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Commodity Price Shocks and Business Cycles in a Resource-Rich Economy

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Abstract

Commodity price shocks can be a key driver of business cycles in resource-rich small open economies. We assess their importance for the Norwegian economy by estimating a structural VAR model and measuring the contribution of oil price shocks to fluctuations in economic activity. Focusing on the oil price collapse of 2014–2016, the VAR evidence indicates sizable spillovers from oil prices to the non-resource economy. We develop and estimate a small open economy DSGE model with a resource extraction sector that demands both materials and investment goods from the rest of the economy. Investment adjustment costs in the oil sector generate gradual and persistent spillovers to mainland activity following oil price shocks. Hence, the model is consistent with the empirical responses obtained from the VAR. Applying the framework to the COVID-19 pandemic, we find that while pandemic-specific shocks dominated the contraction, oil price movements also contributed non-negligibly to the downturn.

Keywords: business cycles, small open economy, commodity prices

JEL classification: E32, F41, F44, Q43

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Sammendrag

Variasjon i internasjonale råvarepriser er en viktig kilde til makroøkonomisk volatilitet i ressursrike små åpne økonomier. Denne artikkelen studerer hvordan oljeprissjokk påvirker norsk økonomi, med særlig vekt på virkninger fra ressurssektoren til fastlandsøkonomien. Vi begynner med å estimere en strukturell VAR-modell for å identifisere de empiriske effektene av oljeprissjokk på norsk økonomi. Med fokus på oljeprisfallet mellom 2014 og 2016, viser VAR-analysen at oljeprissjokk har betydelige og vedvarende effekter på fastlandsøkonomien der aktiviteten reagerer gradvis over tid.

Deretter utvikler og estimerer vi en Bayesiansk DSGE-modell for en liten åpen økonomi med en ressurssektor som er knyttet til fastlandsøkonomien gjennom etterspørsel etter innsatsvarer og investeringsvarer. Den estimerte modellen replikerer i stor grad de empiriske responsene fra VAR-analysen. En sentral mekanisme i modellen er den trege tilpasningen i oljeinvesteringene som gir opphav til en gradvis respons i aktiviteten i fastlandsøkonomien etter et oljeprissjokk. Etterspørselen etter innsatsvarer reagerer derimot mer umiddelbart og bidrar primært til kortsiktige svingninger. Historiske sjokkdekomponeringer gjort med både den strukturelle VAR-modellen og DSGE-modellen indikerer at oljeprisbevegelser bidro betydelig til nedgangen i norsk økonomi i perioden 2014--2016.

DSGE-modellen utvides også med et COVID-19-spesifikt sjokk som vi kaller «tvungen sparing». Sjokket fanger opp de ekstraordinære svingningene i økonomisk aktivitet under pandemien uten en detaljert modell for smittespredning og ledsagende atferdsresponser. Den estimerte modellen antyder at selv om pandemispesifikke sjokk var den viktigste drivkraften bak nedgangen i perioden 2020--2022, bidro også fallet i oljeprisen vesentlig til nedgangen i fastlandsøkonomien. Resultatene indikerer dermed at etablerte transmisjonsmekanismer knyttet til råvarepriser forble kvantitativt viktige også under de ekstraordinære forholdene under pandemien.

1 Introduction

Fluctuations in international commodity prices are widely regarded as an important source of macroeconomic volatility in commodity-exporting economies. An early literature on business cycles in small open economies attributed this volatility to general shocks to the terms of trade (Mendoza, 1995). More recent work, however, emphasizes the importance of focusing on more disaggregated measures of world prices in order to capture the specific transmission channels involved (Fernández et al., 2017; Schmitt-Grohé and Uribe, 2018). In this paper we therefore study the business cycles of a resource-rich economy exposed to fluctuations in the international price of its primary export commodity. Our focus is on Norway, which ranks among the world's largest exporters of crude oil and natural gas. We show that variation in the international price of oil has been an important driver of recent downturns in the Norwegian economy. Oil price shocks also remained quantitatively relevant during the COVID-19 pandemic, despite the unusually large non-standard shocks affecting the economy at the time.

We begin by estimating a structural VAR model to characterize the empirical effects of oil price shocks on the Norwegian economy. We focus on the period when oil prices fell markedly between mid-2014 and early 2016, and the VAR evidence indicates sizable and persistent spillovers from oil prices to the non-resource economy. We then develop a small open economy DSGE model with a resource sector that takes the global resource price as given and is linked to the rest of the economy through demand for materials and investment goods. These distinct demand channels generate different adjustment dynamics following an oil price shock, with sluggish responses in oil investment and more immediate movements in materials demand.

We estimate the model using Norwegian data and Bayesian methods. In the estimated model, the response to an oil price shock is broadly consistent with the VAR evidence. A 10 percent decline in the real price of oil in the DSGE model leads to a gradual and hump-shaped decline in activity in the non-resource economy, with a trough of about 1 percent after 8 quarters. In the VAR, the decline is similar but occurs more slowly. Historical shock decompositions in both the VAR and the DSGE model indicate that oil price movements contributed significantly to the downturn in the Norwegian economy during the period 2014–2016.

The DSGE model is also extended with a COVID-specific preference shock that is only active in the pandemic period. This enables the model to capture the large and abrupt fluctuations in the Norwegian economy during 2020–2022. The shock is labeled a "forced saving" shock, but it serves as a proxy for both policy-driven restrictions on consumption opportunities and voluntary reductions in consumption due to fear of infection. This approach is similar to that used in several recent policy models (see Cardani et al., 2022, 2023; Gundersen et al., 2024). The purpose of the shock is not to model the epidemiological mechanisms of the pandemic, but to capture the unusually large fluctuations in economic activity in a parsimonious way.

During the COVID-19 pandemic in 2020 there was also a substantial decline in the real price of oil. The model indicates that this contributed significantly to the downturn in the Norwegian economy at the time. These results suggest that the structural mechanisms linking oil prices to domestic economic activity continue to matter even during the exceptional circumstances of the pandemic. Studies that compare the economic effects of different pandemic responses across countries should therefore also account for other forces that may influence economic outcomes. In the case of Norway, this includes movements in international commodity prices.

In our model, the resource sector is linked to the non-resource economy through two important demand channels. First, resource extraction uses materials produced in the non-resource sector as inputs, so fluctuations in extraction translate directly into variation in demand for these goods. Second, extraction relies on a sector-specific capital stock, and investment in this capital generates additional demand for goods from the non-resource economy. However, due to adjustment costs, the dynamics of investment demand differ markedly from the demand for materials; we show in Section 6.1 that this distinction is crucial for matching the response of mainland GDP in Norway to oil price shocks.[1]

A third link operates through the distribution of resource sector profits. In resource-rich economies, the macroeconomic impact of these profits depends on how they are allocated. In Norway, a large share of oil-sector profits is transferred to a sovereign wealth fund (the Government Pension Fund Global). While Ferrero and Seneca (2019) show that modeling such a fund can be equivalent to transferring profits directly to households, we break this equivalence by assuming that a share of profits is accumulated in a fund that households do not internalize. We motivate this by the fund's explicit goal of transferring wealth to future generations, which limits its impact on short-term business cycle dynamics. Section 6.2 investigates the importance of this mechanism.

Finally, Norwegian policymakers responded to the downturn during the pandemic by implementing several policies to provide support for households and firms. This included a policy to provide support for the oil industry by incentivizing oil-related investments. Our results concerning the contribution of oil prices to the downturn in the Norwegian economy in 2020 provide some support for such a policy. However, the specific policy that was implemented may not have been an ideal form of short-term economic stimulus. Section 7 discusses the support package for the oil industry in detail.

1.1 Related literature

The papers most closely related to ours are Bergholt et al. (2019) and Ferrero and Seneca (2019). Both papers study the effects of oil price fluctuations in small open economy DSGE models for the Norwegian economy, but they model the oil sector in markedly different ways. Bergholt et al. develop a detailed model of an oil extraction sector and its supply chain linkages to the mainland economy. They find that oil price movements are an important driver of business cycle dynamics

[1] Since oil and gas extraction in Norway is exclusively done offshore, the non-resource economy is referred to as the *mainland* economy.

in Norway. Ferrero and Seneca (2019) in contrast, adopt a more stylized framework with a simple model of an oil sector that requires materials produced on the mainland. This affects the transmission of oil price shocks to the non-oil economy, and their simple model enables them to characterize analytically the optimal monetary policy in response to these shocks.

Our framework strikes a middle ground between these approaches: it incorporates an oil sector where extraction requires both materials and oil-sector-specific capital without modeling all the details of the domestic supply chain. The structure is rich enough to capture both immediate and sluggish movements in demand for domestic goods through materials and investment, while it remains simple enough to be included in larger scale policy models with only a small increase in model complexity.[2] We use the model to analyze the impact of oil prices on recent Norwegian business cycles, including during the COVID-pandemic.

The paper is also related to a literature that finds that global commodity price shocks account for a substantial share of macroeconomic fluctuations in small open economies and emerging markets (Fernández et al., 2017; Fernández et al., 2018; Drechsel and Tenreyro, 2018). More recently, Kohn et al. (2021) show that differences in production structures and trade patterns across countries can amplify the effects of commodity price movements on business cycle volatility in commodity exporters. Focusing on advanced commodity exporters, such as Australia and Canada, Fry-McKibbin et al. (2025) and Bodenstein et al. (2018) show that commodity price booms can increase aggregate output through sectoral reallocation and expansion in domestic demand, often accompanied by exchange rate appreciation. For Norway, empirical evidence in Bjørnland (2009) and Bjørnland and Thorsrud (2016) highlights key transmission channels from oil prices to the mainland economy, including domestic demand and exchange rate movements. These findings complement the DSGE-based results discussed above.

