BUSINESS CYCLES IN COMMODITY ECONOMIES[*]

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Abstract

The recent oil price fall has created concern among policy makers regarding 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 estimate a medium scale New Keynesian model in order to quantify the importance of oil price shocks for Norway – a large, prototype petroleum exporter. The model offers (i) a complete description of how oil prices are affected by international business cycles, and (ii) optimizing behavior in petroleum markets. These features allow us to disentangle the structural sources of oil price shocks, and how they affect Mainland (non-oil) Norway. The estimated model provides three important insights: First, pass-through from oil prices to the oil exporter implies up to 30% higher business cycle volatility in Mainland Norway. Second, the majority of spillover is attributed to non-oil disturbances in the international economy, in particular to innovations in investment efficiency. Conventional oil market disturbances, in contrast, are far less important for the Norwegian business cycle. Third, domestic supply linkages, rather than fiscal and monetary policy, are responsible for most of the transmission.

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1 INTRODUCTION

What drives the business cycle in commodity economies? Declining commodity prices, in particular the massive drop in oil prices, have sparked renewed interest in this question. The concern among market participants and policy makers is not a minor one. Figure 1, taken from the October 2015 Fiscal Monitor Report by IMF (IMF, 2015), shows that countries who rely on non-renewable commodity exports account for a substantial fraction of global economic activity. Thus, 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 focus on commodity users rather than commodity producers. Absence of commodities is particularly evident in the literature using estimated dynamic stochastic general equilibrium (DSGE) models.[1] This is problematic because these models are widely used for projections and policy analysis by most central banks (as well as other policy institutions).

This paper quantifies the importance of international oil price shocks for Norway – a large petroleum exporter. Norway is an interesting case for two reasons: First, the Norwegian economy is highly dependent on trade in commodities, with petroleum accounting for 20-25% of GDP and about 50% of total exports. Second, the economic stabilization policy in Norway has gained significant international interest, in particular the management and spending of petroleum revenues. Norwegian petroleum revenues are saved in a sovereign wealth fund – the Government Pension Fund Global (GPFG) – which invests solely in international assets.[2] The fund has grown tremendously the last 15 years, both in absolute value and as a share of Mainland GDP (see Figure C.1). About 4% of the fund's value is used every year to finance structural budget deficits. 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.
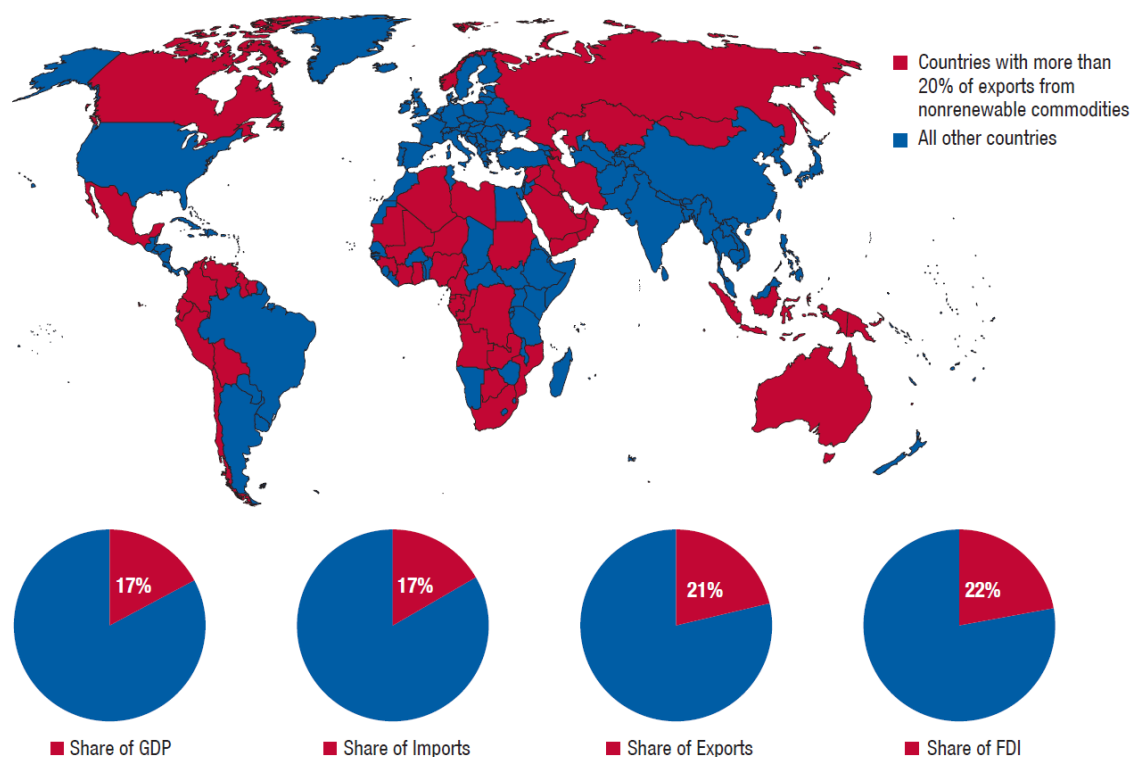
We use Bayesian techniques to estimate a medium scale DSGE model for the Norwegian economy. The structural framework builds on that developed by Bergholt and Seneca (2015), and contributes along several dimensions. First, we model the global economy explicitly (assuming optimizing behavior in international markets) rather than its reduced form vector autoregressive (VAR) representation as in most existing studies. This allows us to identify domestic responses to a range of international business cycle shocks, in addition to the oil shocks considered by e.g. Kilian (2009). Our approach is motivated by Bodenstein, Guerrieri, and Kilian (2012), who argue that "no two structural shocks induce the same monetary policy response [in the US economy], even after controlling

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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 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/).

Figure 1: The role of non-renewable commodity exporters in the global economy

for the impact response of the real price of oil". We suppose that the same logic applies to oil exporting countries. Second, to understand sectoral reallocations following terms of trade movements, we distinguish between firms in the petroleum sector, in manufacturing (non-oil traded sector), and in services (non-traded sector). This is important because oil price fluctuations create sectoral reallocations and trade-offs for policy makers.[3] These trade-offs are at the heart of the current policy debate in many commodity countries, including Norway. Third, we derive dynamics in oil markets from first principles. Oil companies in the model maximize a discounted stream of lifetime dividends, and react to all shocks besides oil price fluctuations. In the short run, costly factor adjustments and utilization of existing fields make oil supply relatively inelastic, in line with empirical evidence (Baumeister and Peersman, 2013a; Hamilton, 2009; Kilian, 2009). Long run capacity is determined by investment in new fields. Importantly, decisions about current oil investments are determined by the entire expected path of break even points – the spreads between oil prices and field costs. Finally, following Bergholt (2014, 2015) our model comes with a supply chain where firms in the Mainland economy provide productive inputs to the oil sector. These inputs are used to extract oil, maintain existing fields, and accumulate future production capacity by exploring new fields. The supply chain, we argue, represents a new and economically important transmission channel in the literature.

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

Finally, our model incorporates a sovereign wealth fund and fiscal policy, accounting for the fact that most oil revenues accrue to the government institutions.

The estimated model is used address three related questions of high importance for policy: First, how important are oil price fluctuations for Mainland Norway? That is, to what extent should policy makers care about oil price volatility? Second, are all oil shocks alike, or does the source of oil price volatility matters? In other words, should policy responses be state contingent? Third, what are the main transmission channels that account for spillover to the domestic economy? This question is key for understanding the effectiveness of different policy targets. Our answer to the first question is that all oil shocks combined, including those in the domestic oil industry, explain only a small part (10%) of the macroeconomic volatility in Mainland Norway. That does not mean that oil is irrelevant. In fact, endogenous oil price responses to non-oil shocks in the model double the role of international shocks, and they amplify Norwegian business cycle fluctuations by about 30%. Regarding the second question we find that conclusions by Bodenstein et al. (2012) carry over to oil exporters: Mainland GDP responds more than 6 times stronger when oil prices move due to some demand shocks instead of a supply shock. Highest pass-through in the short run is attributed to investment shocks, while disturbances in foreign labor markets are important at longer horizons. Finally, the model puts forward domestic supply chains as the main channel for spillover 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, plays only a minor role according to our model.

Our work speaks to the literature on macroeconomic effects of oil price shocks. A key message from this line of work is the two-way causality between oil and macro – oil prices in particular are affected by international business cycle shocks (Baumeister and Peersman, 2013b; Kilian, 2009; Kilian and Murphy, 2012). The majority of theoretical oil-macro models, in contrast, assume oil price exogeneity. Examples include Finn (2000), Kormilitsina (2011), Pieschacon (2012), and Rotemberg and Woodford (1996). A few recent studies aims to address this issue by specifying the way in which oil prices are determined by global demand and supply. Bodenstein and Guerrieri (2012), Nakov and Pescatori (2010) and Peersman and Stevens (2013) provide estimated DSGE models with endogenous oil price fluctuations. While all of these studies 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 summarizes some preliminary results from a simple VAR. The point is to highlight a couple of stylized facts in data, but also to illustrate the limited scope for structural interpretation of reduced form models. Our benchmark DSGE model for an oil exporting economy is presented in Section 3. Section 4 describes the data, calibration choices and posterior estimates. The empirical analysis is presented in Section 5, where focus is on the dynamic responses in Mainland Norway to a set of selected international business cycle shocks. In Section 6 we analyze a number of counterfactual experiments. In particular, we study impulse responses in the counterfactual case where supply chain linkages are shut down. Section 7 concludes.

