into production in sector $j \in \{c, m, s\}$ depends on the share of secondary inputs in the sector's production function (ϕ_j), the sectoral weights in its materials (ζ_j), and the respective import shares in the sectoral goods from manufacturing and services (α_i for $i \in \{m, s\}$).

Cost minimisation gives rise to conditional factor demands so that each factor input is used up until the point where the marginal product equals the factor price. Demands for materials from each sector $j \in \{m, s\}$, and each country block H and F, are given by the conventional downward-sloping demand curves related to the CES aggregates in (2) and (3). In sum, relative factor demands become

$$\frac{N_{j,t}}{X_{j,t}} = \frac{\psi_j}{\phi_j} \frac{P_{rj,t}^x}{\Omega_{j,t}}, \quad \frac{K_{j,t}}{X_{j,t}} = \frac{1 - \phi_j - \psi_j}{\phi_j} \frac{P_{rj,t}^x}{R_t^k}, \quad \frac{X_{mj,t}}{X_{sj,t}} = \frac{\zeta_j}{1 - \zeta_j} \left(\frac{P_{rs,t}}{P_{rm,t}} \right)^{\nu_j} \tag{4}$$

with $X_{Hi,t}/X_{Fi,t} = (\alpha_i / 1 - \alpha_i) \left(P_{rHi,t}/P_{rFi,t} \right)^{-\eta}$ for $i \in \{m, s\}$. Here, $\Omega_{j,t}$ is the real sectoral wage, R_t^k is the rental rate of capital, $P_{rj,t}^x$ is the real price of materials used in sector j (in consumption units), $P_{rj,t}$ is the real price of sector j goods, and $P_{rHj,t}$ and $P_{rFj,t}$ are real prices of the home and foreign components respectively. Notice that imported inputs introduce a cost channel for exchange rate movements: changes in the price of foreign goods directly affect the cost of production across industries.

3.2 MAINLAND FIRMS

Mainland firms in sector $j \in \{m, s\}$ operate under monopolistic competition. They set separate prices for the home market and exports subject to a Calvo price-setting mechanism combined with partial indexation. Prices are set to maximize an expected stream of real dividends given by $\mathbb{E}_t \sum_{s=t}^{\infty} \mathcal{Z}_{t,s} \mathcal{D}_{j,s}$, where $\mathcal{Z}_{t,s}$ is the stochastic discount factor and real dividends are given as revenue minus costs: $\mathcal{D}_{j,t} = P_{rHj,t} A_{Hj,t} + P^*_{rHj,t} A^*_{Hj,t} - TC_{rj,t}$. Here, $A_{Hj,t}$ and $A^*_{Hj,t}$ denote absorption of output from domestic firms in sector j at home and abroad, respectively, and $P_{rHj,t}$ and $P^*_{rHj,t}$ are the associated relative prices (expressed in domestic currency). Absorption is the sum of demand from private and public consumption (C and G), private investment (I), and the use of materials in production. For example, $A_{Hj,t} = C_{Hj,t} + I_{Hj,t} + G_{Hj,t} + X_{Hc,t} + X_{Hm,t} + X_{Hs,t}$. Total real costs are given by factor payments so that $TC_{rj,t} = P^x_{rj,t} X_{jt} + \Omega_{j,t} N_{j,t} + R^k_t K_{j,t}$. The full set of optimality conditions are given in the online appendix. Here we note that, according to the output approach, real value added in sector j can be defined as $VA_{j,t} = P_{rHj,t} A_{Hj,t} + P^*_{rHj,t} A^*_{Hj,t} - P^x_{rj,t} X_{j,t}$. We may rewrite this expression according to the expenditure approach as $VA_{j,t} = P_{rj,t} \left(C_{jt} + I_{jt} + G_{jt} \right) + TB_{j,t} + SB_{j,t}$, where $TB_{j,t} = P^*_{rHj,t} A^*_{Hj,t} - P_{rFj,t} A_{Fj,t}$ is the sectoral trade balance with the rest of the world, and $SB_{j,t} = P_{rj,t} \left(X_{jct} + X_{jmt} + X_{jst} \right) - P^x_{rj,t} X_{j,t}$ is the sectoral trade balance with the rest of the domestic economy.[9] These input-output relations are important interindustry propagation channels in the model.

Sectoral goods are combined into aggregate goods for final uses through CES aggregators corresponding to (2). For example, the aggregate consumption bundle is given as

$$C_t = \left[\xi^{\frac{1}{\nu}} C_{m,t}^{\frac{\nu-1}{\nu}} + (1-\xi)^{\frac{1}{\nu}} C_{s,t}^{\frac{\nu-1}{\nu}} \right]^{\frac{\nu}{\nu-1}}, \tag{5}$$

where ξ is the share of manufactured goods, and ν is the elasticity of substitution between goods and services. Aggregate investment and government consumption are similarly defined with respective manufacturing shares of ϖ and ξ_g, and elasticities ν_i and ν_g. These definitions and associated demand relations allow us to define and express mainland GDP as:

$$GDP_t \equiv \sum_{j \in \{m,s\}} VA_{j,t} = C_t + P^i_{r,t} I_t + P^g_{r,t} G_t + TB_t + P^x_{rc,t} X_{c,t},$$

where $P^i_{r,t}$ and $P^g_{r,t}$ are the relative prices of aggregate investment and government spending, respectively, and TB_t is the non-oil trade balance with the rest of the world. Whilst cross-sectional trade balances between manufacturing and services cancel out, $P^x_{rc,t} X_{c,t}$ remains as a direct demand impulse from oil activity to the mainland economy. Thus, this expression highlights how activity in the oil industry spills over to the non-oil economy through the supply chain.

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[9] To derive this expression, we make use of the CES aggregator in (3) for all uses of sectoral goods, and of the associated demand relations. Alternatively, using the expression for dividends, we may rewrite the expression for sectoral GDP according to the income approach as $VA_{j,t} = \Omega_{j,t} N_{j,t} + R^k_t K_{j,t} + \mathcal{D}_{j,s}$.

3.3 Oil supply firms

Oil supply firms in sector c are specialized in the production of investment goods for domestic oil extraction. Hence, market clearing requires that $Y_{c,t} = I_{o,t} + M_{o,t}$, where $I_{o,t}$ represents gross investment in offshore oil fields, and $M_{o,t}$ are the costs associated with the maintenance of operative rigs. Supply firms operate under perfect competition. Their main role is to aggregate resources required for oil extraction, both from the mainland economy and from abroad. Hence, $P_{rc,t}$, the price of oil investment goods expressed in consumption units, is equal to real marginal costs:

$$P_{rc,t} = \frac{1}{Z_{c,t}} \left(\frac{P^x_{rj,t}}{\phi_c}\right)^{\phi_c} \left(\frac{\Omega_{j,t}}{\psi_c}\right)^{\psi_c} \left(\frac{R^k_t}{1-\phi_c-\psi_c}\right)^{1-\phi_c-\psi_c}.$$

Value added by oil supply firms is defined as output net of intermediate inputs:

$$VA_{c,t} = P_{rc,t}Y_{c,t} - P^x_{rc,t}X_{c,t} = (1-\phi_c)\, P_{rc,t}Y_{c,t}.$$

where the second equality follows after substituting in the conditional materials demand.

3.4 Oil extraction firms

Oil extraction in sector o requires reserves and oil rig services so that

$$Y_{o,t} = Z_{o,t} Q^{1-\alpha_o}_{o,t} \bar{F}^{\alpha_o}_{o,t}, \tag{6}$$

where $Y_{o,t}$ is oil extracted, $Z_{o,t}$ is a productivity shock specific to resource extraction, $Q_{o,t}$ is the available crude oil in the ground, and $\bar{F}_{o,t}$ represents effective oil rig services. As we abstract from issues of depletion and discovery, $Z_{o,t}$ and $Q_{o,t}$ are observationally equivalent. We therefore treat $Q_{o,t}$ as a constant so that $\alpha_o \in [0,1)$ implies decreasing returns to scale. Effective oil rig services are determined by the oil rig capacity in place, $F_{o,t}$, and the utilization rate of that capacity, $U_{o,t}$, according to $\bar{F}_{o,t} = U_{o,t}F_{o,t}$. Since $F_{o,t}$ is given in period t, the level of output can only be changed in the very short run by adjusting the rate of oil rig utilization. A higher utilization rate is associated with higher maintenance costs: $M_{o,t} = a\left(U_{o,t}\right) F_{o,t}$, where $a\left(U_{o,t}\right) = \gamma^1_o \left(U_{o,t} - 1\right) + \frac{\gamma^u_o \gamma^1_o}{2} (U_{o,t} - 1)^2$.

We use standard investment theory to characterize the dynamics of oil rig capacity:

$$F_{o,t+1} = (1-\delta_o)\, F_{o,t} + Z_{F,t} \left[1 - \Psi_o \left(\frac{I_{o,t}}{I_{o,t-1}}\right)\right] I_{o,t}, \tag{7}$$

where $\delta_o \in [0,1]$ represents the rate of depreciation, and $I_{o,t}$ denotes gross off-shore investments. The function $\Psi_o \left(\frac{I_{o,t}}{I_{o,t-1}}\right) = \frac{\epsilon_O}{2} \left(\frac{I_{o,t}}{I_{o,t-1}} - 1\right)^2$ captures adjustment costs associated with changes in oil investments. We interpret the shock to the marginal efficiency of investment, $Z_{F,t}$, as a marginal oil field discovery shock. A positive innovation leads to more operative oil rigs tomorrow for any given level of investment activity today.