Taken together, these findings suggest that the macroeconomic effects of commodity price fluctuations are not specific to Norway, but are relevant more broadly across commodity-exporting economies. We contribute to this literature by studying how such shocks propagate during periods of economic stress, as emphasized in our analysis of the pandemic.

There is a sizable literature studying the global macroeconomic effects of oil-related shocks using structural VAR models. Kilian (2009) shows that the macroeconomic effects depend crucially on the type of oil-market shock, with demand-driven shocks playing a dominant role for real activity. More recent contributions, including Baumeister and Hamilton (2019) and Caldara et al. (2019), revisit this conclusion and argue that oil supply shocks can also have substantial effects when supply elasticities are sufficiently large. Microdata evidence for the United States analyzed in Aastveit et al. (2026) provides support for a larger supply elasticity. In this paper, we abstract from the distinction between different types of oil-market shocks. We model the oil price as an exogenous autoregressive process and focus on the transmission of

[2]The mechanism studied in this paper may be incorporated in the NORA model that is maintained by Statistics Norway and used by the Ministry of Finance in Norway. The model is documented in Gundersen et al. (2024).

commodity price movements to the domestic economy.

Finally, the paper is related to the literature incorporating the COVID-19 pandemic into macroeconomic models. Some papers take an approach similar to ours and model the pandemic as a shock to preferences. For example, in Faria-e-Castro (2021) the pandemic acts as an exogenous shock to preferences in a two-agent New Keynesian model, while in Carroll et al. (2021) it is modeled as a shock to the marginal utility of consumption in a heterogeneous-agent framework. In contrast, Bayer et al. (2023) model the pandemic as a "quarantine shock" that reduces labor supply, either through policy or voluntary behavior. Our paper therefore belongs to the strand of the literature that analyzes the macroeconomic effects of the pandemic using reduced-form shocks, rather than explicitly modeling the spread of infection and its interaction with economic decisions (see Eichenbaum et al., 2021, 2022).

1.2 Organization

This paper is organized as follows. Section 2 presents a structural VAR model that provides some empirical guidance for the strength of the effect of a fall in the oil price on mainland activity in the Norwegian economy. Section 3 presents a small open economy model with a resource extracting sector that takes the commodity price it faces in international markets as given. In Section 4 we parameterize this model to the Norwegian economy by calibrating parameters that determine the model's steady state, and estimating parameters affecting the model's dynamic properties using Bayesian techniques. Section 5 presents results from the model for our case study of recent business cycles in Norway. Section 6 analyzes how robust our results are to modeling choices. Section 7 discusses the policy implemented in response to the 2020 oil price fall through the lens of our model. Section 8 concludes.

2 A simple structural VAR model

To establish some stylized facts about the response of the Norwegian business cycle to oil prices, we first specify a simple VAR model of the Norwegian economy. Our interest lies in the domestic responses to foreign shocks and the impact of oil-specific shocks in particular. We estimate the following reduced form VAR model

$$Z_t = \boldsymbol{\alpha} + \sum_{j=1}^{10} A_j Z_{t-j} + \boldsymbol{e}_t, \quad Z_t = \left[\Delta \ln Y_t^{TP}, \ \ \Delta \ln P_t^o, \ \ \Delta \ln RER_t, \ \ \Delta \ln Y_t^o, \ \ \Delta \ln Y_t^d\right]', \tag{1}$$

where $\mathbb{E}\left[\boldsymbol{e}_t \boldsymbol{e}_t'\right] = \Sigma$. The set of endogenous variables largely follows the specification of Bergholt et al. (2019). However, we do not distinguish between the manufacturing and services sectors in the Norwegian economy, in order to align with the DSGE model introduced in the next section. The vector Z_t consists of a trade-weighted measure of foreign output Y_t^{TP}, the real price of oil P_t^o, the real exchange rate RER_t, the real Norwegian offshore GDP Y_t^o, and finally the CPI-deflated Norwegian mainland GDP Y_t^d.[3] All variables are log-differenced. Following Hamilton and Herrera (2004) and Kilian and Lütkepohl (2017), we specify *ex ante* a rich lag structure common in the macro-oil literature. The dataset runs from 1995Q2 to 2019Q4 and estimation is done by OLS. The estimation data for the VAR is a subset of the variables used in the Bayesian estimation of the DSGE model in Section 4.2 that are described in Appendix B.1.

To derive the orthogonal structural shocks, we follow Bjørnland and Thorsrud (2016) and Bergholt et al. (2019) by imposing short-run zero restrictions on the mapping between the reduced form errors and the structural shocks $\boldsymbol{\varepsilon_t}$. Specifically, we exploit that if we assume that there exists some matrix S that allows us to write $\boldsymbol{e}_t = S\boldsymbol{\varepsilon}_t$, where $\mathbb{E}\left[\boldsymbol{\varepsilon}_t\boldsymbol{\varepsilon}_t'\right] = I$, then imposing a lower triangular structure on S will allow us to recover $\boldsymbol{\varepsilon}_t$ through

$$\mathbb{E}\left[\boldsymbol{e}_t\boldsymbol{e}_t'\right] = \mathbb{E}\left[S\boldsymbol{\varepsilon}_t(S\boldsymbol{\varepsilon}_t)'\right] = \mathbb{E}\left[S\boldsymbol{\varepsilon}_t\boldsymbol{\varepsilon}_t'S'\right] = SS' = \Sigma$$

by doing a Cholesky decomposition on Σ. This results in the following recursive structure:

$$\boldsymbol{e}_t = \begin{bmatrix} S_{11} & 0 & 0 & 0 & 0 \\ S_{21} & S_{22} & 0 & 0 & 0 \\ S_{31} & S_{32} & S_{33} & 0 & 0 \\ S_{41} & S_{42} & S_{43} & S_{44} & 0 \\ S_{51} & S_{52} & S_{53} & S_{54} & S_{55} \end{bmatrix} \begin{bmatrix} \varepsilon_t^{Y^{TP}} \\ \varepsilon_t^{P^o} \\ \varepsilon_t^{RER} \\ \varepsilon_t^{Y^o} \\ \varepsilon_t^{Y^d} \end{bmatrix}_t . \tag{2}$$

This means that endogenous variables ordered at the top cannot respond within the quarter to shocks ordered below. Ordering the foreign variables at the top implies that these cannot respond to domestic shocks contemporaneously. This assumption seems plausible given that Norway is a small open economy. We order trading partner output above the real price of oil given that e.g. Hamilton (2009) has found that real activity responds sluggishly to oil market shocks. The real price of oil is thus allowed to respond immediately to trading partner real activity shocks. Since we are only interested in the effect of $\varepsilon_t^{P^o}$ on domestic variables, we do not seek to identify the domestic shocks. We thus disregard these as non-identified. We note that $\varepsilon_t^{P^o}$ is not identified in a way so that we can distinguish between oil supply and demand shocks. As pointed out by Kilian (2009), the type of oil market shock matters for the macroeconomic responses. However, given that our aim is to study the response of the Norwegian mainland economy, we see it as sufficient to identify only a single shock that we label an oil price shock. This shock will be an amalgamation of different oil market-specific demand and supply shocks commonly studied in the oil-macro literature discussed in the previous section.

Figure 1 shows three impulse response functions following an oil price shock that reduces the oil price by 10 percent. These are the responses of the real price of oil, trading partner

[3]The trade weights are summarized in Table 5.

activity and mainland activity. As the figure shows, foreign activity responds positively and by about 0.3 percent within the first two years. This result is in line with the results of Bjørnland and Thorsrud (2016) who find that a positive commodity price shock causes a temporary and relatively modest reduction in international economic activity. This result is also consistent with Norway's trading partners mainly being energy importers. As energy becomes less expensive, economic activity expands. In contrast to Norway's trading partners, Norwegian mainland activity contracts following the decrease in oil prices. After about 5 years, the activity is almost 1 percent lower than it was initially. This suggests that there are considerable spillover effects from oil prices to the mainland economy and that this is likely to be caused by demand for goods from the mainland by the offshore sector. We will explicitly include this channel in the DSGE model described in Section 3.

From the structural VAR, we can also derive the contribution of each structural shock to the data net of the constant terms. A decomposition of mainland GDP is shown in Figure 2. The results indicate that oil price shocks contributed negatively to the year-on-year growth rate of mainland GDP from 2015 onward, coinciding with the oil price decline that began in the summer of 2014 and reached its trough in January 2016. These findings suggest that oil price shocks can explain a substantial share of the business cycle downturn during this period. In contrast, during the Global Financial Crisis, foreign activity shocks account for most of the downturn.[4]

In summary, our simple VAR model exercise shows that oil price movements have both qualitative and quantitative implications for the business cycle movements of mainland Norway. The evidence suggests that lower oil prices lead to lower economic activity and is consistent with the narrative of a commodity price-driven business cycle downturn in Norway following the oil price decline that began in mid-2014.

3 Model

The starting point for the DSGE model is a small open economy (SOE) model based on models presented in, for example, Adolfson et al. (2007) and Justiniano et al. (2010). The model features common elements such as habits in consumption, sticky prices and wages, and investment adjustment costs that affect the model's dynamic properties. We add a resource extraction sector that demands materials and investment goods from the non-resource economy, and transfers profits from selling the natural resource in international markets to the owners. In this section, we present the various elements of the model, while the equilibrium conditions used to solve the model are presented in Appendix A.1.

[4]We have also performed a standard forecast error variance decomposition (FEVD). It shows that about 10 percent of the variation in mainland GDP can be accounted for by oil price shocks after one year. This increases to 20 percent in the long-run. This is on par with the relative contribution of foreign activity shocks.