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2   A SIMPLE VAR

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 the relationship between international oil price shocks and the Norwegian business cycle. To this end we impose only a minimal set of restrictions on the model, in line with previous VAR literature. The model we estimate is summarized below:

$$A_0\tilde{y}_t = \sum_{j=1}^{\mathcal{J}} A_j\tilde{y}_{t-j} + B\varepsilon_t, \quad \tilde{y}_t = \begin{bmatrix} y_t^* & p_{o,t}^* & q_t & y_{o,t} & y_{m,t} & y_{s,t} \end{bmatrix}',$$

$$\varepsilon_t \text{ iid } N(0,1), \quad B \text{ diagonal}$$

$\tilde{y}_t$ is a (period t) vector of two foreign variables, real activity y_t^* and the real oil price $p_{o,t}^*$ (in USD), 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 assume that ε_t is iid $N(0,1)$ and that B is diagonal. We make two assumptions in order to obtain structural inference. First, in order to identify the international shocks, we 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, is contemporaneously affected by the both the first and second element in ε_t. These restrictions are based on the view that real activity takes time to adjust, while the oil price, like any asset price, is a jump variable. At this point, it is important to emphasize that innovations to the oil price equation might be due to oil specific demand disturbances, by oil specific supply disturbances, or by both. Therefore, we cannot interpret oil price innovations as oil supply shocks – they are simply oil price shocks. Second, following 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 the Norwegian business cycle cannot move y_t^* or $p_{o,t}^*$, neither contemporaneously nor with a lag (A_0 and A_j are lower block triangular). 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 a priori regarding the sign and size of domestic responses. For the same reason we do not make any attempt to identify domestic shocks, as this would require further restrictions on the system. The dataset is the same as that used for estimation of the DSGE model, and is described in more detail later. The sample period is 2000Q1-2014Q4. Because of the limited number of observations we include only one lag in the VAR.

Impulse responses to the two identified shocks are reported in Figure 2 and Figure 3, respectively. Consider first the international oil price shock. A one standard deviation shock to the oil price raises oil prices by about 9% on impact, while international GDP barely moves at all. This is consistent with the view that oil price shocks have limited effects on international activity.[4] Responses in the Norwegian economy, in contrast, are

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[4]Another plausible explanation is that oil specific demand and supply disruptions have offsetting effects on

Figure 2: International oil price shock
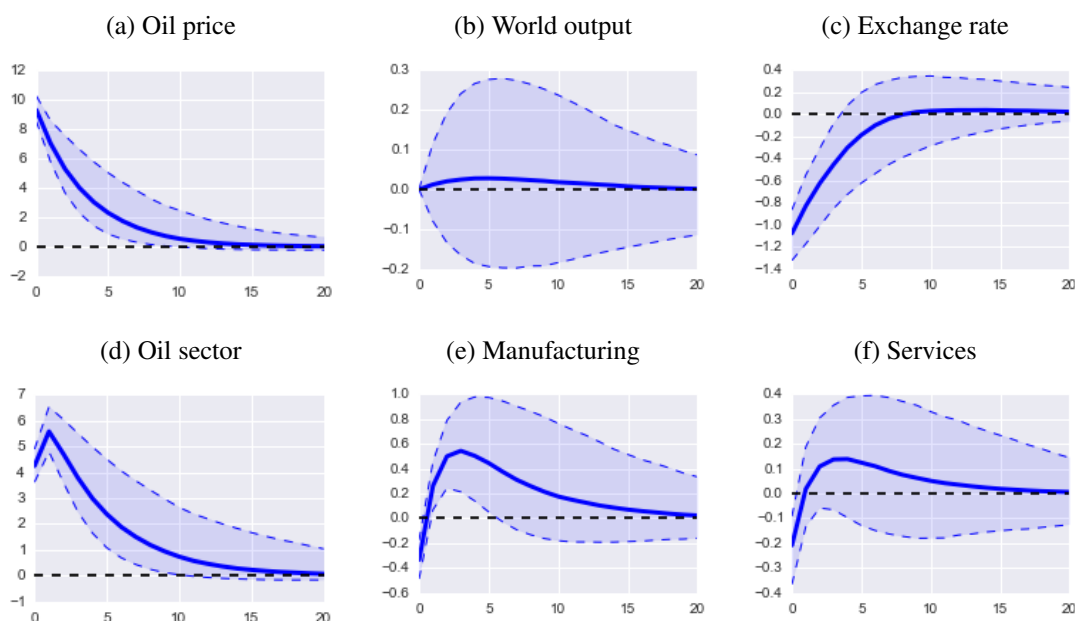
(a) Oil price   (b) World output   (c) Exchange rate

(d) Oil sector   (e) Manufacturing   (f) Services

Note: Impulse responses from a one standard deviation shock to the real oil price. Shaded areas reflect the 67.5 % credible confidence bands.

economically significant. The real exchange rate appreciates by about 1% on impact before gradually returning to the balanced growth path. Value added increases in all three sectors, and the peak response takes place after about 1-4 quarters. Note that the oil sector responds stronger than the manufacturing sector while manufacturing responds stronger than services. The latter observation contrasts with the view that windfall shocks crowd out traded industries. Rather, 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 shock to international activity, we note that both the oil price and sectoral value added in Norway increase substantially, while the exchange rate appreciates.[5] Again, there is a ranking of elasticities: GDP rises more in oil than in manufacturing, and more in manufacturing than in services. Comparing with the oil price shock, we see that value added in oil reacts less, while value added in Mainland Norway reacts more. Intuitively, while rising oil prices stimulate economic activity in Mainland Norway after both shocks, the rise in international activity comes with an additional impulse – more international demand for Norwegian non-oil goods.

In sum, we draw three 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, both shocks are associated with a rather

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international activity. As stated earlier, our oil price shock is likely a mix of the two.

[5]Observant readers might be puzzled by the exchange rate response. After all, should not higher demand abroad (and resulting higher international interest rates) be associated with a depreciation of domestic currency? The DSGE model presented later contributes the exchange rate response to developments in risk premia.

Figure 3: International activity shock
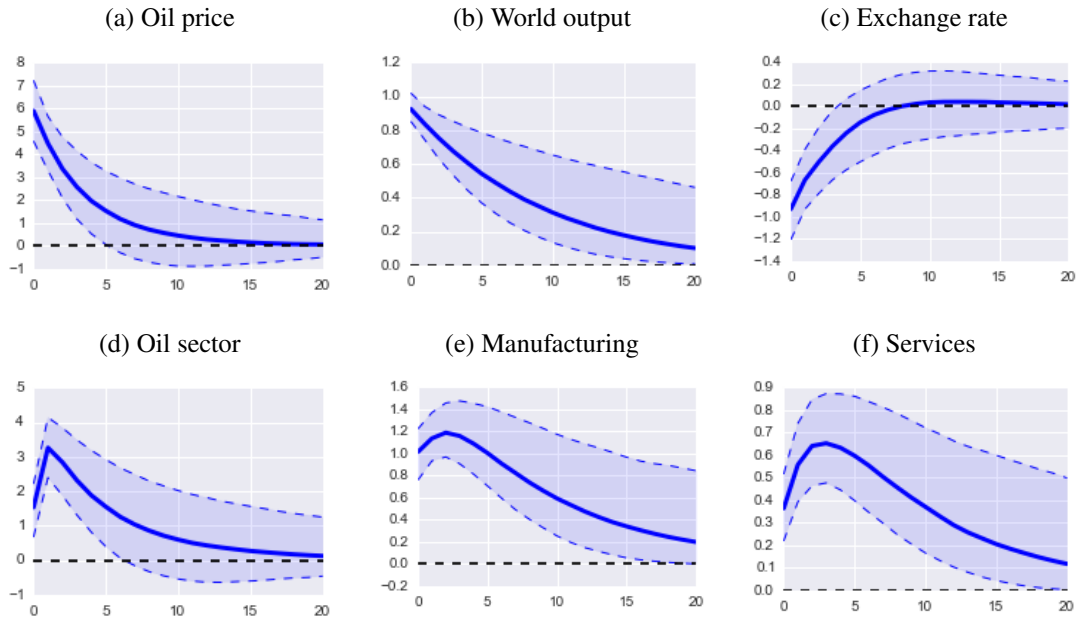
| | (a) Oil price | (b) World output | (c) Exchange rate |
| (d) Oil sector | (e) Manufacturing | (f) Services |

Note: Impulse responses from a one standard deviation shock to the real oil price. Shaded areas reflect the 67.5 % credible confidence bands.

strong exchange rate appreciation. Third, both shocks are associated with higher (positive) pass-through to oil than manufacturing, and higher pass-through to manufacturing than services. Our preliminary conclusions rest upon a minimal set of identifying restrictions. However, these restrictions do not facilitate much economic inference. A number of questions remain unanswered: (i) What are the structural disturbances underlying our VAR innovations? (ii) What are the transmission channels that generate movements in Mainland Norway? (iii) Under which circumstances is oil price pass-through to Mainland Norway high? These questions are key for our understanding of the interaction between Mainland Norway and international business cycles, and for the way policy should respond to oil price volatility. 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.