Extraction firms take the prevailing oil price as given. Subject to extraction technology and the law of motion for oil rig capacity, the representative oil company operates to maximize an appropriately discounted expected stream of cash flows given by

$$\mathbb{E}_t \sum_{s=t}^{\infty} \mathcal{Z}_{t,s} \Pi_{o,t} = \mathbb{E}_t \sum_{s=t}^{\infty} \mathcal{Z}_{t,s} \left[\mathcal{S}_s P^*_{ro,s} Y_{o,s} - P_{rc,s} a \left(U_{o,s}\right) F_{o,s} - P_{rc,s} I_{o,s} \right].$$

Here, $\mathcal{Z}_{t,s}$ is the stochastic discount factor between period t and s, $\mathcal{S}_t$ is the real (consumption) exchange rate, and $P^*_{ro,t}$ is the real oil price defined in foreign currency and relative to the international consumer price level. Cash flows are seen to be large when the foreign currency is strong ($\mathcal{S}_t$ is high), or when the oil price ($P^*_{ro,t}$) or the level of oil production ($Y_{o,t}$) is high. But the price of investment goods ($P_{rc,t}$) also matters, and higher activity in the future comes at the cost of smaller margins today. The oil company first makes an intertemporal decision regarding the accumulation of future production capacity. Second, given the current capital stock, it sets the level of capacity utilization intratemporally.

Intertemporal optimality conditions with respect to $F_{o,t+1}$ and $I_{o,t}$ are stated below:

$$\mathcal{Q}_{o,t} = \beta \mathbb{E}_t \frac{\Lambda_{t+1}}{\Lambda_t} \left[\alpha_o \frac{\mathcal{S}_{t+1} P^*_{ro,t+1} O_{t+1}}{F_{o,t+1}} - P_{rc,t+1} a \left(U_{o,t+1}\right) + \mathcal{Q}_{o,t+1} \left(1 - \delta_o\right) \right] \tag{8}$$

$$\begin{aligned} P_{rc,t} = \mathcal{Q}_{o,t} Z_{F,t} & \left[1 - \Psi_o \left(\frac{I_{o,t}}{I_{o,t-1}} \right) - \Psi'_o \left(\frac{I_{o,t}}{I_{o,t-1}} \right) \frac{I_{o,t}}{I_{o,t-1}} \right] \\ & + \beta \mathbb{E}_t \frac{\Lambda_{t+1}}{\Lambda_t} \mathcal{Q}_{o,t+1} Z_{F,t+1} \Psi'_o \left(\frac{I_{o,t+1}}{I_{o,t}} \right) \left(\frac{I_{o,t+1}}{I_{o,t}} \right)^2 \end{aligned} \tag{9}$$

Equation (8) determines the present marginal value of oil rigs capacity, $\mathcal{Q}_{o,t}$, where Λ_t is the marginal utility of consumption and β is the time discount factor. At the margin, installing more oil rigs tomorrow will add revenues $\alpha_o \frac{\mathcal{S}_{t+1} P^*_{ro,t+1} O_{t+1}}{F_{o,t+1}}$. At the same time, maintenance costs will increase by $P_{rc,t+1} a \left(U_{o,t+1}\right)$. $\mathcal{Q}_{o,t+1} \left(1 - \delta_o\right)$ represents the continuation value net of rig depreciation. Equation (9) aligns the marginal cost of new investments, $P_{rc,t}$, with the marginal gain of more capacity in the next period. The first term on the right represents next period's gain from more capacity net of adjustment costs. The second term reflects that more investment today reduces the need for costly investment adjustments in the future. These forward-looking oil investment relations imply that the oil company bases its decisions on the entire expected future oil price path when undertaking investment projects to accumulate future production capacity.

The intratemporal optimality condition for oil rig utilization is given by

$$\alpha_o \mathcal{S}_t P^*_{ro,t} \frac{Y_{o,t}}{U_{o,t}} = P_{rc,t} a' \left(U_{o,t}\right) F_{o,t}. \tag{10}$$

Equation (10) states that the oil company increases the rate of utilization up until the point where marginal revenues from higher utilization equals marginal maintenance costs. Hence, in the short run, the oil company responds on the margin by adjusting the rate at which active rigs operate.

3.5 HOUSEHOLDS

Household finance their consumption and investment expenditures by means of labor income, rental income on capital, and transfers from the government. Capital accumulation by households is subject to investment adjustment costs. Households set wages subject to a Calvo wage-setting mechanism combined with partial indexation. Decisions are made to maximize life-time utility, which includes external habit formation. Household optimization gives rise to a fairly standard set of optimality conditions, which we derive in the online appendix. Here, we only emphasize a no-arbitrage condition in international asset markets, which is particularly important for the transmission of oil-related shocks through the exchange rate:

$$\mathbb{E}_t \left\{ \beta \frac{\Lambda_{t+1}}{\Lambda_t} \Pi_{t+1}^{-1} \left[R_t - \frac{\mathcal{E}_{t+1}}{\mathcal{E}_t} R_t^* \Upsilon \left(NFA_{t+1}, Z_{B,t}^* \right) \right] \right\} = 0.$$

Here, Π_t is CPI inflation and $\mathcal{E}_t$ is the nominal exchange, while R_t and R_t^* denote the risk-free interest rate at home and abroad, respectively. As in Adolfson et al. (2007), we include an endogenous risk premium on foreign returns, which depends on total net foreign assets, NFA_{t+1}, in deviation from steady state and relative to GDP, and is subject to a shock, $Z_{B,t}^*$: $\Upsilon \left(NFA_{t+1}, Z_{B,t}^* \right) = \exp \left(-\epsilon_B \frac{NFA_{t+1} - NFA}{VA} \right) Z_{B,t}^*$. The total net foreign asset position is the sum of private balances and the sovereign wealth fund.

3.6 THE PUBLIC SECTOR

Government authorities conduct fiscal as well as monetary policy. Our assumptions about these policies are motivated by the institutional setup in Norway. For monetary policy, we assume that the central bank operates in a flexible inflation targeting regime. We approximate this regime by a Taylor-type rule with interest rate smoothing:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R} \right)^{\rho_r} \left[\left(\frac{\Pi_t}{\Pi} \right)^{\rho_\pi} \left(\frac{GDP_t}{GDP_{t-1}} \right)^{\rho_y} \left(\frac{\mathcal{E}_t}{\mathcal{E}_{t-1}} \right)^{\rho_e} \right]^{1-\rho_r} Z_{R,t}. \tag{11}$$

As in Norway, we introduce flexibility in inflation targeting by putting a weight on mainland GDP. Following evidence on monetary policy in small open economies (e.g. Lubik and Schorfheide, 2007), we also allow the central bank to lean against nominal exchange rate movements. $Z_{R,t}$ is a monetary policy shock assumed to follow a white noise process.

On the fiscal side, the government finances expenditures with tax revenues from the mainland economy T_t, transfers from its wealth fund SBD_t, and new public debt D_{t+1}. There is a neutral tax rate τ_o on petroleum income. But revenues from this petroleum tax, $TR_t^o = \tau_o \Pi_{o,t}$, are transferred to the sovereign wealth fund, which invests solely in international markets. The government's intertemporal budget constraint is expressed below in terms of consumption units:

$$P_{r,t}^g G_t - D_{t+1} = T_t - R_{t-1} D_t \Pi_t^{-1} + SBD_t.$$

As in Norway, the fiscal authority draws a fraction ρ_o of the fund's value at the beginning of each period: $SBD_t = \rho_o R^*_{t-1}\frac{\mathcal{E}_t}{\mathcal{E}_{t-1}}\Pi_t^{-1}SWF_t$, where SWF_t denotes the foreign currency value of the fund rolled over after the previous period's transfers. The law of motion for the fund is given by

$$SWF_{t+1} = (1-\rho_o)\, R^*_{t-1}\frac{\mathcal{E}_t}{\mathcal{E}_{t-1}}\Pi_t^{-1}SWF_t + TR^o_t. \tag{12}$$

Our calibration of ρ_o ensures stationarity of the fund. Finally, we let public spending be a function of the state of the economy:

$$\frac{G_t}{G} = \left(\frac{G_{t-1}}{G}\right)^{\rho_g}\left[\left(\frac{GDP_t}{GDP_{t-1}}\right)^{\tau_{gy}}\left(\frac{SBD_t}{SBD}\right)^{\tau_{go}}\right]^{1-\rho_g} Z_{G,t}, \tag{13}$$

where $Z_{G,t}$ is a fiscal demand shock assumed to follow a white noise process.

3.7 OIL IN THE INTERNATIONAL ECONOMY

We model the global economy as a large, relatively resource-poor version of the small resource-rich exporter. The global economy also has a multi-sector structure, and international oil supply is given by the foreign counterpart to (6). But while we abstract from oil demand in the resource-rich economy,[10] oil is demanded by economic agents in the global economy as a consumption good and as a factor of production. Specifically, the aggregate consumption bundle consists of oil, $O^*_{c,t}$, in addition to core non-oil consumption, $\mathcal{C}^*_t$:

$$C^*_t = \left[\xi_o^{*\frac{1}{\varsigma_d^*}} O_{c,t}^{*\frac{\varsigma_d^*-1}{\varsigma_d^*}} + (1-\xi_o^*)^{\frac{1}{\varsigma_d^*}} \mathcal{C}_t^{*\frac{\varsigma_d^*-1}{\varsigma_d^*}}\right]^{\frac{\varsigma_d^*}{\varsigma_d^*-1}}, \tag{14}$$

where ξ^*_o is the oil share, and ς^*_d is the substitution elasticity of demand. Production in foreign sectors $j \in \{c, m, s\}$ requires oil inputs, $O^*_{yj,t}$, according to

$$Y^*_{j,t} = \left[\varphi_o^{*\frac{1}{\varsigma_d^*}} O_{yj,t}^{*\frac{\varsigma_d^*-1}{\varsigma_d^*}} + (1-\varphi_o^*)^{\frac{1}{\varsigma_d^*}} \mathcal{Y}_t^{*\frac{\varsigma_d^*-1}{\varsigma_d^*}}\right]^{\frac{\varsigma_d^*}{\varsigma_d^*-1}}, \tag{15}$$

with $\mathcal{Y}^*_t$ is given as the foreign counterpart to (1). These assumptions give rise household and firm demand schedules for oil:

$$O^*_{c,t} = \frac{\xi^*_o}{1-\xi^*_o} P^{*-\varsigma^*_d}_{ro,t}\,\mathcal{C}^*_t \qquad\qquad O^*_{yj,t} = \frac{\varphi^*_o}{1-\varphi^*_o}\left(\frac{P^*_{ro,t}}{RMC^*_{j,t}}\right)^{-\varsigma^*_d}\mathcal{Y}^*_{j,t} \tag{16}$$

for $j \in \{c, m, s\}$. Total oil demand is then $O^*_t = O^*_{c,t} + O^*_{yc,t} + O^*_{ym,t} + O^*_{ys,t}$. The oil price is determined in equilibrium as the price that clears the global oil market so that $Y^*_{o,t} = O^*_t$. This completes our model description.