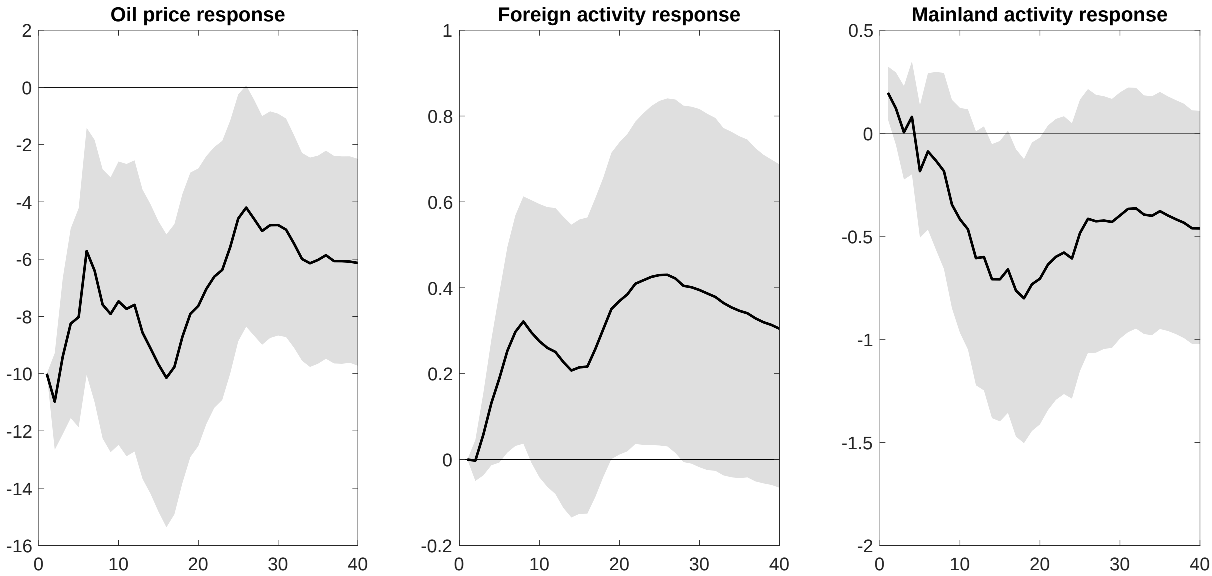


Figure 1: Accumulated impulse response functions from the VAR model in Equation (1) showing the responses to an oil price shock that lowers the oil price by 10 percent. Confidence bands are bootstrapped at the 68% level. The horizontal axis measures time in quarters after the shock occurred, and the vertical axis measures the percentage response of each variable.

3.1 Households

The economy is populated by a large number of identical households that consist of a continuum of members indexed by $j \in [0,1]$. The index j represents the specialized labor service that a household member of that type provides. A member of the household of type j chooses consumption $C_t(j)$, hours worked $N_t(j)$, investment $I_t(j)$, and savings in domestic and/or foreign bonds $B_t(j)$, $B_t^*(j)$ to maximize expected lifetime utility given by

$$\mathbb{E}_t \sum_{\tau=t}^{\infty} \beta^{\tau} \exp\left(Z_{\tau}^{U}\right) U\left(C_{\tau}\left(j\right), N_{\tau}\left(j\right)\right), \tag{3}$$

subject to the budget constraint

$$\begin{aligned} \frac{W_t(j)}{P_t} N_t\left(j\right) + \frac{R_t^K}{P_t} K_t(j) + \frac{\mathcal{D}_t(j)}{P_t} + R_{t-1}\frac{B_t(j)}{P_t} + R_{t-1}^{*} \Upsilon_{t-1} \frac{\varepsilon_t}{P_t} B_t^{*}(j) \\ = \frac{P_t^C}{P_t} C_t(j) + \frac{P_t^C}{P_t} I_t(j) + \frac{B_{t+1}(j)}{P_t} + \frac{\varepsilon_t}{P_t} B_{t+1}^{*}(j) + \frac{T_t(j)}{P_t}, \end{aligned} \tag{4}$$

and the capital accumulation rule

$$K_{t+1}(j) = (1-\delta) K_t(j) + \exp\left(Z_t^I\right) \left[1 - \Phi^d \left(\frac{I_t(j)}{I_{t-1}(j)}\right)\right] I_t(j). \tag{5}$$

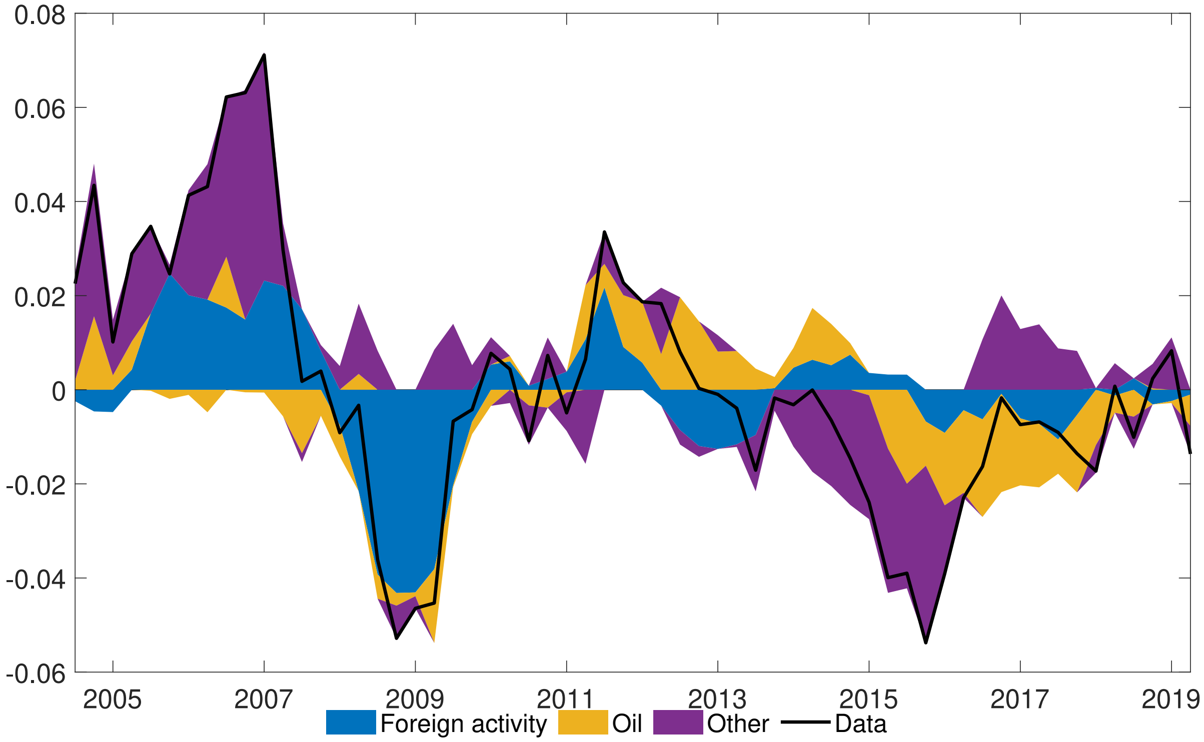


Figure 2: Historical decomposition of CPI-deflated mainland GDP for Norway net of deterministic model factors. The colored areas show how each structural shock has contributed to the overall movement in the data over time. All time series have been transformed to year-on-year growth rates.

In addition to the variables already mentioned, $K_t(j)$ is the capital stock owned by the household at the start of period t, $\mathcal{D}_t(j)$ is the profits transferred to the household, $T_t(j)$ is the lump-sum tax paid, and Z_t^I is an investment-efficiency shock governing the efficiency with which investment expenditures are converted into productive capital.[5]

The investment adjustment cost function takes the following form:

$$\Phi^d\left(\frac{I_t(j)}{I_{t-1}(j)}\right) = \frac{\chi_I}{2}\left(\frac{I_t(j)}{I_{t-1}(j)} - 1\right)^2, \tag{6}$$

where χ_I determines the extent of the adjustment cost.

Prices in the economy are defined as follows: $W_t(j)$ is the wage paid to a household of type j; P_t is the price of the domestic composite intermediate good; and P_t^C is the price of consumption and other final goods, that is, the consumer price index (CPI). Furthermore, R_t^K is the rental rate of capital, R_t is the interest rate on the domestic bond which costs one nominal unit of domestic currency at time t and delivers at time $t+1$, and R_t^* is the corresponding interest rate on foreign bonds. The nominal exchange rate is denoted ε_t, and Υ_t is a debt-elastic risk

[5]We introduce a range of shocks to enable Bayesian estimation of the model. The specification of the shocks is discussed in Section 3.10, with the exception of the preference shock discussed below in Section 3.1.1.

premium given by

$$\Upsilon_t = \exp\left(-\epsilon_B \left(b_t^* - b_{ss}^*\right)\right) \exp\left(Z_t^{B*}\right), \tag{7}$$

where ϵ_B controls the elasticity of the risk premium with respect to the aggregate net foreign asset position b_t^* relative to its steady-state value, b_{ss}^*. The net foreign asset position is:

$$b_t^* \equiv \frac{\varepsilon_t B_{t+1}^*}{P_t}, \tag{8}$$

and $Z_t^{B^*}$ is a risk-premium shock.