3 THE MODEL

In this section we provide a brief description of our macroeconomic model for a prototype, oil exporting economy. The model is based on that developed in a companion paper by Bergholt and Seneca (2015), which in turn builds on Bergholt (2015). The core is an open economy version of Smets and Wouters (2007), as in Adolfson et al. (2007). That is, wage and price setting is subject to monopolistic competition and nominal stickiness à la Calvo (1983). Non-optimized wages and prices are indexed to passed inflation. Households care about the consumption level relative to aggregate past consumption (external habits). Capital accumulation is subject to convex investment adjustment costs.

Figure 4: A bird's eye view on the home economy
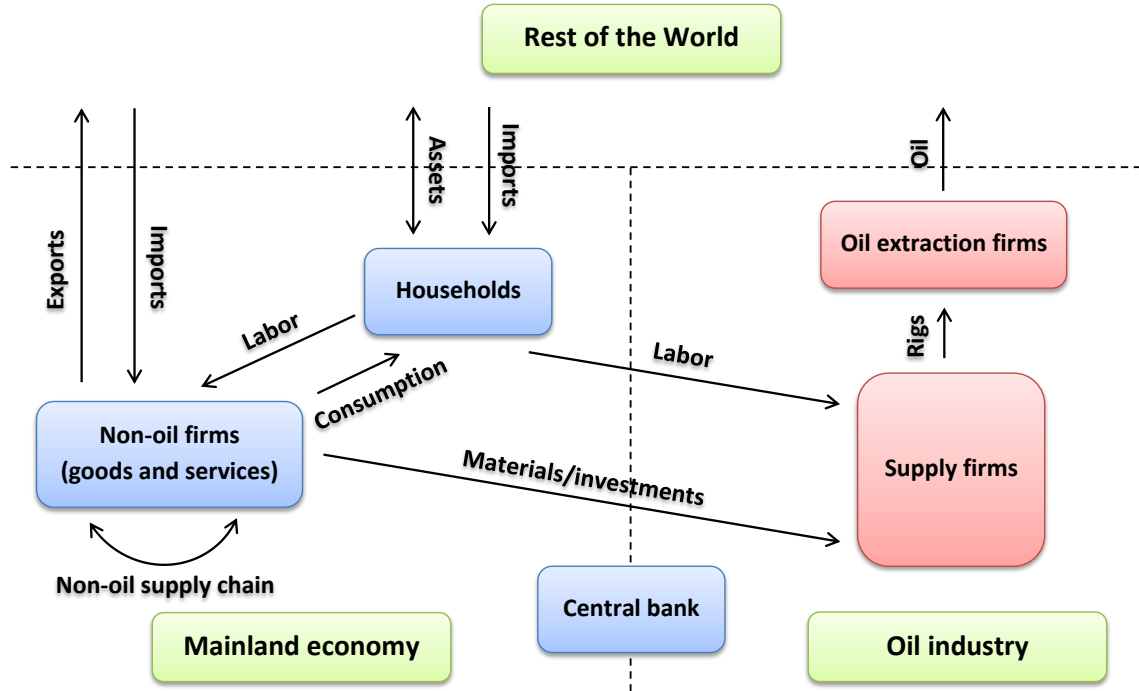
Prices in international markets are invoiced in local currency (so-called local currency pricing), implying imperfect exchange rate pass-through and violations of the law of one price within the business cycle horizon. International capital flows are subject to imperfect risk sharing, with a sovereign risk premium that depends on the external position. The endogenous premium causes deviations from uncovered interest rate parity outside steady state. In contrast to Adolfson et al. (2007), the non-oil supply block consists of two sectors – manufacturing and services. These can differ along several dimensions: The trade intensity, the degree of price stickiness, the role in supplying oil firms, and the importance for production of non-oil consumption and investment goods. Our two-sector structure facilitates analysis of resource movement effects (and resulting policy tradeoffs) as emphasized by e.g. Corden and Neary (1982). We refer to Bergholt and Seneca (2015) for further details regarding the non-oil block. Here, instead, focus is restricted to the oil sector, as well as the link between oil markets and Mainland Norway.

3.1 THE OIL EXPORTER – AN OVERVIEW

A bird's eye view of the home economy is provided in Figure 4. It consists of a non-oil block – the Mainland economy, and an offshore oil industry. Households, living in the Mainland economy, buy consumption and investment goods by domestic and foreign firms. The aggregate consumption and investment baskets are CES-functions of manufactured goods and services. Export and import shares are relatively high in manufacturing, and manufacturing is relatively important in the aggregate investment basket. This im-

plies that consumption has a low import share compared with investments. Expenditures are financed by labor income, financial investments, and transfers from the government. Mainland firms specialize, either in production of manufactured goods (subscript m), or in services (subscript s). Production requires labor, capital and intermediate inputs produced by other firms. Some intermediate inputs are imported, implying a direct cost channel for exchange rate fluctuations. Moreover, as with final goods the intermediate input basket is a CES function of manufactured goods and services. This gives rise to a cross-sectoral production network, allowing international shocks to propagate to service firms with little direct exposure to foreign competition. This is important because the service sector accounts for most of aggregate GDP in data (see Bergholt and Seneca (2015)).

The Mainland economy is linked to the oil sector via a supply chain (subscript c). The supply chain represents an important demand channel for spillover of oil price volatility. Firms in the supply chain use labor, capital and materials, some of which are imported, to produce oil investment goods. Oil investment goods are sold to a competitive oil extraction firm (subscript o), which uses investments to develop new oil fields, build rigs, and to maintain the production capital already in place. Raw oil is extracted from operative fields and sold for a given price in international markets. Finally, we include in the model a government sector. Fiscal authorities obtain tax revenues from oil activity. These revenues are invested abroad in a sovereign wealth fund. Consistent with the fiscal spending rule in Norway, about 4% of the funds value is used every year to finance government activities. The rest of this section describes the oil industry and the public sector in more detail.

3.2   THE OIL INDUSTRY

3.2.1   SUPPLY FIRMS

Activity in the supply chain is subject to a constant returns to scale production function:

$$Y_{c,t} = Z_{c,t} X_{c,t}^{\phi_c} N_{c,t}^{\psi_c} K_{c,t}^{1-\phi_c-\psi_c}$$

$Y_{c,t}$ represents output, $X_{c,t}$ intermediate inputs, $N_{c,t}$ labor hours, $K_{c,t}$ capital, while $Z_{c,t}$ is a productivity shifter. In turn, intermediate inputs is a Cobb-Douglas aggregate of inputs produced in manufacturing and services, respectively: $X_{c,t} = X_{mc,t}^{\zeta_{mc}} X_{sc,t}^{\zeta_{sc}}$. $X_{mc,t}$ ($X_{sc,t}$) denotes supply chain firms' use of materials produced in the manufacturing (service) sector.[6] In turn, materials from sector $j \in \{m, s\}$ are a composite of domestic and imported goods (subscripts H and F): $X_{jc,t} = \left[\alpha_j^{\frac{1}{\eta}} X_{Hj,t}^{\frac{\eta-1}{\eta}} + (1-\alpha_j)^{\frac{1}{\eta}} X_{Fj,t}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}$. The representative supply chain firm solves a static profit maximization problem of the form $P_{rc,t} Y_{c,t} - P_{c,t}^x X_{c,t} - \Omega_{c,t} N_{c,t} - R_{c,t}^k K_{c,t}$, taking prices as given. The optimality conditions

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[6] The corresponding price indexes for $X_{c,t}$ and $X_{jc,t}$ are, measured in consumption units, $P_{rc,t}^x = \frac{1}{\zeta_{mc}^{\zeta_{mc}} \zeta_{sc}^{\zeta_{sc}}} P_{rm,t}^{\zeta_{mc}} P_{rs,t}^{\zeta_{sc}}$ and $P_{rj,t} = \left[\alpha_j P_{rHj,t}^{1-\eta} + (1-\alpha_j) P_{rFj,t}^{1-\eta} \right]^{\frac{1}{1-\eta}}$.

are as follows:

$$N_{c,t} = \psi_c \left(\frac{\Omega_{c,t}}{P_{rc,t}} \right)^{-1} Y_{c,t} \qquad\qquad K_{c,t} = (1 - \phi_c - \psi_c) \left(\frac{R_{c,t}^k}{P_{rc,t}} \right)^{-1} Y_{c,t}$$

$$X_{c,t} = \phi_c \left(\frac{P_{rc,t}^x}{P_{rc,t}} \right)^{-1} Y_{c,t} \qquad\qquad X_{jc,t} = \zeta_{jc} \left(\frac{P_{rj,t}}{P_{rc,t}^x} \right)^{-1} X_{c,t}$$

$$X_{Hjc,t} = \alpha_j \left(\frac{P_{rHj,t}}{P_{rj,t}} \right)^{-\eta} X_{jc,t} \qquad\qquad X_{Fjc,t} = (1 - \alpha_j) \left(\frac{P_{rFj,t}}{P_{rj,t}} \right)^{-\eta} X_{jc,t}$$

Value added in the supply chain is defined as output net of intermediate materials:

$$GDP_{c,t} = P_{rc,t} Y_{c,t} - P_{rc,t}^x X_{c,t} = (1 - \phi_c) P_{rc,t} Y_{c,t}$$

Finally, market clearing between supply chain firms and the oil company is given by

$$I_{o,t} + a(U_{o,t}) F_{o,t} = Y_{c,t},$$

where $I_{o,t}$ represents gross oil investments and $a(U_{o,t}) F_{o,t}$ are the costs associated with maintenance of operative rigs. $a(U_{o,t})$ is a convex function of $U_{o,t}$, the utilization rate of rigs in place $F_{o,t}$.