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[10] Incidentally, cheap hydropower is also abundant in Norway.

4 ESTIMATION

Before taking the model to the data, we solve the dynamic system using standard methods. The solution procedure involves several steps: first, derive a recursive solution for the non-stochastic steady state. Second, calculate a log-linear approximation of the model around this steady state. Third, solve the resulting system of rational expectations equations in order to obtain a linear state-space representation. This representation is used for estimation. We estimate the DSGE model using Bayesian techniques. The approach has been popularized by e.g., An and Schorfheide (2007), Geweke (1999), and Smets and Wouters (2003, 2007).

4.1 DATA

Our dataset is quarterly and covers the period 1995Q1–2015Q4.[11] We use macroeconomic time series for Norway and EU28 in order to inform our model. All data are publicly available from Statistics Norway, Norges Bank, Eurostat, and OECD. Harmonized data on sectoral value added are available for all EU members, as well as Norway. These series allow us to disentangle sectoral dynamics. Moreover, EU28 accounts for most of Norway's international trade. Thus, EU28 serves as a proxy for the international economy from a Norwegian point of view.[12] Our non-oil observables are (for both Norway and EU28): Sectoral value added, core private consumption, investments, wages, consumer prices, and interest rates. Wages and prices are observed as nominal year-on-year growth rates. Domestic CPI and population are used as deflators.[13] Public consumption expenditures are added as an observable to the Norwegian dataset. This facilitates identification of fiscal policy. We also include some oil-specific variables, that is the oil price (Brent, from the Federal Reserve of St. Louis Economic Database), Norwegian oil production, and Norwegian oil investments (both from Statistics Norway). This leaves us with 19 observable variables – nine domestic, two off-shore, and eight international. The variables display several different trends not accounted for by the model. Thus, in line with common practice in the literature, we filter out trends in all quantity series. We choose to work with a backward-looking HP-filter ($\lambda = 1600$) which, consistent with agents' expectations in the model, does not exploit ex-post information about future data realizations. Finally, we allow for measurement errors in the foreign variables, as these are expected to represent a noisy measure of the international economy. The measurement errors are calibrated to capture 10% of the variance of each data series, as in Adolfson et al. (2007, 2008) and Christiano, Trabandt, and Walentin (2011). We use the model and the Kalman smoother to back out realized measurement errors. More details about the construction of observable variables are found in the appendix.

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[11] Norway's Government Pension Fund Global was established in 1996. Flexible inflation targeting was formally introduced in Norway in 2001, but Norges Bank (the Norwegian central bank) started adopting inflation targeting policies as early as in 1992. See Kleivset (2012) for documentation.

[12] As a robustness check we redo the analysis using OECD data in the appendix.

[13] The labor force, an alternative and perhaps better deflator, is not available for the EU28 countries.

Table 1: Calibration

Aggregate					
β	Time discount factor	0.991	ϵ_w, ϵ_p	Monopoly markup	0.2
φ	Inv. labor supply elasticity	1	δ	Capital depreciation	0.025
ν	Sectoral substitution elasticity	2	ϵ_B	Risk premium elasticity	0.005
τ_o	Tax rate on oil	0.8	ρ_o	Average quarterly fund transfer	0.01
ξ_o^*	Oil intensity, int. consumption	0.012	φ_o^*	Oil intensity, int. production	0.011
Sectoral mainland					
		(M), (S)			(M), (S)
ϕ_j	Materials share, gross output	0.50, 0.40	ξ	Consumption shares	0.40, 0.60
ψ_j	Labor share, gross output	0.35, 0.45	ξ_g	Public consumption shares	0.35, 0.65
γ_j^{ex}	Trade share, sector GDP	0.60, 0.21	ϖ	Investment shares	0.70, 0.30
ζ_j	I-O matrix materials	0.70, 0.30			
Oil industry					
α_o	Crude oil share, gross output	0.32	ϖ_c	Supply investment shares	0.54, 0.46
ϕ_c	Materials share, supply chain	0.48	ζ_c	Supply material shares	0.48, 0.52
ψ_c	Labor share, supply chain	0.22			

Note: Calibrated parameters in the benchmark model. The sectors are (M) manufacturing and (S) services.

4.2 CALIBRATION

We calibrate a subset of the parameters in the model. Calibrated values are given in Table 1. The time discount factor implies an annual real interest rate of about 3.6%. The Frisch elasticity φ^{-1}, markup parameters ϵ_w and ϵ_p, and the depreciation rate δ, are all set to standard values. We follow previous literature (e.g. Horvath (2000)) and set sectoral substitution elasticities to one. The risk premium elasticity is low, as in Adolfson et al. (2007). We use national accounts data to match the average share of oil and public expenditures in total GDP. The tax rate on oil is set to 0.8 (the actual tax rate is 0.78) while the average annual fund transfer is set to 4% (consistent with the fiscal rule in Norway).

Remaining parameters are sectoral and deserve further attention. We use a rich set of sectoral data obtained from Statistics Norway and EuroStat in order to calibrate the model. We set ϕ_j, ψ_j and ζ_j in order to match the sectoral expenditure shares in input-output table 1750 for the year 2013, publicly available from Statistics Norway. Based on the same source we choose ϖ to match sectoral investment shares. Sectoral consumption shares ξ and ξ_g, as well as sectoral trade shares γ_j^{ex} and γ_j^{im}, are calibrated based on average numbers in the national accounts for our data sample. We assume same depreciation rate (δ_o) in oil as in the non-oil economy. Given this number, we choose α_o in order to match the average cost share in petroleum. ϕ_c and ψ_c are obtained directly from Statistics Norway while ζ_c and ϖ_c are taken from Eika, Prestmo, and Tveter (2010).[14] Regarding foreign sector shares, we assume the same values as in Norway due to lack of available data. However, based on data from Eurostat for EU27, we choose ξ_o^* and φ_o^* in order to match an oil share in GDP of 3%, and a consumption share in total oil demand of 33%. The online appendix offers a comparison of selected steady state ratios in the model

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[14] See their tables 4.1 and 4.2.

with corresponding sample averages in the data. Most model ratios correspond closely to data: petroleum accounts on average for 21% of aggregate GDP, 45% of total exports, and 24% of investments. The private consumption share in aggregate GDP is relatively low (39%), and the public sector share relatively high (20%), compared with many other developed economies. These numbers illustrate the importance of petroleum activities for the Norwegian economy.

4.3 PRIORS AND POSTERIOR ESTIMATES

Remaining parameters are estimated based on Bayesian inference. Selected prior distributions are reported in Table 2. We choose the priors based on existing open economy DSGE literature, e.g. Adolfson et al. (2007), Christiano et al. (2011), and Justiniano and Preston (2010). Most distributions are standard but some remarks are appropriate. First, although our prior imposes symmetry across countries, the posterior does not. Second, microeconomic evidence suggests cross-sectoral variation in the degree of price stickiness (Bils and Klenow, 2004; Nakamura and Steinsson, 2008). Consistent with this view we put relatively more prior weight on low values for the Calvo parameters in manufacturing. Our prior for fiscal rule parameters τ_{gy} and τ_{go} is normally distributed around zero, implying that the process for public demand is a univariate AR(1). Regarding oil-related parameters, we define by ς_s^* the oil supply elasticity. This parameter is estimated directly, and we use the steady state identity $\gamma_o^u \equiv \frac{a''(1)}{a'(1)} = \frac{\alpha_o}{\varsigma_s^*} + \alpha_o - 1$ to back out γ_o^u. We center the prior for oil supply and demand elasticities around 0.3. This number is in the ballpark of suggestive VAR evidence (Baumeister and Peersman, 2013a; Kilian and Murphy, 2012), although quite high compared with assumptions used in some DSGE studies (e.g. Nakov and Pescatori (2010)). Finally, wage and price markup shocks are normalized so that they enter the New Keynesian Phillips curves with coefficients of unity. We use inverse gamma distributions with two degrees of freedom as priors for standard deviations of all shocks'. This implies infinite prior variances for the shocks' volatilities.