3.1.1 Preference shock

The shock Z_t^U in the households' utility function consists of two components: a standard preference shock Z_t^b and a consumption shock Z_t^{FS}, where FS = "forced savings", that is only active during the COVID-19 pandemic. This follows Cardani et al. (2023) and Gundersen et al. (2025), and enables the model to account for the extraordinary volatility in consumption observed during the pandemic. Specifically, the preference shock Z_t^U is defined as:

$$Z_t^U = \begin{cases} Z_t^b, & \text{in normal times,} \\ Z_t^b + Z_t^{FS}, & \text{during the COVID-19 pandemic,} \end{cases} \tag{9}$$

where Z_t^b is the standard intertemporal preference shock. This shock follows an autoregressive process

$$Z_t^b = \theta_b Z_{t-1}^b + E_t^b, \tag{10}$$

with $E_t^b \sim \mathcal{N}\left(0, \sigma_b^2\right)$. That is, the shock has a persistence given by θ_b and a standard deviation given by σ_b. Z_t^{FS} is a COVID-specific shock that follows an MA process:

$$Z_t^{FS} = E_t^{FS} + \mu_{FS} E_{t-1}^{FS}, \tag{11}$$

with $E_t^{FS} \sim \mathcal{N}\left(0, \sigma_{FS}^2\right)$. These shocks are separately identified because one shock is heteroscedastic and only active during the pandemic, and because they have different dynamic specifications. The estimated sign of the parameter μ_{FS} governs whether forced saving is subsequently reversed, regardless of whether it originates from government policies restricting consumption opportunities or from voluntary withdrawal from economic activity to limit infection risk. The goal of the COVID-specific shock in this paper is to capture the pandemic as the dominant driver of the business cycle at the time, without attempting to separately identify the effects of government policy and behavioral responses.

3.1.2 The utility function

The utility function of household member j is specified as

$$U\left(C_t\left(j\right), N_t\left(j\right)\right) = \frac{\left(C_t(j) - hC_{t-1}\right)^{1-\sigma}}{(1-\sigma)(1-h)^{-\sigma}} - \chi_N \frac{\left[N_t(j)\right]^{1+\phi}}{1+\phi}, \tag{12}$$

where σ is the coefficient of relative risk aversion (and the inverse of the intertemporal elasticity of substitution), χ_N is the weight on the disutility of working, ϕ is the inverse of the Frisch elasticity of labor supply, and h determines the strength of external habits in consumption.

With this specification of the utility function, the marginal utility of consumption is given by

$$\Lambda_t^c(j) = p_t^d \exp\left(Z_t^U\right) \frac{\left(C_t\left(j\right) - hC_{t-1}\right)^{-\sigma}}{\left(1-h\right)^{-\sigma}}, \tag{13}$$

where the price of the domestic composite good relative to the CPI is given by

$$p_t^d \equiv P_t / P_t^C. \tag{14}$$

3.1.3 Labor supply and wage setting

As in Erceg et al. (2000) there is a representative employment agency in the labor market that hires all types of differentiated labor services j. The wage of each type of labor, $W_t(j)$, is set by a union representing workers of that type. The employment agency combines the specialized labor types into a homogeneous labor input that is sold to the intermediate goods producing firms discussed in Section 3.2.2. The aggregation is given by

$$N_t = \left(\int_0^1 N_t\left(j\right)^{\frac{\epsilon_N - 1}{\epsilon_N}} dj\right)^{\frac{\epsilon_N}{\epsilon_N - 1}}, \tag{15}$$

where ϵ_N is the elasticity of substitution between the types of specialized labor inputs. The price of the homogeneous labor input, the aggregate wage W_t, is

$$W_t = \left(\int_0^1 W_t\left(j\right)^{1-\epsilon_N} dj\right)^{\frac{1}{1-\epsilon_N}}. \tag{16}$$

These wages are sticky, so every period a fraction ξ_W of unions representing the different labor types cannot reset their wage. In that case, wages are indexed according to the indexation rule

$$W_t\left(j\right) = \left(\pi_{ss}^C\right)^{1-\omega_W} \left(\pi_{t-1}^C\right)^{\omega_W} W_{t-1}\left(j\right), \tag{17}$$

where $\pi_t^C = P_t^C / P_{t-1}^C$ is CPI-inflation, and $\omega_W \in [0, 1]$ controls the degree of wage indexation.

When a union representing household members of type j is allowed to reset its wage, it chooses the optimal wage in a way consistent with utility maximization of its members' households. It takes the decisions of other unions and the aggregate consumption and prices as given, and takes into account the evolution of the demand for the labor service it provides as long as it cannot reoptimize:

$$N_{t+k|t}(j) = \left(\frac{\Omega^W_{t+k} W_t(j)}{W_{t+k}}\right)^{-\epsilon_N} N_{t+k}. \tag{18}$$

The variable Ω^W_{t+k} accounts for the cumulative effect of wage indexation:

$$\Omega^W_{t+k} = \begin{cases} 1 & k = 0 \\ \prod_{l=1}^{k} \left(\pi^C_{ss}\right)^{1-\omega_W} \left(\pi^C_{t+l-1}\right)^{\omega_W} & k > 0. \end{cases} \tag{19}$$

A union resetting the wage will thus maximize the function

$$\max_{W_t(j)} \quad \mathbb{E}_t \sum_{k=0}^{\infty} (\beta\xi_W)^k \left[\Lambda_{t+k} \frac{\Omega^W_{t+k} W_t(j)}{P_{t+k}} - \chi_N \exp(Z^U_{t+k}) \frac{\left(N_{t+k|t}(j)\right)^{1+\phi}}{1+\phi}\right]. \tag{20}$$

Note that we assume that there is perfect insurance within the households, so that in equilibrium $C_t(j) = C_t$ for all j. Hence, all unions resetting wages set their wage with the same markup over the marginal rate of substitution.

3.2 Production of domestic goods

The structure of production of domestic goods in this economy consists of a continuum of intermediate goods producers that use capital and labor to produce unique intermediate goods and an aggregator that bundles intermediate goods into a domestic composite good. The domestic composite good is used as a component of consumption, investment, and government spending in the non-resource economy, for materials needed in resource extraction, investment in a resource-sector-specific capital stock, and it is exported abroad.

3.2.1 Domestic composite good

A representative, competitive firm bundles intermediate goods into a composite good Y_t using a standard CES production function:

$$Y_t = \left(\int_0^1 Y_t(i)^{\frac{\epsilon_D - 1}{\epsilon_D}} di\right)^{\frac{\epsilon_D}{\epsilon_D - 1}}, \tag{21}$$

where $Y_t(i)$ is the amount used of intermediate good i, and ϵ_D is the elasticity of substitution between the domestic intermediate goods.

The standard profit maximization problem yields the following demand schedule for intermediate good i:

$$Y_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\epsilon_D} Y_t, \tag{22}$$

where $P_t(i)$ is the price of intermediate good i and P_t is the price of the domestic composite good.

3.2.2 Domestic intermediate goods

There is a unit measure of domestic intermediate goods producers indexed by i. Producer i rents capital, $K_t(i)$, from households, and hires labor, $N_t(i)$, from the labor union, to produce intermediate good i. Producer i's production function is

$$Y_t(i) = \exp\left(Z_t^Y\right)(K_t(i))^{\alpha}(N_t(i))^{1-\alpha} - FC, \tag{23}$$

where α is the capital share parameter in the production function, Z_t^Y is a productivity shock affecting all producers equally, and FC is a fixed cost of production that ensures that intermediate goods producers do not make any profits in the steady state of the economy.

Monopolistic competition between intermediate goods producing firms implies that they have market power and can set their own price. However, prices are sticky so every period, as in Calvo (1983), a fraction ξ_P of firms cannot optimally reset their price. For these firms, the price is reset according to the indexation rule

$$P_t(i) = \pi_{ss}^{1-\omega_P}\pi_{t-1}^{\omega_P}P_{t-1}(i), \tag{24}$$

where $\pi_t \equiv P_t/P_{t-1}$ is gross domestic inflation, π_{ss} is its steady-state value, and $\omega_P \in [0,1]$ controls the degree of indexation to realized inflation.

Intermediate goods producer i then has two problems to solve: a *cost minimization* problem and a *price setting* problem.

Cost minimization: Producer i chooses capital and labor to minimize the cost of producing a given amount $Y_t(i)$ of intermediate good i taking the rental rate of capital R_t^K and the wage W_t as given. The problem is:

$$\min_{K_t(i),N_t(i)} W_tN_t(i) + R_t^KK_t(i) + \lambda_t^Q(i)\left\{Y_t(i) - \exp\left(Z_t^Y\right)(K_t(i))^{\alpha}(N_t(i))^{1-\alpha} + FC\right\}, \tag{25}$$

where $\lambda_t^Q(i)$ is the nominal marginal cost of producing an additional unit of intermediate good i.

Price setting: When producer i can reset its price, it chooses the optimal price $\tilde{P}_t(i)$ by maximizing the expected present discounted value of future profits:

$$\mathbb{E}_t\sum_{k=0}^{\infty}(\beta\xi_P)^k\frac{\Lambda_{t+k}^cP_t}{\Lambda_t^cP_{t+k}}\left\{\Omega_{t+k}^p\tilde{P}_t(i)Y_{t+k|t}(i) - \lambda_{t+k}^QY_{t+k|t}(i)\right\}, \tag{26}$$

subject to the demand function (22) and the cost minimization problem (25). The variable $Y_{t+k|t}(i)$ is the amount sold of intermediate good i in period $t+k$ when producer i last reset its price in period t. Ω_t^P accounts for the cumulative effect of the price indexation in Equation (24):

$$\Omega_{t+k}^{p} = \begin{cases} 1 & k=0 \\ \prod_{j=1}^{k} \pi_{ss}^{1-\omega_P} \pi_{t+j-1}^{\omega_P} & k>0. \end{cases} \tag{27}$$

3.3 Final goods production

A representative final goods producer combines the domestic composite good with goods imported from abroad to produce a final good used for consumption, investment and government spending. The production function for the final goods producer is a standard CES function, so for $X_t \in \{C_t, I_t, G_t\}$ we have:

$$X_t = \left[(1-\alpha_m)^{1/\eta} \left(X_t^d \right)^{\frac{\eta-1}{\eta}} + \alpha_m^{1/\eta} \left(X_t^m \right)^{\frac{\eta-1}{\eta}} \right]^{\eta/(\eta-1)}, \tag{28}$$

where X_t^d is the input of the domestic composite good, and X_t^m is the input of imported goods. The parameter α_m is the weight on imported inputs, and η is the elasticity of substitution between domestic and foreign inputs in the production of the final good.