3.2.2   EXTRACTION FIRMS

We use standard investment theory, similar to e.g. Peersman and Stevens (2013), to characterize how oil extraction takes place. Oil extraction requires both oil in the ground and rig services. We assume a simple Cobb-Douglas production technology:

$$O_t = Z_{o,t} Q_{o,t}^{1-\alpha_o} \bar{F}_{o,t}^{\alpha_o}$$

O_t is oil output, $Q_{o,t}$ is oil in the ground, and $\bar{F}_{o,t} = U_{o,t} F_{o,t}$ represents the effective fields currently in operation. $Z_{o,t}$ is a conventional productivity shock specific to oil production. $\alpha_o \in [0,1)$ implies decreasing returns to scale, capturing that oil in the ground is second factor of production. We stress that $F_{o,t}$, the number of fields in place, is given in period t. Thus, the only way to change output in the very short run is by adjusting $U_{o,t}$. The representative oil company seeks no maximize an expected stream of cash flows:

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

$\mathcal{Z}_{t,s}$ 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 The latter is defined in foreign currency and relative to the international consumer price level. The expression above makes it clear that cash flows are large in circumstances with i) strong foreign currency ($\mathcal{S}_t$), ii) high oil price ($P_{ro,t}^*$), and iii) high oil output (O_t). But also factor costs and expected future revenue

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margins matter. Taking the oil price and factor costs as given, the oil company makes decisions along two dimensions. First, it makes an intertemporal decision regarding the accumulation of future production capacity. Second, it makes an intratemporal decision, given current capacity, regarding the level of output. The maximization problem is subject to a law of motion for active fields:

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

The convex function $\Psi_o \left(\frac{I_{o,t}}{I_{o,t-1}} \right)$ captures adjustment costs associated with changes in oil investments. Regarding the efficiency shock $Z_{F,t}$, one might interpret it as an oil field discovery shock. A positive innovation leads to more operative fields tomorrow for any given level of investment activity today. Finally, the parameter δ_o measures the degree to which oil capital depreciates over time. Optimality conditions for the oil producer with respect to $F_{o,t+1}$ and $I_{o,t}$ are stated below:

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

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

The first equation determines the properly discounted present marginal value of installed oil rigs $\mathcal{Q}_{o,t}$. Λ_t is the marginal utility of consumption and β is the time discount factor. More rigs tomorrow will, on the margin, add revenues $\alpha_o \frac{\mathcal{S}_{t+1} P^*_{ro,t+1} O_{t+1}}{F_{o,t+1}}$. At the same time the maintenance costs increase by the amount $P_{rc,t+1} a \left(U_{o,t+1} \right)$. $\mathcal{Q}_{o,t+1} \left(1 - \delta_o \right)$ represents the continuation value net of rig depreciation. The second optimality condition above equates the marginal cost of new investments, $P_{rc,t}$, with the marginal gain of having more rigs in the next period. The first term represents next period's rig increase net of adjustment costs. The second term reflects that more investments today relax the need for investment adjustments in the future. Optimal rig utilization is given by a static condition:

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

This equation says that oil firms increase the utilization of rigs up until the point where the marginal revenue from higher utilization equals marginal costs. The optimality conditions above summarize how oil extraction firms operate in the model. In the short run, they change output by adjusting the rate to which active rigs in place operate. In the long run, oil firms undertake investment projects in order to accumulate future production capacity. This leads to highly forward looking decision making. Rather than the current oil price, the oil company cares about the entire expected price path. The forward looking behavior breaks the contemporaneous link between current oil prices and investment decisions.

3.3 THE PUBLIC SECTOR

tba
Fiscal policy

- Government oil revenues

  Tax revenues: $\qquad\qquad\qquad\qquad TR_t^o = \tau_o \Pi_{o,t}$

  Sovereign wealth fund: $\qquad\quad SWF_t = (1 - \rho_o) R_{t-1}^* \dfrac{\mathcal{E}_t}{\mathcal{E}_{t-1}} \Pi_t^{-1} SWF_{t-1} + TR_t^o$

  Structural budget deficit: $\qquad SBD_t = \rho_o R_{t-1}^* \dfrac{\mathcal{E}_t}{\mathcal{E}_{t-1}} \Pi_t^{-1} SWF_{t-1}$

  Public budget: $\qquad\qquad\quad P_{r,t}^g G_t - D_t = T_t - R_{t-1} D_{t-1} \Pi_t^{-1} + SBD_t$

- Public spending:

$$G_t = G\left(\text{``economic state}_t\text{''}\right), \qquad G_{j,t} = \xi_j^g \left(\frac{P_{rj,t}}{P_{r,t}^g}\right)^{-\nu_g} G_t$$

- Monetary policy: $R_t = R\left(\text{``economic state}_t\text{''}\right)$, e.g.

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_r} \left[\left(\frac{P_t}{P_{t-4}}\right)^{\rho_\pi} \left(\frac{GDP_t}{GDP_{t-4}}\right)^{\rho_y} \left(\frac{\mathcal{E}_t}{\mathcal{E}_{t-1}}\right)^{\rho_e}\right]^{1-\rho_r} Z_{R,t}$$

MODEL DESCRIPTION FROM SLIDES STARTS HERE

- SOE:

  - Oil sector and Mainland Norway

  - Mainland Norway linked to oil via supply chain

  - Fiscal policy: tax revenues, sovereign wealth fund, fiscal spending rule

  - Active monetary policy (Taylor rule)

3.4 OTHER RELATIONSHIPS

Aggregate Mainland (non-oil) GDP:

$$GDP_t = \sum_{j=1}^{\mathcal{J}} GDP_{j,t} = \sum_{j=1}^{\mathcal{J}} \left(P_{rHj,t} X_{Hj,t} + P_{rHj,t}^* X_{Hj,t}^* - P_{rj,t}^m M_{j,t}\right)$$
$$= C_t + P_{r,t}^i I_t + P_{r,t}^g G_t + TB_t + P_{r,t}^{io} I_{o,t} + P_{r,t}^{mo} M_{o,t}$$

Table 1: Calibration

				Markup, labor and goods markets	0.2
β	Time discount factor	0.99	ϵ_w, ϵ_p	Markup, labor and goods markets	0.2
σ	Inverse intertemporal elasticity	1	δ	Capital depreciation	0.025
φ	Inverse labor supply elasticity	2	ϵ_B	Risk premium elasticity	0.005

		SOE Mainland		*SOE Oil*	*ROW*	
		(M)	(S)	(O)	(M)	(S)
α_o	Raw oil share, gross output	–	–	0.41	–	–
ϕ_j	Materials share, gross output	0.5	0.4	0.25	0.5	0.4
ψ_j	Labor share, gross output	0.4	0.4	0.05	0.4	0.4
$\gamma_j^{ex}, \gamma_j^{im}$	Trade share, sector GDP	0.6	0.15	–	–	–
ξ_j	Sector share, consumption	0.4	0.6	–	0.4	0.6
ξ_g	Sector share, public consumption	0.1	0.9	–	–	–
ϖ_j	Input-output matrix investments	0.75	0.75	0.73	0.75	0.75
		0.25	0.25	0.27	0.25	0.25
ζ_{lj}	I-O matrix materials	0.7	0.3	0.33	0.7	0.3
		0.3	0.7	0.67	0.3	0.7

Note: Calibrated values in benchmark model. The sectors are (M) manufacturing and (S) services. The two I-O matrices at the bottom display the fraction of total materials used in each sector that comes from each of the other sectors. Columns represent consumption (input), and rows production (output).

4 ESTIMATION

In order to fit the DSGE model to data, we estimate several parameters using Bayesian techniques. This approach has been popularized by e.g. An and Schorfheide (2007), Geweke (1999), and Smets and Wouters (2003, 2007). Our dataset consists of oil prices and macroeconomic variables covering the period 2000Q1–2014Q4. The selected sample length is motivated on two grounds. First, several time series, in particular those from the international economy, are available only from 2000Q1. Second, the millennium came with several institutional breaks in the Norwegian economy: The sovereign wealth fund started to accumulate (see Figure C.1), the oil industry became a significant fraction of total GDP, and an explicit inflation target was introduced as the new monetary policy regime.

4.1 DATA

We use macroeconomic time series from Norway, EU28, and the oil price in order to inform our model. EU28 serves as a proxy for the international economy from a Norwegian point of view. The source for our data is Statistics Norway for Norwegian variables, and Eurostat for European data. Our main variables are (for both Norway and EU28): Sectoral value added, consumption, investments, wages, prices, and the interest rate. We deflate nominal values by the domestic CPI and population.[7] We also include some oil

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[7]We would have preferred to use the labor force, but we do not have these data for the EU28 countries.