The joint posterior distribution is built using the random walk Metropolis-Hastings algorithm. We generate 3,000,000 draws and discard the first 2,000,000 as burn-in. The large number of draws is needed in order to obtain convergence. The jumping distribution used is tuned in order to get an acceptance rate of 30%. Table 2 summarizes the joint posterior distribution. Most parameters are found to be in line with those from previous studies. Most parameter estimates are also fairly similar when comparing economies, although estimated wage stickiness is higher abroad while prices are more sticky in Norway. The posterior points to large differences in the degree of price stickiness across sectors in Norway. Consistent with microeconomic evidence, our model suggests that prices in services change on average only about every 10th quarter. Also, the posterior weight on inflation in the Taylor rule is quite low in EU28, perhaps a result of the long period with low interest rates in our sample. The fiscal parameters τ_{gy} and τ_{go} have posterior distributions centered around 0.07-0.16, implying limited transmission from oil prices via fiscal policy. Regarding elasticities in the oil sector, we find that the supply elasticity is close

Table 2: Prior and posterior distributions

		Prior	Posterior domestic and oil			Posterior foreign		
		Prior(P1,P2)	Mode	Mean	5%-95%	Mode	Mean	5%-95%
χ_C	Habit	B(0.70,0.10)	0.80	0.80	0.69-0.91	0.74	0.82	0.76-0.87
ϵ_I	Inv. adj. cost	G(5.00,1.00)	4.70	4.47	3.44-5.49	4.85	5.33	4.22-6.33
θ_w	Calvo wages	B(0.65,0.07)	0.82	0.82	0.76-0.88	0.95	0.94	0.92-0.96
ι_w	Indexation, π_w	B(0.30,0.15)	0.48	0.46	0.25-0.69	0.13	0.15	0.05-0.25
θ_{pm}	Calvo manu.	B(0.45,0.07)	0.79	0.76	0.71-0.82	0.45	0.41	0.31-0.52
θ_{ps}	Calvo serv.	B(0.65,0.07)	0.87	0.86	0.83-0.90	0.72	0.71	0.62-0.81
ι_p	Indexation, π_p	B(0.30,0.15)	0.10	0.19	0.05-0.34	0.25	0.45	0.27-0.64
ρ_r	Smoothing, r	B(0.50,0.10)	0.84	0.83	0.80-0.87	0.80	0.80	0.76-0.85
ρ_π	Taylor, π	N(2.00,0.20)	1.93	2.11	1.80-2.42	1.48	1.37	1.19-1.55
ρ_{de}	Taylor, Δe	N(0.10,0.05)	0.11	0.08	0.03-0.15	–	–	–
ρ_y	Taylor, gdp	N(0.13,0.05)	0.14	0.17	0.09-0.25	0.12	0.16	0.09-0.25
η	H-F elasticity	G(1.00,0.15)	0.47	0.52	0.45-0.58	–	–	–
τ_{gy}	Fiscal, gdp	N(0.00,0.15)	0.16	0.13	-0.04-0.29	–	–	–
τ_{go}	Fiscal, swf	N(0.00,0.15)	0.07	0.10	-0.01-0.19	–	–	–
ρ_g	Fiscal, g	B(0.50,0.15)	0.61	0.69	0.56-0.81	–	–	–
ϵ_O	Inv. adj. cost oil	G(5.00,1.00)	7.03	5.88	4.27-7.32	–	–	–
ς_d^*	Oil demand elast.	G(0.30,0.15)	–	–	–	0.09	0.17	0.06-0.30
ς_s^*	Oil supply elast.	G(0.30,0.15)	–	–	–	0.03	0.02	0.01-0.03
ρ_A	Technology	B(0.35,0.15)	0.48	0.44	0.32-0.57	0.95	0.93	0.90-0.96
ρ_I	Investment	B(0.35,0.15)	0.23	0.32	0.14-0.48	0.85	0.81	0.70-0.91
ρ_U	Preferences	B(0.35,0.15)	0.30	0.53	0.29-0.79	0.74	0.68	0.51-0.86
ρ_W	Wage markup	B(0.35,0.15)	0.56	0.54	0.40-0.71	0.34	0.31	0.14-0.45
ρ_M	Price markup	B(0.35,0.15)	0.75	0.73	0.65-0.81	0.85	0.78	0.65-0.92
ρ_B	UIP	B(0.50,0.15)	0.86	0.90	0.85-0.94	–	–	–
ρ_F	Oil investment	B(0.50,0.15)	0.85	0.79	0.70-0.88	–	–	–
ρ_{Ao}	Oil supply	B(0.50,0.15)	0.78	0.76	0.66-0.85	0.93	0.91	0.87-0.95
σ_{Am}	Sd tech. manu.	IG(0.50,2.00)	2.14	2.13	1.77-2.48	0.55	0.50	0.34-0.66
σ_{As}	Sd tech. serv.	IG(0.50,2.00)	3.38	3.65	3.11-4.17	0.71	0.83	0.59-1.07
σ_I	Sd investment	IG(0.50,2.00)	10.55	9.07	6.57-11.78	1.21	1.39	0.80-1.99
σ_U	Sd preferences	IG(0.50,2.00)	3.97	4.53	2.35-6.79	1.30	1.67	1.04-2.29
σ_G	Sd government	IG(0.50,2.00)	0.89	0.86	0.74-0.97	–	–	–
σ_W	Sd labor supply	IG(0.10,2.00)	0.23	0.25	0.18-0.31	0.13	0.15	0.10-0.20
σ_{Mm}	Sd markup manu.	IG(0.10,2.00)	0.38	0.44	0.29-0.59	0.17	0.19	0.07-0.30
σ_{Ms}	Sd markup serv.	IG(0.10,2.00)	0.13	0.12	0.08-0.17	0.11	0.16	0.08-0.23
σ_R	Sd mon. pol.	IG(0.02,2.00)	0.17	0.16	0.14-0.19	0.15	0.14	0.11-0.17
σ_B	Sd UIP	IG(0.50,2.00)	0.33	0.28	0.21-0.34	–	–	–
σ_F	Sd oil inv.	IG(0.50,2.00)	9.47	9.86	6.53-12.87	–	–	–
σ_{Ao}	Sd oil supply	IG(0.50,2.00)	2.75	2.87	2.49-3.24	1.12	2.13	0.66-3.84

Note: Posterior moments are computed from 3,000,000 draws generated by the Random Walk Metropolis-Hastings algorithm, where the first 2,000,000 are used as burn-in. B denotes the beta distribution, N normal, G gamma, and IG inverse gamma. P1 and P2 denote the prior mean and standard deviation. For IG, P1 and P2 denote the prior mode and degrees of freedom, respectively. Shock volatilities are multiplied by 100 relative to the text.

to zero, in line with arguments put forward by Kilian and Murphy (2012). The estimated demand elasticity is somewhat lower than that found in the DSGE model by Bodenstein, Erceg, and Guerrieri (2011) for the US economy, but higher than in recent empirical studies (Baumeister and Peersman, 2013a,b). Turning to the shock processes we get highly persistent TFP shocks abroad, suggesting that they can be important at longer horizons. Investment efficiency shocks are the most volatile, but one should have in mind that their impact elasticity – the capital depreciation rate – is low. In total, there is a tendency of more volatile domestic innovations, while at the same time more persistence in the foreign business cycle shocks. Smoothed shock series are reported in the appendix. We note that all shocks in our sample fluctuate around zero.

4.4 MODEL FIT

Given the large number of observables and the tight restrictions embedded in the model, it is a massive challenge to fit all the properties of data. Following Adolfson et al. (2007), we gauge the model's fit by comparing observable variables with one step ahead predicted values from the model. The one sided Kalman filter is used to generate predictions. Figure 4 reports posterior median estimates. Most predictions look reasonable: the model is able to track the large decline in GDP and other real variables around 2008-2009, and it does so without having to sacrifice the fit of inflation series and the exchange rate (which moved little during the crisis). However, for some variables we observe systematic biases. Inflation in EU28, for instance, is associated with an upward trend in the forecast errors. The model also fails to account for the relatively high levels of oil production in Norway towards the end of the sample. Regarding oil prices, the model misses out on the post-crisis rise, as well as the recent fall. We attribute these discrepancies to the high oil price volatility in data – high compared with that called for by economic mechanisms in the model. Some oil price volatility is soaked up by international oil supply shocks, some comes about due to low estimated demand and supply elasticities, and some is attributed by the model to unusually large shocks in the selected data sample. For completeness we also report the international variables before measurement errors are taken out. The Kalman filter interprets certain large fluctuations in data as noise. However, perhaps except for the oil price we do not find a significant role for measurement error in our sample.

As an alternative measure of fit, we compare the empirical cross-correlation functions with those based on model simulations. This is done as follows: for every 1000 draw from the posterior MCMC chain, we perform 100 stochastic simulations, each of 500 periods. For every simulation we save a subsample of the same size as the data sample and calculate moments of interest. Results are reported in the online appendix. Note first that the model predicts substantial business cycle co-movement across countries. This is promising given DSGE models' limited ability to account for international business cycle synchronization (see Justiniano and Preston (2010) and Bergholt (2015)). However, the figures also reveal that some variables, in particular domestic consumption and GDP, are too persistent compared with data. Others, like the exchange rate, are not persistent enough. These observations illustrate important trade-offs during estimation – the model has to strike a balance between all the different empirical moments. Nevertheless, our overall assessment is that it provides a reasonable description of data, and the fit is comparable with that of other estimated models for small open economies.