Note that for simplicity, we have the same weight on foreign inputs α_m and the same elasticity of substitution for each of the final goods $X_t \in \{C_t, I_t, G_t\}$. Hence, these final goods all have the same price, which we denote P_t^C for the price of consumption or the consumer price index (CPI). Profit maximization and the zero profit condition imply that P_t^C is given by

$$P_t^C = \left((1-\alpha_m)(P_t)^{1-\eta} + \alpha_m \left(\varepsilon_t P_t^* \right)^{1-\eta} \right)^{1/(1-\eta)}, \tag{29}$$

where we have used that the price of the imported good is given by $P_t^m = \varepsilon_t P_t^*$, where ε_t is the nominal exchange rate and P_t^* is the price of foreign goods in foreign currency. This holds because of the law of one price. The modeling of the foreign economy is discussed in Section 3.6.

CPI inflation is then given by

$$\pi_t^C \equiv P_t^C / P_{t-1}^C. \tag{30}$$

The representative final goods producer is competitive, and the standard profit maximization problem gives the demand for the two inputs as:

$$X_t^d = (1-\alpha_m) \left(P_t / P_t^X \right)^{-\eta} X_t, \tag{31}$$

$$X_t^m = \alpha_m \left(\varepsilon_t P_t^* / P_t^X \right)^{-\eta} X_t, \tag{32}$$

for each final good $X_t \in \{C_t, I_t, G_t\}$.

3.4 Resource sector

A representative firm in the resource sector extracts a natural resource and sells it in international markets. In order to operate, it demands materials M_t in the form of domestically produced goods and utilizes a capital stock specific to the resource sector K_t^o.[6] The accumulation of capital in the resource sector requires investment goods produced domestically I_t^o and is subject to investment adjustment costs similar to those that apply to the accumulation of capital in the rest of the economy.

The production function in the resource sector is given by

$$Y_t^o = A_o \exp\left(Z_t^{Y,o}\right) M_t^{\nu_m} \left(K_t^o\right)^{\nu_k}, \tag{33}$$

where A_o is the steady-state productivity of resource extraction, and $\nu_m, \nu_k \in [0,1]$ denote the output elasticities of oil production with respect to materials and resource-sector-specific capital, governing how intensively these inputs are used. In the calibration of these parameters we allow $\nu_m + \nu_k < 1$ implying decreasing returns to scale. This is consistent with a fixed factor (for example, resource reserves) or some other geological constraint on resource extraction. $Z_t^{Y,o}$ is a productivity shock in the resource sector.

The representative producer chooses M_t and I_t^o to maximize expected discounted real profits given by

$$\mathbb{E}_t \sum_{\tau=t}^{\infty} \beta^\tau \Lambda_\tau^c \frac{1}{P_\tau} \left[P_\tau^o Y_\tau^o - P_\tau M_\tau - P_\tau I_\tau^o\right], \tag{34}$$

subject to the capital accumulation equation

$$K_{t+1}^o = (1-\delta_o) K_t^o + \exp\left(Z_t^{I,o}\right) \left[1 - \Phi^o\left(\frac{I_t^o}{I_{t-1}^o}\right)\right] I_t^o, \tag{35}$$

where δ_o is the depreciation rate of capital in the resource sector. The price of the resource in international markets, P_t^o and the price of the domestically produced materials and investment goods, P_t, are taken as given. The investment adjustment cost function takes the following form:

$$\Phi^o\left(\frac{I_t^o}{I_{t-1}^o}\right) \equiv \frac{\chi_o}{2}\left(\frac{I_t^o}{I_{t-1}^o} - 1\right)^2, \tag{36}$$

where χ_o determines the extent of the adjustment cost. $Z_t^{I,o}$ is an investment-efficiency shock in the resource sector.

[6] We use the superscript o for variables in the resource sector in anticipation of our application of the model to the Norwegian economy. In that case, the natural resources in question are crude oil and natural gas, which we simplify in this model to mean "oil".

The price of the natural resource in domestic currency $P_t^o = \epsilon_t P_t^{o*}$, where P_t^{o*} is the price in foreign currency. The real price of the natural resource in international markets is defined as:

$$p_t^{o*} \equiv P_t^{o*}/P_t^*,$$

where P_t^* is the foreign price level.

Following Omotosho (2022) the real resource price in foreign currency follows the exogenous process

$$p_t^{o*} = \left(p_{t-1}^{o*}\right)^{\theta_{p,o}} \exp\left(E_t^{p,o}\right), \tag{37}$$

where $E_t^{p,o} \sim \mathcal{N}\left(0, \sigma_{p,o}^2\right)$ is a shock to the real resource price with a persistence $\theta_{p,o} \in [0, 1)$ and a standard deviation $\sigma_{p,o}$.

3.5 Government institutions

The model contains two government institutions: a fiscal authority that needs to finance government spending, and a central bank that conducts monetary policy.

3.5.1 Fiscal authority

The fiscal authority faces an exogenously given stream of government spending G_t that it needs to finance either via lump-sum taxes T_t or via the issuance of government bonds B_t. The budget constraint it faces is:

$$P_t^G G_t + R_{t-1} B_t = B_{t+1} + T_t, \tag{38}$$

where P_t^G denotes the price of government spending, and B_t is the stock of bonds at the start of period t.

Note that we simplify the model by ignoring any direct ownership by the government of firms in the resource sector. Any transfer of profits from the resource sector to the government would in any case simply reduce the need for lump-sum taxation. This is isomorphic to our setup where the resource sector transfers profits to the households who then can use them to pay the necessary lump-sum tax.

The exogenous process for the stream of government spending is given by

$$G_t = G_{ss} \exp(Z_t^G). \tag{39}$$

The size of government spending is calibrated to the share of government spending in domestic (non-resource sector) GDP in the data. However, we do not impose any pro- or countercyclicality of government spending. Its dynamics are driven purely by an exogenous government spending shock Z_t^G.

3.5.2 Central bank

A central bank sets the interest rate on domestic bonds according to a standard Taylor rule. The rule is a function of deviations of domestic inflation and output from their steady-state values, and allows for interest rate smoothing. It is given by

$$R_t = R_{ss}\left(\frac{R_{t-1}}{R_{ss}}\right)^{\rho_R}\left(\left(\frac{\pi_t^C}{\pi_{ss}^C}\right)^{\psi_\pi}\left(\frac{GDP_t^d}{GDP_{ss}^d}\right)^{\psi_Y}\right)^{1-\rho_R}\exp\left(Z_t^R\right), \tag{40}$$

where $\rho_R \in [0,1)$ controls the degree of interest rate smoothing, GDP^d denotes mainland GDP (discussed further in Section 3.8), ψ_π and ψ_Y are weights on deviations of inflation and mainland GDP from their steady-state values, and Z_t^R is a domestic monetary policy shock.

3.6 Foreign economy

The foreign economy and its impact on the domestic non-resource economy is modeled using a parsimonious three-equation framework. The equations capture fluctuations in foreign demand and the associated demand for exports of the domestic composite good, movements in the foreign price level that affect the real exchange rate, and changes in foreign nominal interest rates that influence the nominal exchange rate through an uncovered interest rate parity condition. These equations provide a tractable representation of foreign demand, price setting, and monetary policy relevant for the small open economy, in addition to the international resource price dynamics discussed in Section 3.4.

3.6.1 Foreign demand

The foreign economy is modeled as a simple one-good economy so that output equals consumption $Y_t^* = C_t^*$. Demand is determined by an Euler equation with a constant-relative risk aversion (CRRA) utility function without habits. The Euler equation is

$$\beta^*\mathbb{E}_t\left[\frac{R_t^*}{\pi_{t+1}^*}\exp\left(Z_{t+1}^{Y*}\right)\left(Y_{t+1}^*\right)^{-\sigma^*}\right] = \exp\left(Z_t^{Y*}\right)\left(Y_t^*\right)^{-\sigma^*}, \tag{41}$$

where R_t^* is the nominal interest rate abroad, π_t^* is inflation in the foreign economy, and Z_t^{Y*} is a foreign demand shock. The parameters are σ^*, the coefficient of relative risk aversion, and β^*, the discount factor.

As in the domestic economy, the final good in the foreign economy is produced with inputs produced in the foreign economy and inputs imported from the domestic non-resource sector. Production is given by

$$Y_t^* = \left[\left(1-\alpha_t^f\right)^{1/\eta_f}\left(Y_t^{d*}\right)^{\frac{\eta_f-1}{\eta_f}} + \left(\alpha_t^f\right)^{1/\eta_f}\left(Y_t^x\right)^{\frac{\eta_f-1}{\eta_f}}\right]^{\eta_f/(\eta_f-1)}, \tag{42}$$

where Y_t^{d*} are goods produced in the foreign economy and Y_t^x are imported goods (corresponding to exports from the domestic non-resource sector). The parameter η_f is the elasticity of substitution between inputs abroad, while $\alpha_t^f = \alpha_f \exp\left(Z_t^X\right)$ is the weight placed on imported inputs in the foreign economy. It is subject to a shock Z_t^X that affects the demand for exports from the domestic non-resource economy without influencing overall demand, interest rates and inflation abroad.