Table 2: Steady state ratios in the benchmark model

	Description	Data	Model
C/VA	Consumption share in aggregate GDP	0.38	0.39
I/VA	Investment share in aggregate GDP	0.21	0.20
G/VA	Public spending share in aggregate GDP	0.21	0.18
$(X_H^* + O)/\text{VA}$	Export share in aggregate GDP	0.48	0.47
X_F/VA	Import share in aggregate GDP	0.28	0.27
GDP_O/VA	Oil share in aggregate GDP	0.22	0.20
GDP_M/VA	Manufacturing share in aggregate GDP	0.29	0.33
GDP_S/VA	Service sector share in aggregate GDP	0.49	0.47
I_O/I	Oil share in aggregate investments	0.25	0.22
$O/(X_H^* + O)$	Oil share in aggregate exports	0.47	0.45
μ_M	Share of labor force in manufacturing	–	0.33
μ_S	Share of labor force in services	–	0.65
μ_O	Share of labor force in oil sector	–	0.02

Note: This table presents ratios in the non-stochastic steady state as implied by the calibration in Table 1. "Data" refers to corresponding sample averages in data.

specific variables, that is the oil price (Brent, from the FRED database), Norwegian oil production, and Norwegian oil investments (both from statistics Norway). More details about the construction of variables used during estimation are found in the appendix.

4.2 CALIBRATION

We calibrate a subset of the parameters in the model. The calibrated parameters and their respective values are given in Table 1. Parameters not related to the sectoral dimension are set to common values in the literature. The time discount factor implies an annual real interest rate of about 4%. A unitary intertemporal elasticity is consistent with balanced growth. The calibrated Frisch elasticity φ^{-1} is higher than suggested by some microeconomic studies, but still low compared with assumptions used in many DSGE models. Finally, the risk premium elasticity is set to 0.005, in line with e.g. Adolfson et al. (2007). The remaining calibrated parameters are chosen based on sectoral data. These data suggest that the manufacturing industry supplies most investment goods and is far more trade intensive than services, while the latter produces the majority of private and public consumption goods. Turning to the oil industry, we see that it is highly capital intensive, while at the same time demands most intermediate inputs from services. These sectoral differences give rise to asymmetric effects of various business cycle shocks, and to potentially important trade-offs for policy makers. Finally, note that we assume country symmetry in the sense that calibrated parameters are identical across countries. Table 2 offers a comparison of selected steady state ratios in the model with corresponding sample averages in data. VA refers to total value added in the Norwegian economy including oil. Note that we do not have data on labor shares across sectors. Still, the minor labor share

Table 3: 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)	0.74	0.74	0.62-0.87	0.63	0.54	0.39-0.72
ϵ_I	Inv. adj. cost	G(5.00,1.00)	4.85	4.51	3.43-5.55	4.51	5.20	3.28-7.02
θ_w	Calvo wages	B(0.65,0.07)	0.78	0.76	0.70-0.83	0.70	0.68	0.61-0.76
ι_w	Indexation, π_w	B(0.30,0.15)	0.28	0.30	0.06-0.52	0.21	0.29	0.06-0.48
θ_{p1}	Calvo prices 1	B(0.45,0.07)	0.69	0.68	0.62-0.75	0.40	0.43	0.35-0.50
θ_{p2}	Calvo prices 2	B(0.75,0.07)	0.91	0.90	0.86-0.95	0.93	0.88	0.82-0.94
ι_p	Indexation, π_p	B(0.30,0.15)	0.28	0.30	0.07-0.50	0.54	0.36	0.12-0.59
ρ_r	Smoothing, r	B(0.50,0.10)	0.93	0.93	0.91-0.95	0.83	0.85	0.82-0.89
ρ_π	Taylor, π	N(2.00,0.20)	1.64	1.63	1.35-1.91	2.06	1.96	1.69-2.23
ρ_{de}	Taylor, Δe	N(0.10,0.05)	0.03	0.02	-0.04-0.07	–	–	–
ρ_y	Taylor, gdp	N(0.13,0.05)	0.21	0.14	0.08-0.21	0.16	0.14	0.08-0.20
η	H-F elasticity	G(1.00,0.15)	0.67	0.59	0.48-0.70	–	–	–
ϵ_O	Inv. adj. cost oil	G(10.00,1.00)	10.08	9.48	8.23-10.69	–	–	–
η^{od}	Oil demand elast.	G(0.15,0.10)	0.11	0.13	0.05-0.21	–	–	–
η^{os}	Oil supply elast.	G(0.15,0.10)	0.02	0.05	0.01-0.08	–	–	–
γ_c^o	Cons. share oil	B(0.50,0.10)	0.45	0.48	0.33-0.62	–	–	–
ρ_A	Technology	B(0.35,0.15)	0.41	0.40	0.26-0.55	0.52	0.58	0.39-0.78
ρ_I	Investment	B(0.35,0.15)	0.07	0.15	0.03-0.25	0.48	0.41	0.24-0.59
ρ_U	Preferences	B(0.35,0.15)	0.28	0.23	0.05-0.41	0.30	0.57	0.34-0.79
ρ_W	Wage markup	B(0.35,0.15)	0.31	0.28	0.11-0.43	0.14	0.10	0.02-0.18
ρ_M	Price markup	B(0.35,0.15)	0.62	0.52	0.34-0.70	0.23	0.40	0.19-0.61
ρ_B	UIP	B(0.50,0.15)	0.85	0.86	0.80-0.92	–	–	–
ρ_{OS}	Oil investment	B(0.50,0.15)	0.40	0.37	0.21-0.54	–	–	–
ρ_{OD}^*	Oil demand	B(0.50,0.15)	0.82	0.81	0.77-0.87	–	–	–
ρ_{AO}	Oil supply	B(0.50,0.15)	0.64	0.56	0.39-0.73	–	–	–
σ_{A1}	Sd technology 1	IG(0.80,2.00)	3.80	3.71	2.94-4.44	0.26	0.29	0.19-0.39
σ_{A2}	Sd technology 2	IG(0.80,2.00)	4.81	4.52	3.65-5.32	0.58	0.54	0.35-0.72
σ_I	Sd investment	IG(1.60,2.00)	31.21	26.92	21.31-32.38	6.19	9.01	4.73-13.65
σ_U	Sd preferences	IG(0.80,2.00)	3.59	4.54	2.43-6.87	1.94	1.76	1.04-2.49
σ_W	Sd labor supply	IG(0.40,2.00)	0.73	0.77	0.59-0.96	0.96	1.14	0.94-1.33
σ_{M1}	Sd markup 1	IG(1.60,2.00)	1.01	1.01	0.63-1.37	0.92	0.76	0.50-1.00
σ_{M2}	Sd markup 2	IG(0.40,2.00)	0.16	0.24	0.12-0.35	0.16	0.17	0.11-0.23
σ_R	Sd mon. pol.	IG(0.02,2.00)	0.06	0.06	0.05-0.07	0.08	0.07	0.06-0.08
σ_B	Sd UIP	IG(0.80,2.00)	0.36	0.36	0.22-0.49	–	–	–
σ_{OS}	Sd oil inv.	IG(1.60,2.00)	53.26	51.45	44.57-58.18	–	–	–
σ_{OD}	Sd oil price	IG(1.60,2.00)	1.54	2.24	1.31-3.19	–	–	–
σ_{AO}	Sd oil supply	IG(1.60,2.00)	4.22	4.43	3.72-5.12	–	–	–

Note: B denotes the beta distribution, N normal, G gamma, IG inverse gamma, P1 prior mean, P2 prior standard deviation. Posterior moments are computed from 500000 draws generated by the Random Walk Metropolis-Hastings algorithm, where the first 200000 are used as burn-in. The volatility of shocks is multiplied by 100 relative to the text.

in oil (2% of the labor force) is consistent with surveys conducted by statistics Norway.[8]

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[8]The indirect labor share, which includes labor used in the production of oil related products, is higher both in the model and in data.

4.3 PRIORS AND POSTERIOR PARAMETER ESTIMATES

Remaining parameters are estimated based on Bayesian inference. Selected prior distributions are reported in Table 3. We choose the priors based on existing open economy DSGE literature, e.g. Adolfson et al. (2007), Christiano, Trabandt, and Walentin (2011), and Justiniano and Preston (2010). Most distributions are standard but some remarks are in place. 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 assume a beta distribution for Calvo parameters in manufacturing that is skewed more to the left. Regarding oil related parameters, we center the prior for oil investment adjustment costs around 10, twice the size of non-oil investment adjustment costs. Oil supply and demand elasticities are centered around 0.15. This number is in the ballpark of suggestive VAR evidence (Baumeister and Peersman, 2013a; Kilian and Murphy, 2012), although quite low compared with assumptions used in some DSGE studies (e.g. Nakov and Pescatori (2010)). Finally, we center the prior consumption share in total oil use around 50%.