Figure 4: Data versus one step ahead filtered estimates (median)

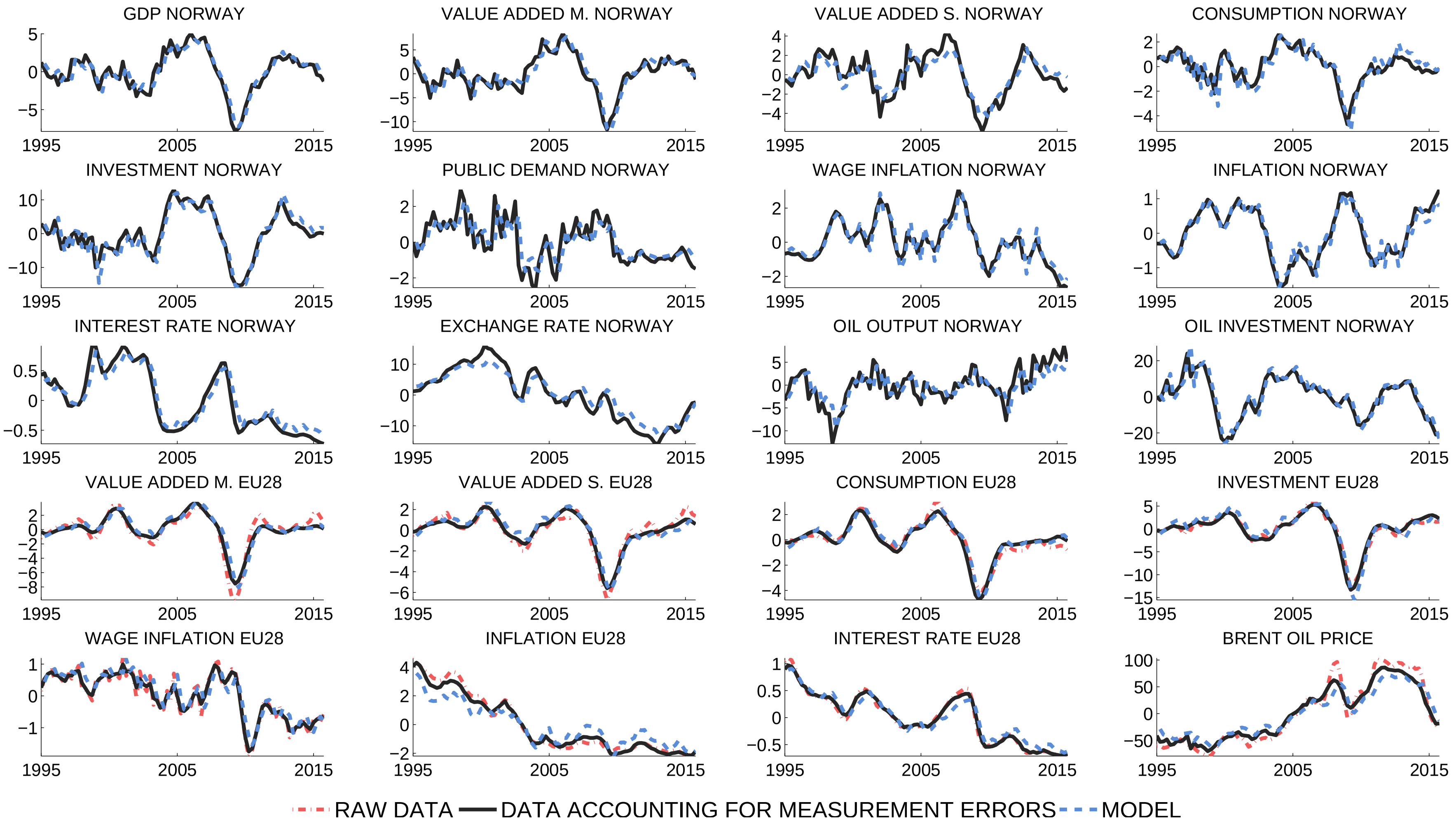
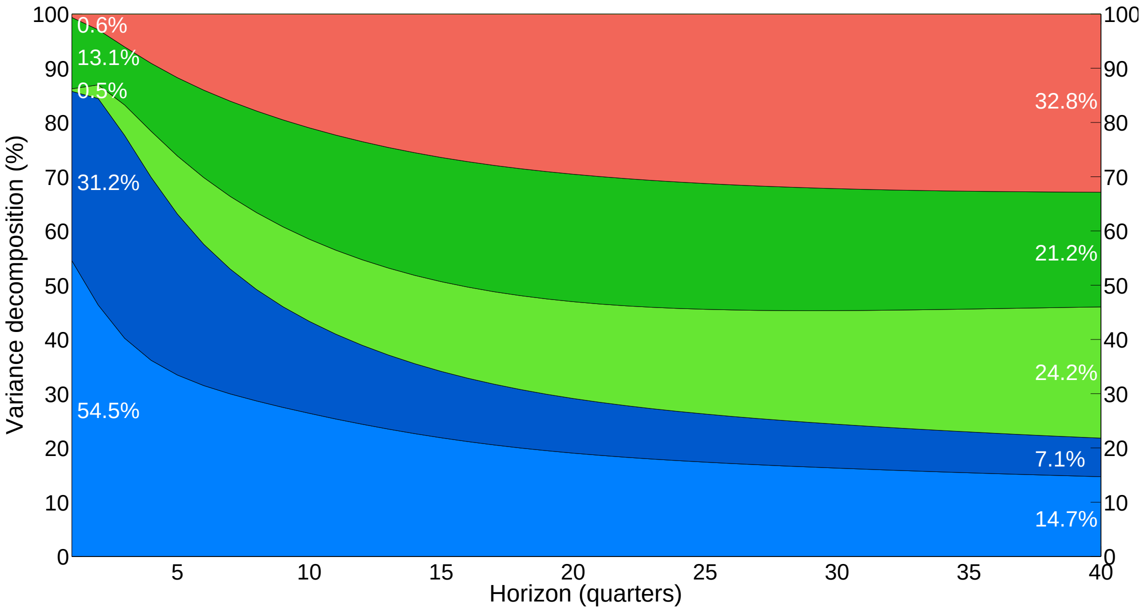


Figure 5: Forecast error variance decomposition of mainland GDP



Note: Forecast error variance decomposition of GDP in mainland Norway. Calculated at the posterior mean. Shocks are decomposed as follows: Domestic supply shocks (light blue), domestic demand shocks (dark blue), international supply shocks (light green), international demand shocks (dark green), and shocks in oil markets (light red). Numbers in white at the left and right hand side are decompositions at the 1- and 40-quarter horizons, respectively.

5 BUSINESS CYCLE ANALYSIS

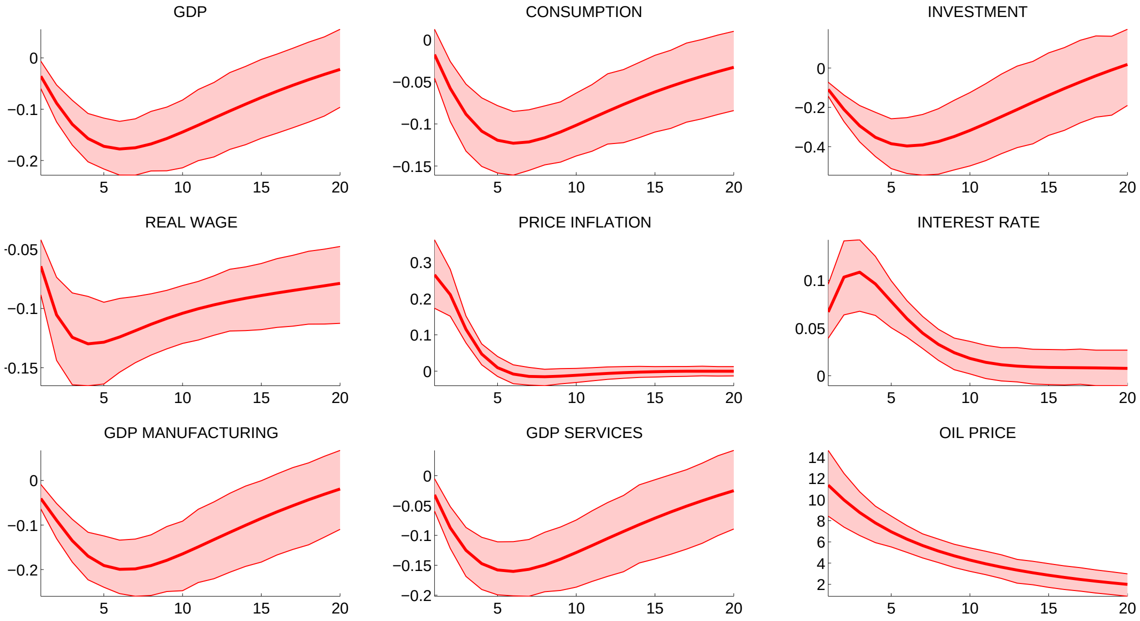
Having discussed the model's ability to fit data, we now turn to the analysis of its macroeconomic implications. This section documents the importance of international oil and non-oil shocks for the Norwegian business cycle, as implied by the estimated model. We decompose macroeconomic fluctuations into the parts attributed to specific shocks, and analyze how selected international disturbances transmit into the mainland economy.

5.1 VARIANCE DECOMPOSITIONS

Figure 5 shows the forecast error variance decomposition (FEVD) of mainland GDP at different business cycle horizons. Historical decompositions of all the shocks are provided in the appendix. The contribution of shocks to the international and Norwegian oil industries (oil extraction productivity shocks and Norwegian oil investment efficiency shocks) is shown in red. We label innovations to TFP in mainland industries as well as to wage and price markups as supply shocks. Domestic supply shocks are shown in light blue, and foreign supply shocks in light green. We refer to the remaining non-oil shocks as demand shocks. Domestic (foreign) demand shocks are shown in dark blue (green).

In the very short run (one quarter), about 85% of the unexpected volatility in mainland Norway can be traced back to domestic shocks. Of these, both supply and demand factors are important, in particular innovations to sectoral TFP and investment efficiency. Oil

Figure 6: International responses to an international oil price shock



Note: Bayesian impulse responses of international variables to an international oil price shock (one standard deviation). Mean (solid line) and 90% highest probability intervals (shaded area) based on every 1000th draw from the posterior MCMC chain. Inflation and the interest rate are expressed in annual terms.

shocks and foreign shocks, in contrast, account for only a minor share of the volatility at short horizons. But the importance of shocks outside mainland Norway rises as the forecasting horizon expands. At the 5-year horizon, for example, foreign supply and demand shocks account for about 40% of the fluctuations in GDP, substantially more than found in e.g. estimated small open economy models for the Swedish economy (Adolfson et al., 2007; Christiano et al., 2011). Moreover, disturbances in the oil industry, particularly shocks to foreign oil extraction productivity, also become more important as the forecasting horizon increases. Beyond the 5-year horizon, oil shocks account for more than 30% of fluctuations in Norwegian mainland GDP.