The price of the imported input in the foreign economy is P_t/ε_t. The demand for exports of the domestic composite good is therefore given by

$$Y_t^x = \alpha_f \exp\left(Z_t^X\right)\left(P_t/\varepsilon_t P_t^*\right)^{-\eta_f} Y_t^* = \alpha_f \exp\left(Z_t^X\right)\left(\frac{RER_t}{p_t^d}\right)^{\eta_f} Y_t^*, \tag{43}$$

where the real exchange rate RER_t is defined as the price of foreign goods in domestic currency relative to the consumer price index:

$$RER_t = \varepsilon_t P_t^*/P_t^C. \tag{44}$$

3.6.2 Foreign inflation

Inflation abroad is determined by a New Keynesian Phillips curve given by

$$\pi_t^* = \pi_{ss}^*\left(\frac{\mathbb{E}_t\pi_{t+1}^*}{\pi_{ss}^*}\right)^{\beta^*}\left(\frac{Y_t^*}{Y_{ss}^*}\right)^{\frac{(\sigma^*+\varphi^*)(1-\xi^*)(1-\beta^*\xi^*)}{\xi^*}}\exp\left(Z_t^{\pi*}\right), \tag{45}$$

where the exponent on output relative to its steady-state value is analogous to the one that arises in the domestic economy. That is, we allow for parameters φ^* and ξ^* to correspond with the inverse of the Frisch elasticity and price stickiness abroad, even though we do not explicitly model these aspects of the foreign economy. Z_t^* is a cost-push shock abroad.

3.6.3 Foreign central bank

A central bank in the foreign economy sets the interest rate on foreign bonds using a Taylor rule similar to the domestic one. The rule is given by

$$R_t^* = R_{ss}^*\left(\frac{R_{t-1}^*}{R_{ss}^*}\right)^{\rho_{R*}}\left(\left(\frac{\pi_t^*}{\pi_{ss}^*}\right)^{\psi_{\pi*}}\left(\frac{Y_t^*}{Y_{ss}^*}\right)^{\psi_{Y*}}\right)^{1-\rho_{R*}}\exp\left(Z_t^{R*}\right), \tag{46}$$

where ρ_{R*} determines interest rate smoothing abroad, and $\psi_{\pi*}$ and ψ_{Y*} are the Taylor rule coefficients on inflation and output, respectively. Z_t^{R*} is a monetary policy shock in the foreign economy.

3.7 Market clearing

Total production of the domestic composite good has to equal demand from the domestic non-resource economy, from foreign trading partners, and from the resource sector. Thus, we have the following market clearing condition:

$$C_t^d + I_t^d + G_t^d + Y_t^x + M_t + I_t^o = Y_t. \tag{47}$$

In addition, the domestic markets for capital, labor, and bonds all clear as is implied by our choice of notation.

3.8 National accounts

In the national accounts for this economy we want to separately account for the gross domestic products in the non-resource sector and the resource sector. This is not common, but in Norway, which will be our focus when taking this model to the data in Section 4, the national accounts produced by Statistics Norway contain measures of total GDP and mainland GDP.[7] When discussing business cycle fluctuations in Norway, economists and policy makers measure business cycles based on variation in mainland GDP.

The market clearing condition in Equation (47) implies the following expression for nominal non-resource sector GDP, $\mathcal{Y}_t^d = P_t Y_t$:

$$\mathcal{Y}_t^d = P_t C_t^d + P_t I_t^d + P_t G_t^d + P_t Y_t^x + P_t M_t + P_t I_t^o. \tag{48}$$

The final goods $\mathcal{X}_t \in \{C_t, I_t, G_t\}$ all contain imported components, so we define real net exports from the domestic non-resource sector as

$$NX_t^d = p_t^d Y_t^x - RER_t \left(C_t^m + I_t^m + G_t^m\right), \tag{49}$$

where we have deflated with the consumer price index P_t^C. Our measure of domestic real GDP for the non-resource sector is then given by:

$$GDP_t^d = \frac{P_t Y_t}{P_t^C} = C_t + I_t + G_t + p_t^d M_t + p_t^d I_t^o + NX_t^d. \tag{50}$$

Nominal GDP in the resource sector, $\mathcal{Y}_t^o$, is defined as nominal gross value added in that sector:

$$\mathcal{Y}_t^o = P_t^o Y_t^o - P_t M_t. \tag{51}$$

Nominal GDP for the total economy is then $\mathcal{Y}_t = \mathcal{Y}_t^d + \mathcal{Y}_t^o$, and this gives the equation for

[7] This label follows from the fact that the resource sector in Norway consists exclusively of offshore production of crude oil and natural gas.

real GDP:

$$GDP_t \equiv \frac{\mathcal{Y}_t}{P_t^C} = C_t + I_t + G_t + p_t^d I_t^o + NX_t, \tag{52}$$

where real net exports for the total economy is

$$NX_t = NX_t^d + p_t^{o*} RER_t Y_t^o. \tag{53}$$

3.9 Evolution of net foreign assets

The evolution of net foreign assets for this economy is derived from the households' budget constraint in Equation (4), the government budget constraint in Equation (38), the market clearing condition in Equation (47), and the expression for profits transferred to the household sector $\mathcal{D}_t$. We model the transfer of profits in a non-standard way which is discussed in the next subsection.

3.9.1 Distribution of resource sector profits

Profits are transferred to the household sector from domestic intermediate goods producers and from the resource sector. The expression we use for profits is:

$$\mathcal{D}_t = P_t Y_t - W_t N_t - R_t^K K_t + (1 - s_f)\left(P_t^o Y_t^o - P_t M_t - P_t I_t^o\right), \tag{54}$$

where s_f denotes a share of profits that are *not* transferred to the households. When taking the model to Norwegian data in Section 4, we think of 'f' as denoting "the fund". That is, a substantial amount of resource sector profits are transferred into a sovereign wealth fund and the existence of the fund does not affect households' decisions.[8]

In Norway, the sovereign wealth fund—the Government Pension Fund Global (GPFG)—receives transfers from the resource sector through three channels: a tax on the profits of petroleum companies operating offshore on Norway's continental shelf, net cash flow from the State's Direct Financial Interest (SDØE), and dividends from Equinor.[9] In our simple model, these transfers into the fund are captured by setting $s_f > 0$.

The key modeling decision with regard to the sovereign wealth fund is that the forward looking, optimizing households in the model, do not take the existence of the fund into account when making their decisions. In an appendix, Ferrero and Seneca (2019) explicitly model a sovereign wealth fund that invests in foreign assets. They show a result similar to Ricardian

[8]For other resource-rich economies it may be natural to think of 'f' as denoting "foreigners" if substantial resource sector profits are transferred abroad.

[9]The Government has direct ownership of about 30 percent of the oil and natural gas reserves. Equinor, formerly Statoil, used to be fully government owned. It was listed on the Oslo Stock Exchange in 2001, and the name was changed in 2018. The Norwegian government maintains ownership of a majority of the company, and owned 67 percent of the shares at the end of 2025.

equivalence, that a sovereign wealth fund that forward looking households know will be transferred to them over time can be equivalent to simply transferring all resource sector profits directly to households.

Our model breaks this equivalence result. We want to focus on business cycles over a horizon of about 10 years. The fund's stated purpose is to transfer wealth to future generations, therefore, we ignore its impact in the short term.[10] While it is true that having a claim to future payments from the fund may affect pension and precautionary savings decisions of Norwegian households, this claim is very different from households' own wealth. They cannot borrow against it in the bank, and their dependents do not inherit it upon their death. In our view, transferring all oil profits to the households, or to a fund equivalent to that, would massively overstate the impact of oil prices on short-term business cycle fluctuations.

3.9.2 Net foreign assets

With the expression for the transfer of profits to the households in Equation (54), we can derive the following expression for the evolution of net foreign assets:

$$b_t^* = \frac{1}{p_t^d} NX_t - s_f \left(p_t^{o*} \frac{RER_t}{p_t^d} Y_t^o - M_t - I_t^o \right) + R_{t-1}^* \Upsilon_{t-1} b_{t-1}^* \frac{\varepsilon_t}{\varepsilon_{t-1}} (\pi_t)^{-1} . \tag{55}$$

The expression says that the evolution of net foreign assets is driven by overall net exports net of transfers to the sovereign wealth fund. In Section 6.2 we discuss the implications for both overall and mainland net exports in the model's steady state when net foreign assets are constant.

3.10 Shocks

The shocks in the model, with the exception of Z_t^{FS} described in Equation (11), are first order autoregressive processes of the form

$$Z_t^X = \theta_X Z_{t-1}^X + \sigma_X E_t^X, \qquad 0 < \theta_X < 1 \tag{56}$$

for $X \in \{b, G, I, I^o, P, p^o, R, W, X, Y, Y^o, B^*, R^*, Y^*, \pi^*\}$. Note however, that for the monetary policy shocks we set $\theta_R = \theta_{R^*} = 0$. There is no persistence in the monetary policy shocks, but there is interest rate smoothing in both the domestic and foreign Taylor rules.

[10] The Norwegian government states that the goal of the fund is to "facilitate long-term considerations in the spending of government petroleum revenues, thus ensuring that the petroleum wealth benefits both current and future generations." (Finansdepartementet, 2025).

4 Parameterizing the model

In this section, we parameterize the model to study business cycles in the Norwegian economy. In Norway, the resource sector consists of extraction of oil and natural gas offshore. We will model this as an "oil sector" and focus on the impact of fluctuations in oil prices on activity in the mainland economy. A subset of the parameters in the model are calibrated with reference to common values in the literature or to match the steady state of the model to averages in the data. The rest are estimated using Bayesian methods.