The joint posterior distribution is built using the random walk Metropolis-Hastings algorithm. We make 500000 draws and use the first 200000 as burn-in. The jumping distribution used is tuned in order to get an acceptance rate of 30%. Table 3 summarizes the resulting 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 habit persistence and price stickiness in manufacturing are higher in Norway. Price indexation on the other side is lower. Consistent with microeconomic evidence the posterior points to large differences in the degree of price stickiness across sectors. The estimates suggest that prices in services change on average only about every 10th quarter. Also, the estimated interest rate inertia is quite high in both countries. Regarding elasticities in the oil sector, we find that the supply elasticity in particular is close to zero, in line with arguments put forward by Kilian and Murphy (2012). Turning to the shock processes we get highly persistent UIP shocks, while domestic (non-oil) investment shocks behave almost as white noise. However, the latter have very large innovations, suggesting a major role for investment shocks at very short horizons. If anything, there is a tendency of more volatile domestic innovations, while at the same time more persistence in the foreign business cycle shocks.

5 ANALYSIS

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 innovations transmit into Mainland Norway.

Figure 5: Forecast error variance decomposition of Mainland GDP
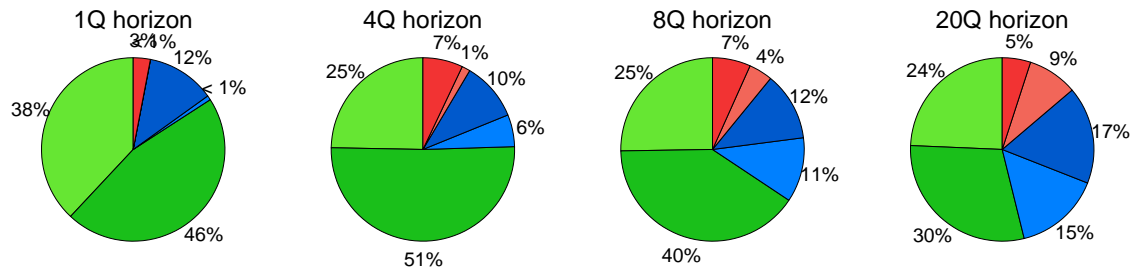
Note: Forecast error variance decomposition at different business cycle horizons of GDP in Mainland Norway. Shocks are decomposed as follows: Domestic demand shocks (dark green), domestic supply shocks (light green), international demand shocks (dark blue), international supply shocks (light blue), offshore Norwegian oil shocks (dark red), and international oil shocks (light red).

5.1 VARIANCE DECOMPOSITIONS

Figure 5 shows the forecast error variance decomposition of Mainland GDP at different business cycle horizons. We label as domestic (foreign) supply shocks innovations to domestic (foreign) sectoral TFP, price markups, and wage markups. The remaining non-oil shocks are defined as demand driven (note that all non-oil innovations are demand shocks from oil producers' point of view). In addition we separate between foreign oil supply and demand shocks on the one side, and shocks in offshore Norway on the other. In the very short run (1 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 (innovations to sectoral TFP and investment efficiency each account for about 34%). Oil shocks, in contrast, account for only a negligible share of the volatility. The importance of shocks outside Mainland Norway rises as the forecasting horizon expands. At the 5-year horizon they account for about 46% of the fluctuations in GDP, substantially more than what is found in e.g. estimated small open economy models for the Swedish economy (Adolfson et al., 2007; Christiano et al., 2011). At least some of this difference is likely due to the importance of petroleum exports for Norway.[9] However, the total contribution by oil shocks is not large – about 3% in the very short run and 14% at the 5-year horizon. That is, our model does not support the view that oil shocks are crucial for macroeconomic fluctuations in Mainland Norway. How can this be? Later we argue that the foreign non-oil block in our model is able to soak up much of the oil price fluctuations in data – fluctuations that otherwise would be interpreted as oil shocks.

How important are business cycle shocks outside Mainland Norway for the Norwegian economy? Table 4 reports the long run variance decomposition for Mainland variables, as well as a set of oil variables. Among the domestic shocks, innovations to investment efficiency are the most prominent. But substantial macroeconomic volatility is attributed to external events. All external shocks combined explain more than 50% of the volatility in

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[9]Bergholt (2015), analyzing business cycle fluctuations in the Canadian economy, suggests firm-to-firm trade as an alternative explanation.

Mainland GDP, suggesting ample international transmission. The model assigns most of the international transmission to non-oil events, in particular to international investment and labor market shocks. Oil price innovations, in contrast, explain only 12%. In fact, all oil shocks combined account for only 30% of the external spillover to Mainland Norway. Oil shocks are more important for consumption and the non-oil trade balance, a point we discuss in more detail below. Regarding volatility in the oil sector, it turns out that most is explained by shocks in domestic and international oil markets: Oil value added, utilization and the sovereign fund are well explained by oil price shocks, while oil investment shocks account for most of the variability in factor use. Output, in contrast, is driven by investment and productivity shocks in the offshore sector. At this point, we emphasize that the limited importance of oil shocks for Mainland Norway probably understates the role of oil price fluctuations for domestic volatility. This is because significant oil price volatility – about 30% – is attributed by the model to conventional business cycle events. Oil price fluctuations caused by non-oil, macroeconomic disturbances create volatility in Mainland Norway. But those 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.[10]

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[10]In other words, the model predicts that 30% of the oil price volatility is demand driven. VAR literature finds a more important role for demand shocks, while the opposite tends to be the case for estimated DGSE models with observable oil price (see, e.g. Nakov and Pescatori (2010) and Peersman and Stevens (2013)).

Table 4: Forecast error variance decomposition (percent)

Variable	All Mainland shocks	Decomposition																			
		σ_{A1}	σ_{A2}	σ_R	σ_U	σ_I	σ_M	σ_S	σ_W	σ_{A1}^*	σ_{A2}^*	σ_R^*	σ_U^*	σ_I^*	σ_M^*	σ_S^*	σ_W^*	σ_B^*	σ_{OD}^*	σ_{OS}^*	σ_{AO}^*
		Panel A: Mainland Norway																			
GDP	45.5	3.0	3.7	4.1	3.1	17.3	1.1	6.5	6.6	0.1	0.1	0.6	0.8	17.4	0.4	2.3	13.2	3.2	11.8	4.3	0.2
Consumption	34.4	0.7	1.4	2.7	11.9	8.3	1.1	4.3	4.0	0.1	0.0	0.7	1.2	18.7	0.3	2.6	12.1	2.7	23.5	3.1	0.6
Investment	60.8	1.4	0.6	2.4	0.1	41.2	4.9	5.3	4.8	0.0	0.0	0.3	0.1	9.2	0.1	0.7	6.6	3.3	7.7	10.9	0.1
Public spending	54.1	2.3	1.6	17.3	3.1	5.5	9.4	10.7	4.2	0.1	0.1	0.8	0.5	14.2	0.3	1.3	12.7	5.5	1.8	8.6	0.1
Trade balance	47.0	7.4	8.9	1.4	1.6	10.5	10.7	3.9	2.5	0.1	0.1	0.4	1.6	7.5	0.4	0.8	3.6	14.1	18.8	5.2	0.4
Hours	94.9	21.3	57.8	1.3	1.0	3.5	1.7	2.4	5.7	0.0	0.0	0.1	0.3	1.3	0.0	0.2	0.7	0.3	0.9	1.3	0.0
Interest rate	63.9	3.1	2.1	11.1	0.7	11.1	10.6	18.9	6.4	0.1	0.0	0.3	0.7	7.4	0.3	1.4	5.9	6.0	11.7	1.9	0.3
CPI inflation	82.7	12.4	2.1	3.1	0.2	1.6	36.3	24.1	2.9	0.3	0.0	0.2	0.1	0.8	1.5	0.9	3.4	7.6	2.2	0.2	0.1
Real wage	51.2	0.6	0.6	0.5	0.2	2.0	3.6	12.6	31.1	0.1	0.0	0.5	0.7	15.6	0.2	1.9	10.1	2.5	15.3	1.4	0.3
Real exchange rate	24.5	0.5	0.1	2.8	0.1	5.0	5.2	7.5	3.3	0.1	0.1	1.4	0.7	17.2	0.4	4.5	12.6	20.2	16.9	1.1	0.4
		Panel B: Oil sector and associated variables																			
Output	2.2	0.0	0.0	0.2	0.0	0.8	0.3	0.3	0.7	0.0	0.0	0.0	0.2	3.3	0.0	0.1	1.7	0.6	1.2	35.4	55.2
Value added	2.6	0.0	0.0	0.3	0.0	0.6	0.5	0.7	0.4	0.1	0.1	0.6	7.3	5.6	0.4	2.3	4.7	1.7	67.4	2.5	4.7
Utilization	1.5	0.1	0.0	0.2	0.0	0.2	0.5	0.2	0.2	0.1	0.1	0.6	7.0	3.2	0.4	2.2	3.3	1.2	65.7	10.1	4.6
Materials	5.0	0.1	0.0	0.3	0.0	1.8	0.6	0.6	1.5	0.0	0.0	0.1	0.6	7.5	0.0	0.1	3.8	1.4	3.0	78.4	0.1
Hours	4.9	0.1	0.0	0.3	0.0	1.8	0.6	0.6	1.5	0.0	0.0	0.1	0.6	7.3	0.0	0.1	3.7	1.4	3.0	78.7	0.1
Investments	7.1	0.2	0.0	0.5	0.0	2.4	1.0	0.9	2.0	0.0	0.0	0.1	0.4	7.8	0.0	0.2	4.5	1.5	3.0	75.2	0.0
Sovereign wealth fund	6.2	0.1	0.0	0.7	0.1	1.0	1.7	1.9	0.8	0.0	0.0	0.2	3.9	7.3	0.0	1.0	3.5	5.7	59.3	11.0	1.7
Present value of fields	13.5	0.5	0.2	2.4	0.0	1.0	2.5	5.6	1.2	0.0	0.1	0.4	0.7	4.2	0.1	1.7	5.5	0.3	20.2	53.1	0.2
Rig capacity	4.9	0.1	0.0	0.3	0.0	1.8	0.6	0.6	1.5	0.0	0.0	0.1	0.5	7.4	0.0	0.1	3.7	1.4	2.6	79.1	0.1
Real oil price	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	1.0	6.9	8.8	0.5	3.6	7.2	0.0	71.7	0.0	0.0

Note: Calculated at the posterior mean. Note that when the forecasting horizon s becomes large, the contribution of a shock to the s step ahead forecast error converges to that shock's contribution to the unconditional volatility. Thus, Panel E reports each shock's contribution to long run volatility.