We emphasize that the contribution of oil shocks in Figure 5 understates the importance of oil price movements for the Norwegian business cycle. This is because the model attributes up to a quarter of oil price volatility to conventional business cycle events in the global economy.[15] Oil price fluctuations caused by non-oil disturbances create volatility in mainland Norway through supply chain links to the oil industry and the exchange rate. But these fluctuations are not understood by the model as oil shocks per se. Rather, they are interpreted as demand shocks from the point of view of oil producers. This observation also helps explain why foreign shocks are more important for Norway than results reported for other small open economies would suggest. In sum, our results support the view that oil shocks, and movements in the oil price more generally, are important factors behind macroeconomic fluctuations in mainland Norway.

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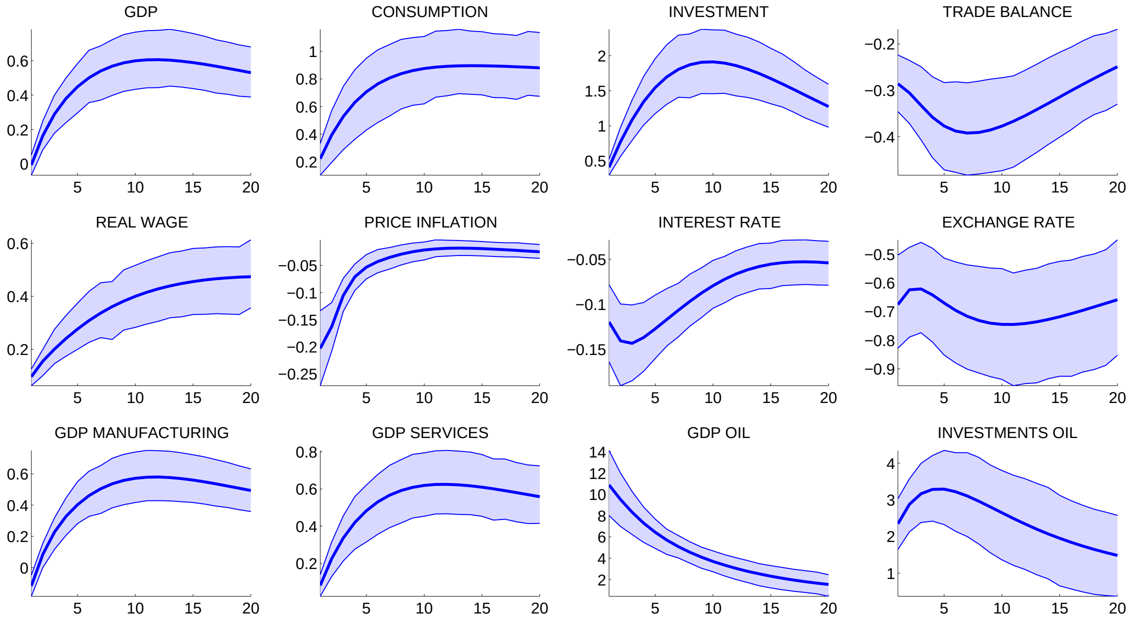
[15] In other words, the model predicts that a quarter of oil price volatility is demand-driven. This is less than in some VAR studies, but more than in most estimated DSGE models (e.g. Nakov and Pescatori (2010)).

Figure 7: Domestic responses to an international oil price shock



Note: Bayesian impulse responses of domestic variables to an international oil price shock (one standard deviation). Mean (solid line) and 90% highest probability intervals (shaded area) based on every 1000th draw from the posterior MCMC chain. All variables except value added and investments in oil are from the mainland economy. Inflation and the interest rate are expressed in annual terms.

5.2 ON THE TRANSMISSION TO MAINLAND NORWAY

We now turn to the transmission of international shocks to mainland Norway. First, we analyze an international oil supply shock. We will sometimes refer to this shock simply as an oil price shock.[16] Second, we study an international investment shock – an important demand shifter in our model.

5.2.1 INTERNATIONAL OIL PRICE SHOCKS

Figure 6 shows the estimated responses of all foreign observables to a drop in international oil productivity. Several contractionary effects are at play. On the firm side, the cost effect of higher oil prices implies rising inflation as firms want to stabilize their markups. Monetary authorities increase policy rates and the entire real interest rate path shifts up. On the household side, aggregate demand declines as a result of higher real interest rates. Although non-oil consumption becomes cheaper relative to oil, the substitution effect is quantitatively small (due to low estimated substitution elasticity) and also non-oil consumption drops. Thus, the oil price shock causes a contraction in demand as well as supply in the international economy.

Figure 7 shows the implications for observables in Norway.[17] The oil price shock is

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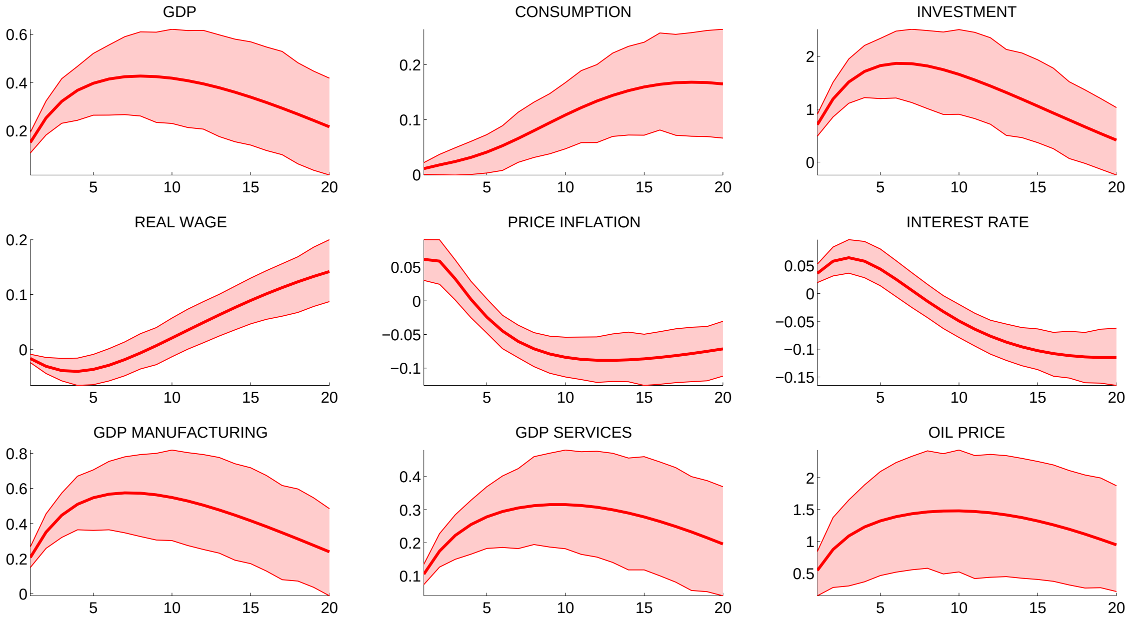
[16] Oil specific demand and supply disturbances as identified by Kilian (2009) and others are observationally equivalent in our setup (they have the same qualitative implications for our set of observables).

[17] Impulse responses to selected unobservables in the oil industry are shown in the online appendix.

Figure 8: International responses to an international investment efficiency shock



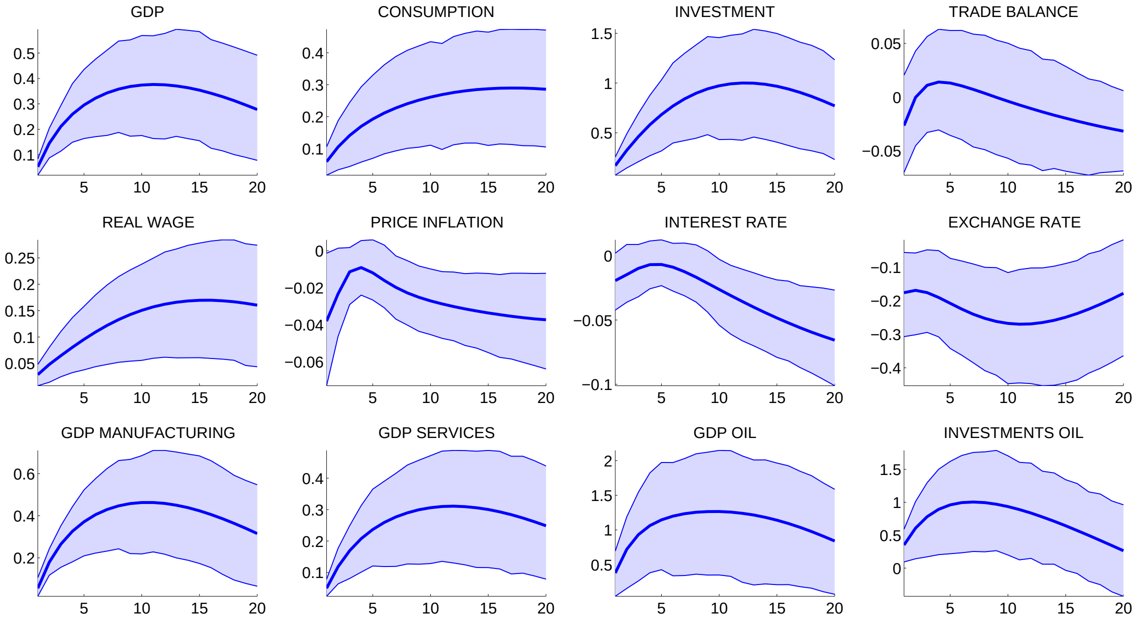
Note: Bayesian impulse responses to an international investment efficiency shock (one standard deviation). See Figure 6 for details.

associated with a prolonged period of higher economic activity. Mainland GDP peaks after three years at around 0.6%. This domestic boom occurs despite the recession in the global economy induced by the shock. It is the result of rising demand, in large part due to a stronger need for productive inputs in the oil industry.