4.1 Calibrated parameters

The calibrated parameters are listed in Table 1. We set the discount factor β to 0.994 to match the annualized neutral real interest rate over our sample period, which is 2.2 percent.[11] The labor disutility parameter χ_N is set to 5.5, which implies that the steady-state labor supply is roughly 1/3 of the time endowment. The coefficient of relative risk aversion σ is set to 1, which implies a logarithmic utility function, and the inverse Frisch elasticity of labor supply ϕ is also set to 1.

The capital share in domestic production, α, is set to 0.30. The depreciation rate of domestic capital δ is set to 0.0135, which implies an annual depreciation rate of 5.4 percent. The model then matches the steady-state ratio of mainland investment to mainland GDP. The elasticity of substitution between different varieties of domestic goods ϵ_D is set to 6, which implies a steady-state markup of 20 percent. Following Adolfson et al. (2005), the parameter ϵ_N governing the elasticity of substitution between different types of labor is set to 21, implying a steady-state wage markup of 5 percent.

The import share in domestic final goods α_m is set to 0.357, which is consistent with the sample average import share in the KVARTS quarterly macroeconomic model for Norway (Boug et al., 2023). As in Gundersen et al. (2024), the elasticities of substitution between domestic and foreign inputs in domestic and foreign production are set to 0.5 and 1.5, respectively.

The share of oil production in total GDP s_o is set to match the ratio of offshore GDP to total GDP in the data. Material inputs used in oil extraction relative to mainland GDP, $s_{m,o}$, and oil-sector capital as a share of the total capital stock, $s_{k,o}$, are set to the sample averages in the KVARTS quarterly macroeconomic model for Norway (Boug et al., 2023). The steady-state shares of oil investment and government spending in mainland GDP, $s_{i,o}$ and s_g, are set to the sample averages in the estimation data. The depreciation rate of oil-sector capital δ_o is set to match the ratio of offshore investments to the offshore capital stock. This gives a value of 0.0286, which implies an annual depreciation rate of about 11 percent.

The share of profits from the resource sector that is transferred to a fund, s_f, is set to 0.78, which corresponds with the tax rate on profits facing firms operating in the oil and gas sector

[11] Footnote 17 provides details on the construction of the neutral real interest rate series.

on Norway's continental shelf. The parameters of the production function in the oil sector, A_o, ν_m, and ν_k, are derived in the model's steady state to match the share parameters $s_{m,o}$ and $s_{k,o}$.

Domestic and foreign inflation is assumed to be zero in steady state, so $\pi_{ss} = \pi^* = 1$, to be consistent with the detrended data we use for estimation. The foreign discount factor β^* equals the domestic discount factor. The preference parameters for the foreign economy are set to standard values in the literature: $\sigma^* = 1$ and $\phi^* = 2$.

Table 1: Calibrated parameters

Parameter	Description	Value
Preferences		
β	Discount factor	0.994
χ_N	Labor disutility parameter	5.5
ϕ	Labor supply elasticity	1
σ	Risk aversion	1
Domestic goods production		
α	Share of capital in production	0.30
δ	Depreciation rate of capital (quarterly)	0.0135
ϵ_D	Elasticity of substitution between intermediate inputs	6
ϵ_N	Elasticity of substitution between labor types	21
Final goods production		
α_m	Import share	0.357
η	Elasticity of substitution between domestic and foreign goods	0.5
Oil sector and petroleum revenue allocation		
s_o	Share of oil production in GDP	0.201
s_m	Share of materials in oil extraction in mainland GDP	0.0187
$s_{i,o}$	Share of oil investment in mainland GDP	0.0679
$s_{k,o}$	Share of total capital that is oil-specific	0.136
s_f	Share of oil profits transferred to the oil fund	0.78
A_o	Steady-state productivity in the oil sector	0.34
δ_o	Depreciation rate of oil-sector capital (quarterly)	0.0286
ν_m	Share of materials in oil extraction	0.055
ν_k	Share of capital in oil extraction	0.24
Fiscal and monetary policy		
s_g	Share of government spending in mainland GDP	0.267
π_{ss}	Steady-state inflation rate	1
Foreign economy parameters / targets		
β^*	Foreign discount factor	0.994
σ^*	Foreign risk aversion	1
φ^*	Foreign inverse Frisch elasticity of labor supply	2
η_f	Foreign elasticity of substitution between domestic and foreign goods	1.5
π^*_{ss}	Steady-state foreign inflation rate	1

4.2 Bayesian estimation

The remaining parameters of the model are estimated using Bayesian methods. The model is log-linearized around the deterministic steady state and solved using standard techniques.[12] The resulting state-space representation is then estimated using Bayesian inference, combining prior information on the parameters with the likelihood implied by the model and the observed data. The likelihood function is evaluated using a heteroscedastic Kalman filter.[13] Table 2 lists our choices of prior distributions for the estimated parameters which correspond to standard choices in the literature.[14]

We use 15 observables in the estimation corresponding to the model variables: $\{GDP^d, C, I, I^o, G, X, W, \pi^C, R, RER, Y^o, p^{o,*}, Y^*, \pi^*, R^*\}$ where X_t is the total exports from the Norwegian economy:[15]

$$X_t = p_t^d Y_t^x + p_t^{o*} RER_t Y_t^o. \tag{57}$$

The series we use are quarterly and seasonally adjusted where appropriate. Generally, we use the log-difference for all the real variables and construct gap-variables for inflation and interest rates. For mainland GDP and its components, we construct real variables by deflating nominal variables by the CPI which is consistent with the structural VAR in Section 2 and with the variables in the model. We also allow for measurement error in mainland GDP and its components. The details of our data sources and the mapping between the data series and variables in the model are described in Appendix B.1.

4.3 Estimated parameters

Posterior distributions are obtained using Markov Chain Monte Carlo (MCMC) methods, and results from the model are obtained based on the posterior mode of all parameters. Table 3 shows the estimation results for the structural parameters. Results for the persistences of each shock and the standard deviations of their innovations are deferred to Appendix B.2.

Most parameters fall within the range typically reported in medium-scale DSGE models (see, for example, Adolfson et al., 2007; Smets and Wouters, 2003, 2007; Justiniano et al., 2013; Bergholt et al., 2019).

The posterior mean of habit persistence, $h = 0.82$, is in line with common estimates in the literature. For example, Justiniano et al. (2013) report a posterior mean of 0.82 for the United States, and Gundersen et al. (2024) find a posterior mean of 0.75 for Norway.

[12] The model is estimated using Dynare 5.4. (Adjemian et al., 2022).

[13] This allows the COVID-specific forced saving shock to have a standard deviation of $\sigma_{FS} = 0$ outside of the pandemic, and an estimated standard deviation for the period 2020Q1–2021Q4.

[14] See for example Adolfson et al. (2007); Justiniano and Preston (2010); Smets and Wouters (2007).

[15] We use total exports instead of net exports because we want to use the log-difference of real variables. For Norway, total net exports was negative in 1998Q4, so taking logs leads to an error.

Table 2: Prior distributions

Parameter	Description	Type	Mean	Std.
Structural parameters				
h	Habit persistence in consumption	$\mathcal{B}$	0.7	0.1
ϵ_B	Debt elasticity of risk premium	$\mathcal{IG}$	0.01	1.5
χ_I	Domestic investment adjustment cost	$\mathcal{G}$	5	1
χ_O	Oil investment adjustment cost	$\mathcal{G}$	5	1
ω_P	Price indexation	$\mathcal{B}$	0.5	0.15
ω_W	Wage indexation	$\mathcal{B}$	0.5	0.15
ψ_π	Monetary policy response to inflation	$\mathcal{N}$	1.7	0.3
ψ_Y	Monetary policy response to output	$\mathcal{G}$	0.25	0.125
ρ_R	Interest rate smoothing	$\mathcal{B}$	0.6	0.2
ξ_P	Calvo price stickiness	$\mathcal{B}$	0.66	0.1
ξ_W	Calvo wage stickiness	$\mathcal{B}$	0.66	0.1
$\psi_{\pi*}$	Foreign monetary policy response to inflation	$\mathcal{G}$	1.7	0.3
ψ_{Y*}	Foreign monetary policy response to output	$\mathcal{G}$	0.25	0.125
ρ_{R*}	Foreign interest rate smoothing	$\mathcal{B}$	0.75	0.15
ξ^*	Foreign Calvo price stickiness	$\mathcal{B}$	0.66	0.1
Shock processes				
μ_{FS}	MA coefficient of COVID-specific forced savings shock	$\mathcal{N}$	0	1
θ_X	Persistences of shocks	$\mathcal{B}$	0.5	0.15
σ_X	Standard deviations of shock innovations	$\mathcal{IG}$	0.5	1.5

Note: The same priors are set for all persistence parameters θ_X for $X \in \{b, G, I, I^o, P, p^o, W, X, Y, Y^o, B^*, Y^*, \pi^*\}$, and for all standard deviations σ_X for $X \in \{b, FS, G, I, I^o, P, p^o, R, W, X, Y, Y^o, B^*, R^*, Y^*, \pi^*\}$. For the distribution types, $\mathcal{B}$ represents beta, $\mathcal{G}$ gamma, $\mathcal{IG}$ inverse gamma, and $\mathcal{N}$ normal.

Investment adjustment costs are also of standard magnitude. For the non-resource sector, the posterior mean of χ_I falls within the usual range in the literature. For the oil sector, the estimate is very close to the estimate of 5.88 reported by Bergholt et al. (2019) for the Norwegian offshore sector. The estimated debt-elasticity of the risk premium is small, in line with the standard calibrations for small open economies (Schmitt-Grohé and Uribe, 2003).