Figure 6: An oil price shock
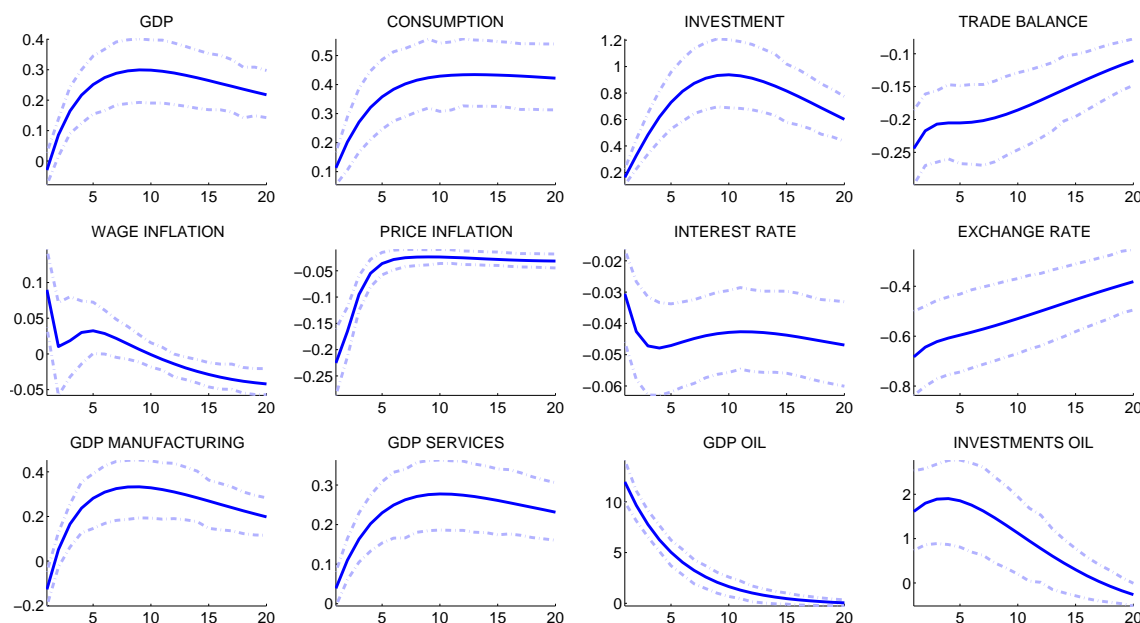
Note: Bayesian impulse responses to an international oil price shock (one standard deviation). Mean (solid) and 90% highest probability intervals (dotted) based on 1200 equally spaced draws from the posterior. Inflation and the interest rate are expressed in annual terms.

5.2 ON THE TRANSMISSION TO MAINLAND NORWAY

This section sheds light on the transmission of international business cycle shocks to Mainland Norway. First, based on estimated impulse response functions from the model, we analyze an international oil price shock. Although other disturbances are more important for the Norwegian business cycle, this shock provides better understanding of how oil price volatility propagates through the economy. Second, we describe the transmission of international investment shocks.

5.2.1 INTERNATIONAL OIL PRICE SHOCKS

Figure 6 shows the impulse responses in Mainland Norway to an international oil price shock. On impact the real oil price jumps 12.3%. This is associated with a prolonged boom in the oil exporting economy, with a peak response in Mainland GDP of 0.3% after 2.5 years. The boom is a result of rising demand in Mainland Norway, in part due to stronger need for productive inputs in the oil sector. Higher activity leads to more demand for productive resources, rising Mainland investments, and higher real factor prices. The non-oil trade balance drops because some demand is targeted towards foreign goods. Despite all these demand side effects, we get a decline in domestic inflation. This is attributed to the strong exchange rate appreciation caused by expected future external balance improvements. Monetary authorities, trying to bring inflation back to target, responds with lower policy rates. These developments are associated with a downward shift in the real interest rate path, implying rising consumption in Mainland Norway. Regarding sectoral

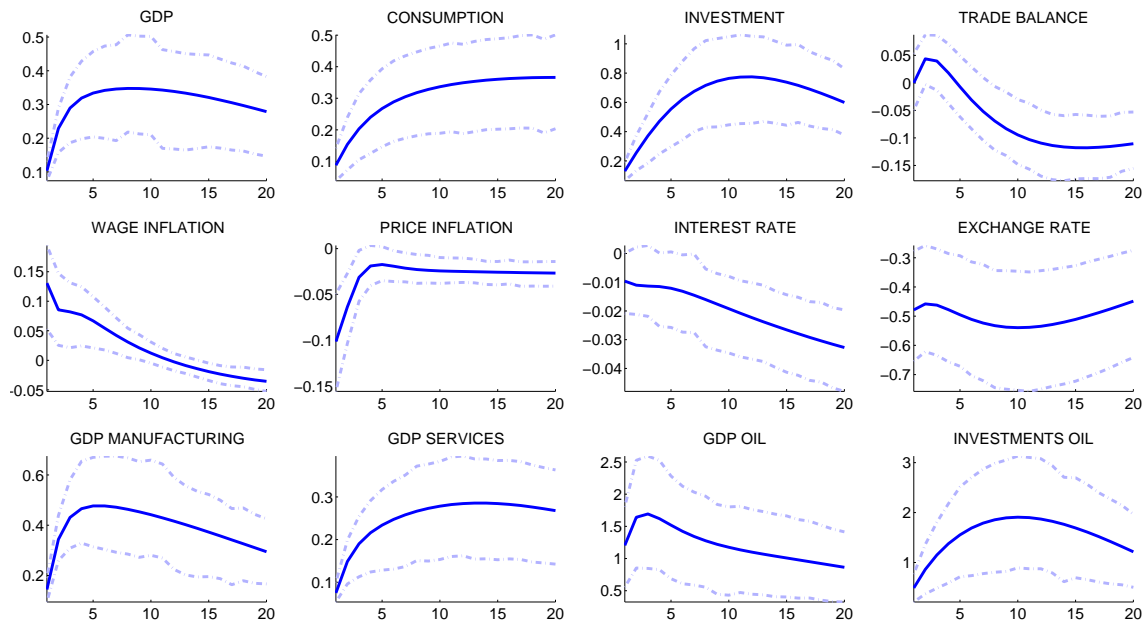Figure 7: An international investment efficiency shock
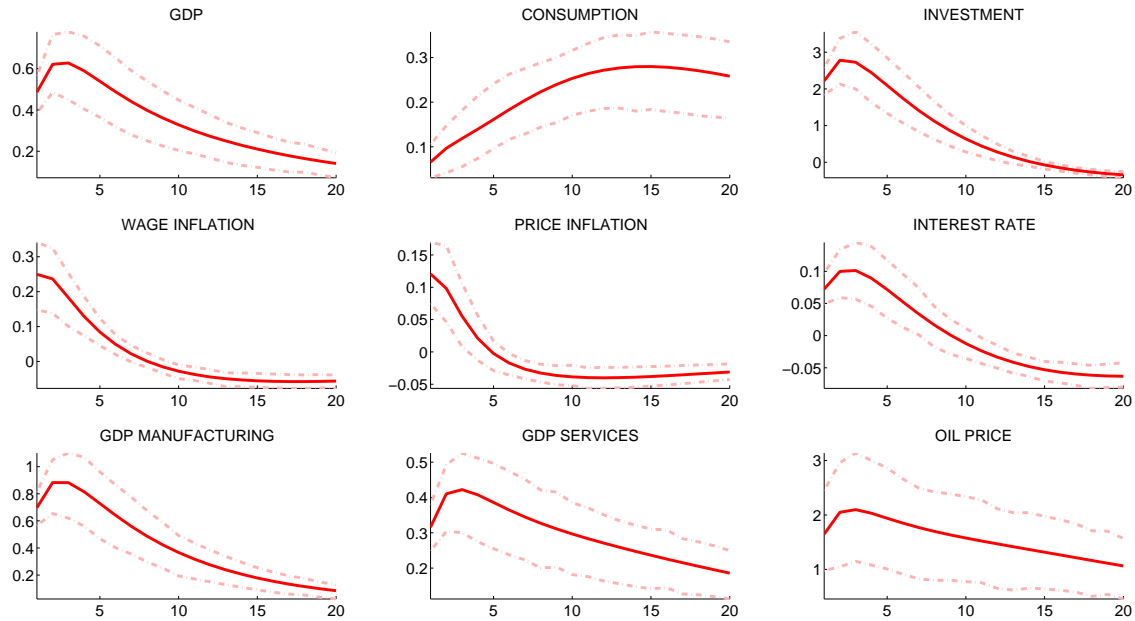
Note: Bayesian impulse responses to an international investment efficiency shock (one standard deviation). See Figure 6 for details.

responses, we see that value added booms more in manufacturing than in services after some periods. The reason is the importance of manufactured goods for the supply chain. Oil extraction, in contrast, hardly moves on impact (not shown). This is because of large adjustments costs in the short run. Inelastic supply implies that GDP in the oil sector closely tracks the oil price. Finally, in order to improve future capacity the oil industry increases investments by almost 2%.