The transmission mechanism is as follows. In the short run, oil extraction firms respond to the increase in the oil price by increasing the utilization of existing oil fields. Such adjustments are costly, however, and the initial production response is muted. But oil extraction firms are forward-looking and base their decisions on the entire expected path for the oil price. As the oil price increases persistently, the present marginal value of offshore capital increases above the price of new investments. Extraction firms therefore respond by increasing investments in oil fields. Since adjustments to the capital stock are also very costly, this process is slow and leads to highly persistent dynamics in the oil industry. The increase in oil investments leads to a persistent increase in the demand for supplies from the oil supply sector. In turn, supply firms respond by increasing their own input factors. Hence, the use of materials and investment goods from manufacturing and service firms increase as does employment. This is the supply chain channel through which activity in the oil industry spills over to the mainland economy.

Like a typical demand shock, the increase in the oil price generates co-movement of key macroeconomic variables. Real wages, investment and consumption increase along with output after the international oil productivity shock. But unlike the effects of a typical demand disturbance, we get a substantial strengthening of the real exchange rate and an initial drop in inflation. With higher oil revenues, the home country's net international asset position improves and its assets are perceived to be less risky. This improvement

Figure 9: Domestic responses to an international investment efficiency shock



Note: Bayesian impulse responses to an international investment efficiency shock (one standard deviation). See Figure 7 for details.

leads to an immediate jump in the exchange rate. In turn, some of the appreciation passes through to consumer prices. CPI inflation is affected both directly through imported inflation and indirectly through the effect on domestic prices. As the exchange rate appreciates, imported materials become cheaper. This reduces costs at home, particularly in the trade-intensive manufacturing sector, and firms respond by reducing prices in the first periods after the shock. Monetary authorities, trying to bring inflation back to target, respond by lowering policy rates. These developments are associated with a downward shift in the real interest rate path, further supporting aggregate demand.

The combination of weak international demand, strong domestic demand and a strong exchange rate, which induces international substitution towards foreign goods, leads to a persistent non-oil trade deficit. This deficit is driven, mostly, by the trade-intensive manufacturing sector. Initially, manufacturing output falls slightly. But in contrast to the Dutch Disease hypothesis (Corden and Neary, 1982), both manufacturing and services output increase and over time display fairly similar dynamics. The reason is that both sectors provide inputs to the supply chain. Dutch Disease effects are effectively eliminated by manufacturing firms' reorientation towards the domestic oil industry.

5.2.2 INTERNATIONAL INVESTMENT SHOCKS

Next we analyze the effects of an international investment shock.[18] International responses are shown in Figure 8. The shock causes an international boom, in particular

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[18] This shock implies higher investment efficiency abroad, and thus, higher investment demand than implied by capital returns and investment prices.

among manufacturing firms who produce most investment goods. Consumption is in part crowded out by investments, and in part stimulated by expected future capital abundance. The latter effect eventually dominates, according to our model, and the demand components increase along with output. As oil is used both in production and consumption, the demand for oil increases and the market clearing oil price goes up. Hence, in contrast to the oil supply shock, the investment shock delivers an increase in the oil price which resembles a demand-driven business cycle in the international economy.

Dynamics in the oil-exporting economy are plotted in Figure 9. Again, domestic activity increases persistently and mainland GDP peaks after about three years. But now, the mainland economy is stimulated both by an increase in the oil price, transmitting through the oil industry as described above, and by a global expansion, which increases demand for home manufacturing and services exports. The persistent increase in the oil price leads to a substantial improvement in the overall external position, which explains why the exchange rate appreciates. The appreciation, in turn, has a series of interesting implications: domestic inflation declines, as do nominal and real interest rates. This stimulates consumption and investment demand.

As after the oil supply shock, key macroeconomic variables co-move following the international investment shock. In fact, we emphasize that the responses in the mainland economy are qualitatively similar following the two shocks despite the very different implications for the global economy. What seems to matter for dynamics in the Norwegian economy is the response of the oil price. Despite a global expansion, the boost to domestic activity is actually smaller following the international investment shock than after the oil supply shock. The reason for this is the more muted oil price response to a typical investment shock.

5.2.3 CONDITIONAL PASS-THROUGH TO MAINLAND GDP

To shed further light on the question of whether the propagation of oil price fluctuations depends on the underlying structural disturbances, Table 3 lists the peak responses of mainland GDP to the international shocks in the model. All innovations are normalized such that the oil price jumps by 10%. Notice that the mean response of mainland GDP is positive regardless of the shock considered: an increase in the oil price increases mainland GDP in all but a few exceptional cases. The supply chain channel dominates Dutch Disease effects in most situations. But there is substantial variation across shocks. Also the time from when a shock occurs to the peak in GDP differs across shocks, from four quarters for markup innovations in manufacturing to three years for oil supply disruptions. Hence, the ultimate source of disturbances is by no means irrelevant for the quantitative implications for the mainland economy. A shock to international investment efficiency that increases the oil price by as much as an oil supply shock has a much larger effect on mainland GDP. An oil price rise driven by productivity in international manufacturing has a particularly large effect on mainland GDP. The reason is that the oil price increase is associated with a substantial boom in the global economy in this case. One should have

Table 3: Peak response of mainland GDP to 10% oil price increase

	Response of mainland GDP		
Underlying international shock	*Mean*	*HPD interval*	*# lags*
Oil supply	0.53	(0.39-0.68)	12
Manufacturing productivity	3.12	(1.40-4.79)	7
Service productivity	1.07	($-$0.43-2.38)	6
Investment demand	2.54	(1.10-3.84)	11
Consumption demand	1.39	(0.67-2.07)	12
Labor market	2.58	(1.32-3.92)	10
Manufacturing markup	1.77	(0.13-3.44)	4
Service markup	0.63	($-$0.23-1.46)	5
Monetary policy	2.14	(1.10-3.04)	9

Note: Pass-through from oil price to mainland GDP. Defined as the peak response of GDP when the oil price increases 10%, conditional on a given shock. Based on every 1000th draw from the posterior MCMC chain. HPD interval represents the 90% highest probability interval. # lags denotes the number of periods from the shock to the peak response.

in mind, however, that many of the shocks considered here play only a minor role for oil price fluctuations. Large oil price movements are often driven by oil supply shocks in our model. By contrast, a productivity shock in international manufacturing of a magnitude required to induce a 10% oil price change is hardly ever seen in our data.

6 INSPECTING THE MECHANISMS

This section inspects selected mechanisms at play in transmitting oil price shocks to the mainland economy. To this end we simulate the posterior model, but with alternative assumptions regarding some key parameters. The exercise is based on the implicit assumption that our baseline model reflects the true structure of the economy. Our aim here is to highlight, ceteris paribus, some potentially important transmission channels. We acknowledge, however, that policy parameters are likely to change in practice when the economic structure is altered. Selected impulse responses are reported in Figure 10.[19]

6.1 FISCAL POLICY

First we ask to what extent the fiscal regime in Norway helps shield the domestic economy from volatility in international commodity markets. Key features of the current regime are a sovereign wealth fund and a public spending rule for oil wealth. Hence, in the baseline model all public oil revenues are transferred to a fund, which invests solely in international markets. Only about 4% of the fund's value is used every year to finance

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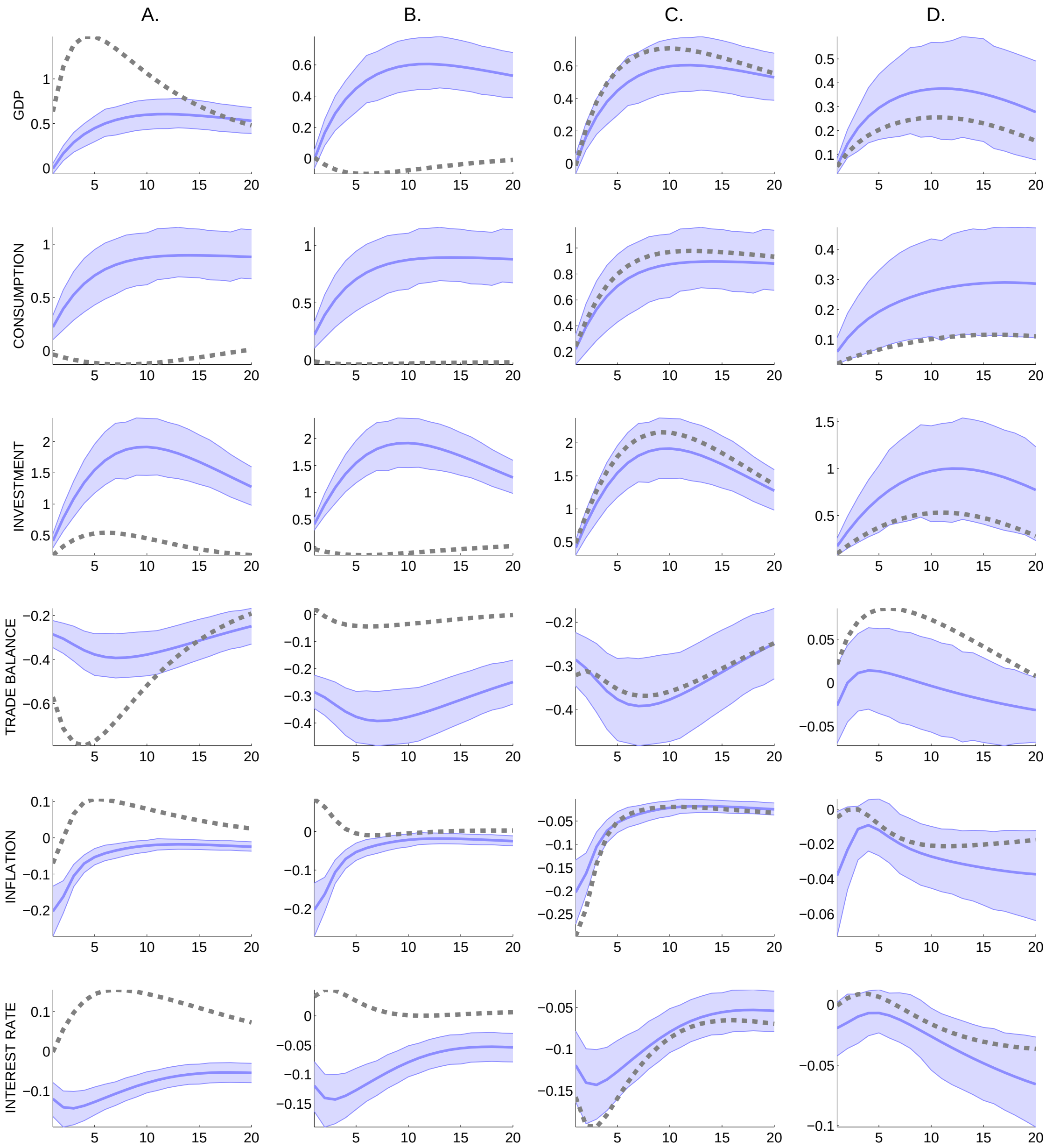
[19] The full set of impulse responses is provided in the appendix. We refer to these throughout the discussion in this section.

Figure 10: Counterfactual dynamics



Note: Bayesian impulse responses to international shocks (one standard deviation). Baseline model (blue) and counterfactual simulations (gray). Column A: An international oil price shock without the sovereign wealth fund. Column B: An international oil price shock without the supply chain. Column C: An international oil price shock without feedback to macro. Column D: An international investment shock without feedback to oil. See Figure 7 for details.

public expenditures in line with the institutional setup in Norway. We now simulate the model conditional on a vastly different fiscal regime: instead of saving for the future, we assume that all oil revenues are spent on a continuous basis by fiscal authorities. The rest of the model is left unchanged.

Column A in Figure 10 contrasts the impulse responses to an oil price shock under this counterfactual with those from the baseline estimation. Now mainland GDP increases more than twice as much as in the baseline model with a sovereign wealth fund, driven by the spike in public demand. Monetary policy increases the interest rate in order to stabilize output and bring inflation back to target. Private consumption is crowded out by the public sector and actually falls, while non-oil investments display a much more muted response. Hence, the dynamics in the mainland economy are dramatically altered by the change in fiscal regime. The role of oil price shocks for GDP, under this regime, increases to 25% at the one-quarter horizon and 47% in the long run. Note also that the symmetry of the model would imply an equally dramatic recession in the case of an oil price fall.

6.2 THE SUPPLY CHAIN

Next we study the importance of the supply chain channel. Column B in Figure 10 reports the impulse responses to an oil supply shock when we assume that oil can be extracted without the use of mainland inputs. In our model, this assumption corresponds to setting $\alpha_o = 0$. Now, oil revenues increase one-to-one with the oil price. But because all oil revenues are transferred to the sovereign wealth fund, the mainland economy is only affected by oil price movements via expected future government spending and exchange rate adjustments to the net asset position. The differences to responses in the baseline model are striking: mainland GDP, consumption and investment all fall when the supply chain is shut down, while CPI inflation and the interest rate increase.

The intuition behind the drop in domestic GDP is as follows. In our baseline model, higher oil prices lead to lower activity in the international economy, but also to rising factor demand in the oil industry. Rising factor demand is, from the point of view of mainland firms, a positive demand shock. In the baseline model, such factor demand impulses dominate the international recession. But in absence of positive demand effects from oil supply firms, the contractionary effects in the international economy come to dominate. An improved asset position driven by higher oil revenue transfers to the sovereign wealth fund only works to worsen the international competitiveness of mainland industries through upward pressure on the exchange rate.

6.3 ON THE TWO-WAY CAUSALITY BETWEEN OIL AND MACRO

Finally, we turn to the implications for our oil-exporting economy of ignoring the endogenous interactions between oil and macro in the international economy. We do this in two ways. First, we show the impulse responses in the Norwegian mainland economy to a foreign oil supply shock without feedback to the macroeconomy abroad. Second, we show responses to a foreign business cycle shock without feedback to the oil price. These exercises effectively assume an exogenous AR(1) process for the real oil price as is commonly assumed in the theoretical literature (Blanchard and Galí, 2007; Kormilitsina, 2011; Pieschacon, 2012).

We shut down the international macro effects of oil price volatility by setting the oil intensities in consumption and production abroad to zero. Column C in Figure 10 reports the impulse responses to an oil price shock under this alternative assumption. Effectively, the dashed lines isolate the effects on the mainland economy from movements in the global oil price working through the domestic oil sector. While mainland GDP and other real variables respond somewhat more strongly than in the baseline model, the differences are quantitatively small. A stronger effect under this counterfactual is attributed to our abstraction from the effects at home of lower activity abroad following an oil supply shock. But with a large oil industry with supply chain links to the mainland economy, the conventional international transmission channels are of second-order importance with large oil price movements.

Oil price exogeneity has implications for the transmission of all international shocks in the model. Here, we limit our attention to a rise in international investment efficiency. Column D in Figure 10 shows the impulse responses to a foreign investment shock keeping the oil price fixed. The shock is associated with more demand and higher prices abroad, resulting in positive spillovers to the domestic economy. But particularly for consumption and investment, rising oil prices are an important part of the transmission in the general, as evidence by comparing the baseline with the counterfactual. We conclude from these counterfactual simulations that international oil-macro interactions make an economically less significant difference for effects of oil price movements on the oil-exporting economy than on oil-importing economies.

6.4 ROBUSTNESS

In the online appendix, we outline a robustness exercise where we use aggregate data for the OECD to proxy for the international economy, rather than data for the EU28. While the OECD dataset is likely to be more informative for the oil price determination as it covers a larger share of the global economy, the non-availability of data for sectoral value-added across OECD countries poses a challenge for the identification of sectoral parameters in the foreign block of the model. Also, the EU28 represents Norway's closest trading partners and contains valuable information about conventional trade linkages. Estimated parameter values characterizing the Norwegian economy are not particularly sensitive to the choice of proxy for the international economy, nor are impulse responses very different across the two specifications. Hence, the main conclusions are robust to changing the international dataset. Specifically, the estimation using OECD data remains consistent with the view that oil price movements are important for the Norwegian business cycle, and that the supply chain is an important propagation mechanism. The role of foreign shocks is, however, reduced compared with the estimation using the EU28 data. This is evident particularly at longer horizons, though it remains larger than in most other studies of small open economies (e.g. Adolfson et al., 2007). Less persistence in the estimated foreign shocks is a contributing factor. A conservative reading of our main results would, therefore, suggest that the role assigned to domestic shocks in our analysis is more likely to be too small rather than too large.

7 CONCLUDING REMARKS

In this paper we study how the business cycle of an oil-exporting, small open economy is affected by international shocks. The contribution is two-fold. First, while most previous literature has focused on the role of oil for net importers, we analyze how oil price fluctuations influence a prototype oil exporter. Second, we do so through the lenses of an estimated DSGE model rather than reduced form regressions. The model comes with a fully specified international block, including endogenous determination of supply and demand in oil markets. In this way our approach allows us to identify and interpret a rich set of dynamics at play, complementing previous VAR-based literature.

We estimate the model using data for Norway and its main trading partner, EU28. We believe the Norwegian economy is a particularly interesting case study. It is a developed economy with a highly specialized commodity export sector, and its fiscal regime has gained significant international attention in recent years. The Norwegian experience should be of great interest for other commodity exporting economies.

The estimated model provides several important insights. First, the commodity industry supply chain is a very important transmissions mechanism for commodity price movements in resource-rich economies. Second, commodity and other global shocks play a more important role in business cycle fluctuations in these economies. Third, while no two shocks are alike, we find that conventional trade channels make an economically less significant difference for the transmission of global shocks to the oil-exporting economy than for the oil-importing economies studied e.g. by Bodenstein et al. (2012).

Regarding the effects of an oil price shock, we find that it typically creates a boom in all sectors of mainland Norway, coupled with a strong exchange rate appreciation and lower inflation. This result is consistent with those from an estimated VAR model with only a few identifying restrictions. The positive spillover to mainland Norway is significantly weakened by the fact that all oil revenues are saved in a sovereign wealth fund. The domestic supply chains, in contrast, amplifies the spillover. We quantify each of these transmission channels. With a spend-as-you-go fiscal rule, the peak response of mainland GDP is more than twice as high. Without the supply chain, the oil price shock actually leads to lower GDP and higher inflation.

Finally, we want to point out some possibilities for future research. First, while our focus is on business cycles in commodity economies, we do not account for the fact that oil is a non-renewable resource. Analyzing this issue requires other solution approaches and makes estimation significantly more challenging. Second, a natural next step is to address policy implications. Existing literature on optimal policy (in commodity economies) is based on highly stylized and calibrated models (Bergholt, 2014; Ferrero and Seneca, 2015; Catão and Chang, 2013; Hevia and Nicolini, 2013). Our work might serve as a starting point for more quantitative investigation of policy and welfare, along the lines of Schmitt-Grohé and Uribe (2006). Third, we stress that our analysis abstracts from several frictions that are likely to play a role in practice. Financial frictions, in particular those originating in commodity markets, represent an interesting avenue for future work.

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