5.2.2   INTERNATIONAL INVESTMENT SHOCKS

Next we analyze the effects of an international investment shock. In order to understand responses in the oil exporting economy, we first describe international dynamics. Impulse responses in the international economy are shown in Figure 7. Higher investment efficiency abroad leads to investment demand beyond that implied by spreads between capital returns and investment prices. GDP booms as a result, in particular in manufacturing which produces most investment goods. The need for factor inputs creates rising factor prices which, in turn, causes inflation. Monetary authorities respond with higher policy rates. International consumption is influenced by two opposing forces: First, rising demand for investment goods crowds out consumption. Second, the investment boom will at some point lead to capital abundance, implying higher consumption. According to the estimated model, the latter effect dominates throughout. Finally, the real oil price rises because (i) oil is used to produce investment goods, and (ii) households demand more of all consumption goods (including oil). The persistent consumption response (which is due to capital abundance) maps into persistently high oil prices in the international economy.

Figure 8: An international investment efficiency shock

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

Dynamics in the oil exporting economy are plotted in Figure 8. GDP in Mainland Norway peaks at 0.35% after 2 years. Also consumption and investments rise. Perhaps surprisingly the non-oil trade balance turns negative after one year. Should not higher demand abroad lead to positive net exports? The oil price increase implies, as in the case with pure oil price shocks, a substantial improvement in the overall external position. The resulting exchange rate appreciation, coupled with higher oil sector demand for imports, cause the drop in non-oil trade balances. Inflation and interest rates fall for the same reason.

5.2.3 PASS-THROUGH FROM OIL PRICE TO MAINLAND GDP

One question of particular relevance for policy is whether the propagation of oil price volatility depends on the source of the shock. Suppose the oil price increases by, say, 10%. Are the effects on Mainland Norway a function of underlying, structural innovations, or are all shocks alike? Table 5 provides some information about this issue. If the oil price jump is caused by reduced international oil supply, then Mainland GDP increases only 0.16-0.33%. A 10% rise in the oil price due to international investment demand, in contrast, increases Mainland GDP by 1.04-2.42%. That is, for the same magnitude of oil price volatility, the peak response of GDP is almost 7 times stronger in the latter situation. The model predicts this difference because contractionary oil supply shocks disrupt international non-oil activity. The consequence is a minor boom for the oil exporter. More generally, the extent to which Mainland GDP responds to oil price fluctuations depends on the source of volatility, and no two structural shocks are alike. Also the time from a

Table 5: Peak response of Mainland GDP to 10% oil price increase

| Underlying international shock	Response of Mainland GDP		
	Mean	HPD interval	# lags
Oil supply	0.24	0.16-0.33	10
Manufacturing productivity	1.37	0.55-2.29	4
Service productivity	1.08	0.09-2.23	7
Monetary policy	0.77	0.45-1.14	5
Consumption demand	0.42	0.33-0.51	2
Investment demand	1.66	1.04-2.42	8
Manufacturing markup	1.12	0.65-1.63	3
Service markup	0.94	0.36-1.55	5
Labor market	1.68	0.91-2.43	7

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 1200 equally spaced draws from the posterior. HPD interval represents the 90% highest probability interval. # lags denotes number of periods from the shock to the peak response.

shock occurs to GDP peaks differs across shocks, from 2 quarters for consumption driven innovations to 2.5 years for oil supply disruptions.
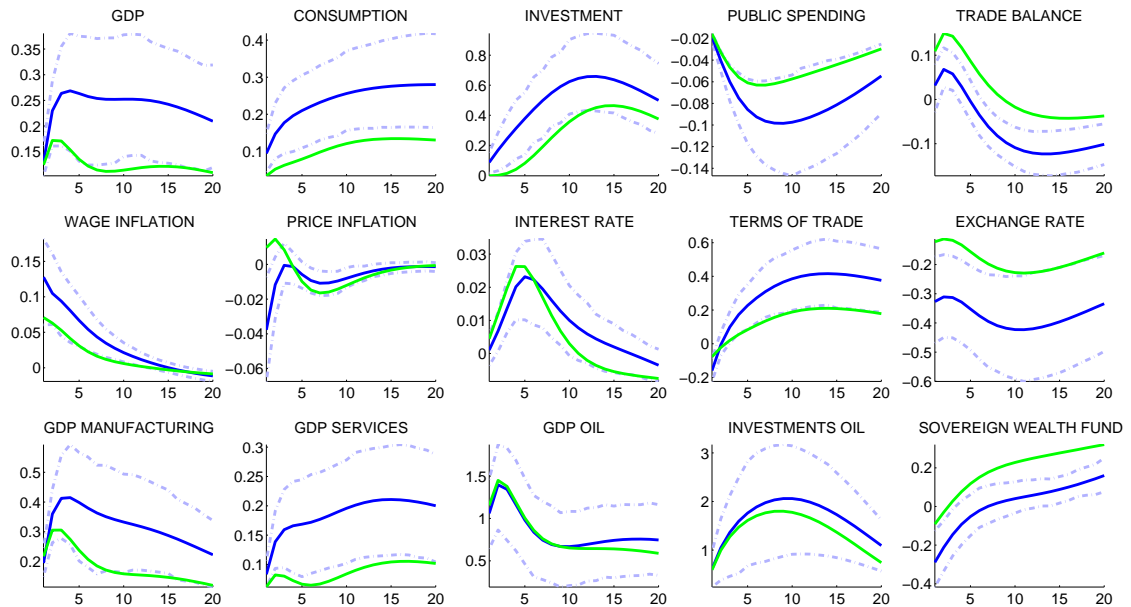
6 COUNTERFACTUALS

6.1 CAN MONETARY POLICY MAKE A DIFFERENCE?

Transmission under strict inflation targeting
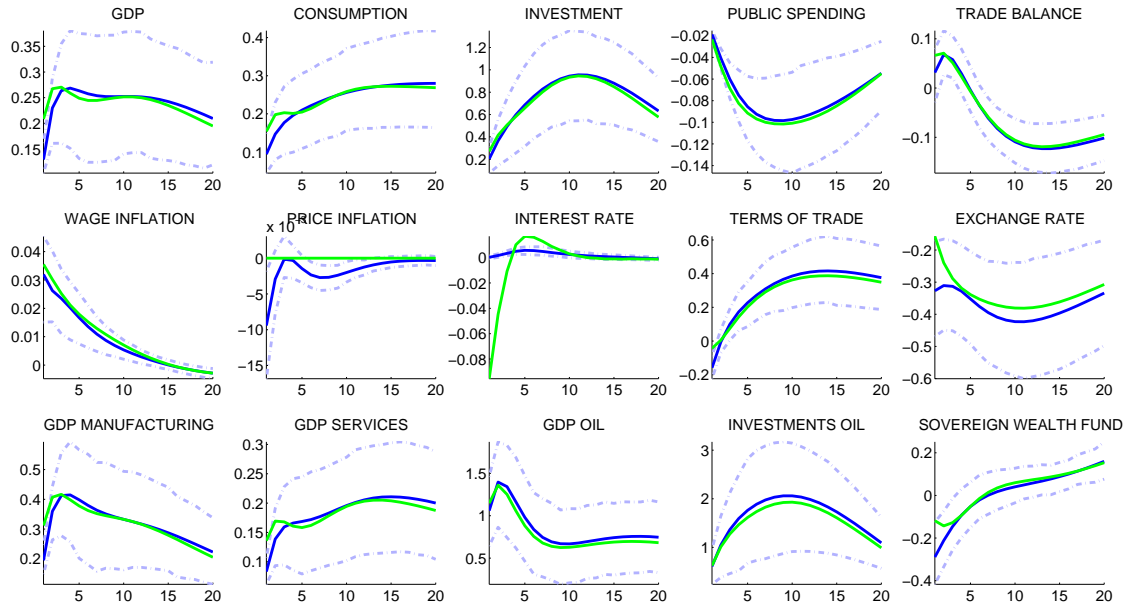
6.2 THE ROLE OF THE SUPPLY CHAIN

Transmission without the supply chain channel

7 CONCLUDING REMARKS

- Estimation of joint dynamics in oil markets, international economy, and the Norwegian economy

- 50% of volatility in Mainland Norway attributed to external events, 15% to pure oil shocks.

- Not all oil shocks are oil shocks. Rather, they are conventional business cycle shocks $\Rightarrow$ no two shocks are alike

- Source of oil price volatility matters a great deal

- Amplification mechanisms

- Supply chain the key transmission channel (resource movement effect), fiscal and monetary policy less relevant

- Inflation targeting vs. other measures

- Work in progress

  - Structural change
  - Monetary policy lessons

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