The estimated nominal rigidities differ from those typically found in the DSGE literature, with both price and wage stickiness being higher. However, they are consistent with the estimates in Leeper et al. (2017) and Bianchi et al. (2023). These estimates therefore imply the common DSGE result that the frequency of price adjustment is lower than suggested by micro-level evidence (e.g., Bils and Klenow, 2004, Nakamura and Steinsson, 2008).

The combination of relatively low price indexation and high wage indexation is consistent with earlier findings for Norway in Bergholt et al. (2019), as well as evidence for the euro area and the U.S. in Smets and Wouters (2003) and Smets and Wouters (2007), respectively.

The monetary policy parameters are broadly in line with empirical estimates and satisfy the Taylor principle. The policy rate responds strongly to inflation, with a posterior mean of ψ_π

Table 3: Posterior distributions: structural parameters

Parameter	Description	Post. mean	Post. mode	10%	90%
h	Habit persistence in consumption	0.82	0.84	0.75	0.90
ϵ_B	Debt elasticity of risk premium	0.005	0.004	0.003	0.007
χ_I	Investment adjustment cost	6.39	6.11	4.77	7.97
χ_O	Oil investment adjustment cost	5.87	6.36	4.48	7.24
ω_P	Price indexation	0.17	0.22	0.05	0.28
ω_W	Wage indexation	0.47	0.46	0.23	0.71
ψ_π	MP response to inflation	2.80	2.95	2.45	3.14
ψ_Y	MP response to output	0.03	0.03	0.01	0.04
ρ_R	Interest rate smoothing	0.86	0.86	0.84	0.89
ξ_P	Calvo price stickiness	0.95	0.97	0.93	0.98
ξ_W	Calvo wage stickiness	0.91	0.92	0.88	0.94
$\psi_{\pi*}$	Foreign MP response to inflation	2.00	1.97	1.49	2.49
ψ_{Y*}	Foreign MP response to output	0.06	0.03	0.01	0.11
ρ_{R*}	Foreign interest rate smoothing	0.92	0.91	0.90	0.94
ξ^*	Foreign Calvo price stickiness	0.87	0.85	0.82	0.92

Note: Posterior moments are based on draws from the posterior distribution. Credible intervals report the 90% highest posterior density intervals. MP = Monetary policy.

larger than two, similar to the estimate of 2.32 in Justiniano et al. (2013) for the U.S. The small output coefficient ψ_Y and the high degree of interest rate smoothing ρ_R are likewise typical in the literature.

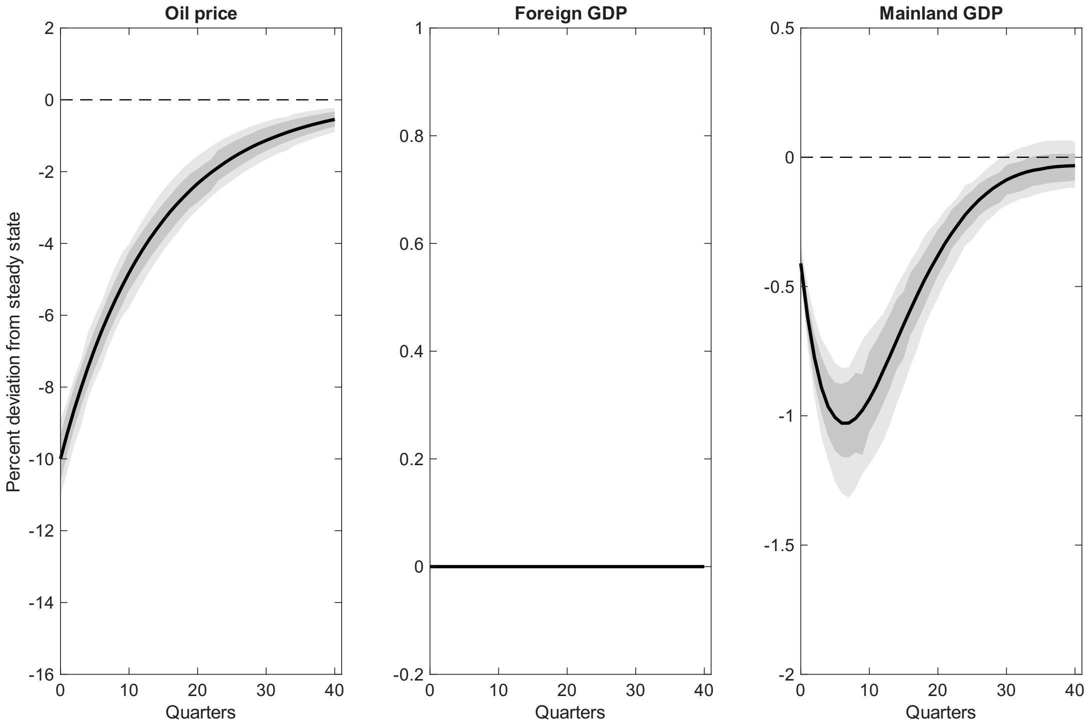
Finally, the parameters governing the dynamics of the foreign economy are in line with typical values in the literature.

5 Results

Once we have parameterized the model, we consider the implications of an oil price shock in the model and compare the results to the empirical results presented in Section 2. Then we use the model to analyze the downturns in the Norwegian economy in 2014–2016 and during the COVID-19 pandemic in 2020–2022.

5.1 Impulse responses after an oil price shock

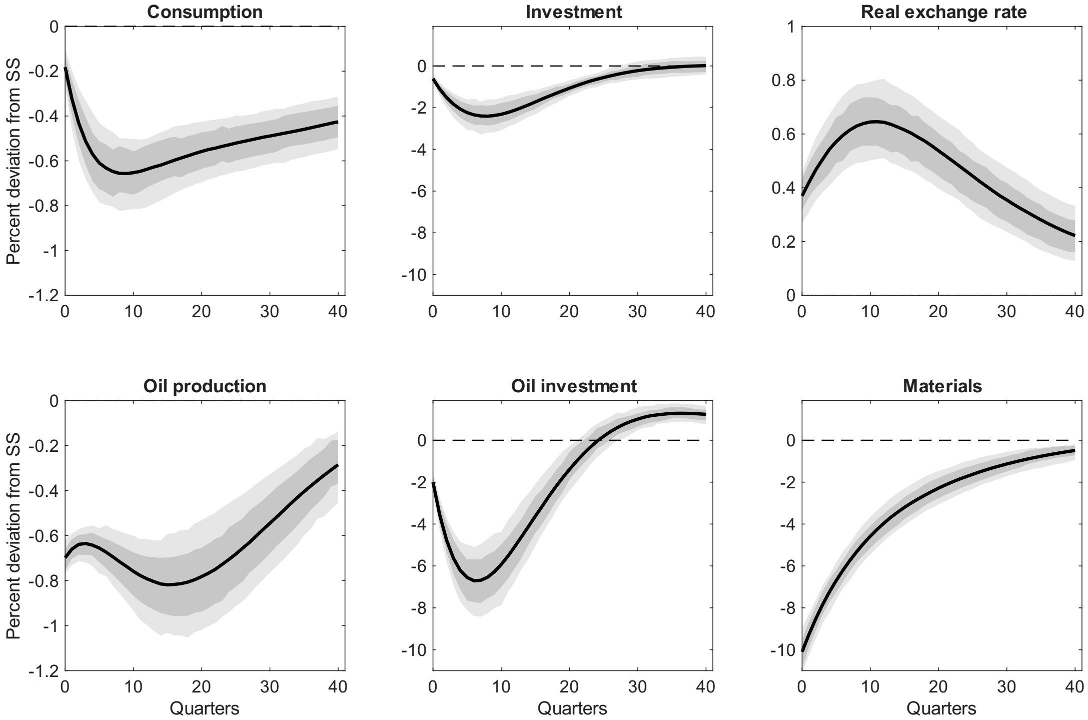
Figure 3 shows impulse responses to a negative oil price shock scaled to generate a 10 percent decline in the oil price upon impact. When comparing with the response in the structural VAR in Figure 1, we see that the response in mainland GDP in our DSGE model is very similar. Mainland GDP contracts by about 1 percent relative to its steady-state value after 8 quarters. This is a slightly deeper and faster contraction than in the VAR. Note that the DSGE model focuses on the Norwegian economy while keeping the model of the foreign economy parsimonious. We have therefore not attempted to model any response in economic activity among Norway's trading partners to an oil price shock. An increase in their economic activity, as in the VAR model, would likely increase the demand for mainland exports and dampen the negative effect on mainland GDP in Norway.



Note: The figure reports impulse responses to a negative oil price shock calibrated to generate a 10 percent decline in the oil price on impact. Responses are expressed as percent deviations from steady state. Dark shaded areas denote 68 percent credible intervals, while light shaded areas denote 90 percent credible intervals.

Figure 3: Impulse responses to an oil price shock in the DSGE model

Going beyond the comparison with the VAR, Figure 4 shows impulse responses for additional variables from the model in response to the same decline in the real price of oil. Upon impact, oil production declines and this leads to a sharp fall in the demand for materials from the mainland. Over time, gradual adjustment in investment in oil-specific capital in the oil sector leads to a hump-shaped response in the fall in demand for domestic goods for investment purposes. This gives the hump-shaped response in mainland GDP that we observe in Figure 3. The response in oil investment in our model is that it falls by about 6.5 percent 8 quarters after a 10 percent decline in the oil price. This effect is slightly larger than the empirical estimate in Skretting (2024), who finds that a 10 percent increase in oil prices raises oil investment by 4 percent after



Note: The figure reports impulse responses to a negative oil price shock calibrated to generate a 10 percent decline in the oil price on impact. Responses are expressed as percent deviations from steady state. Dark shaded areas denote 68 percent credible intervals, while light shaded areas denote 90 percent credible intervals.

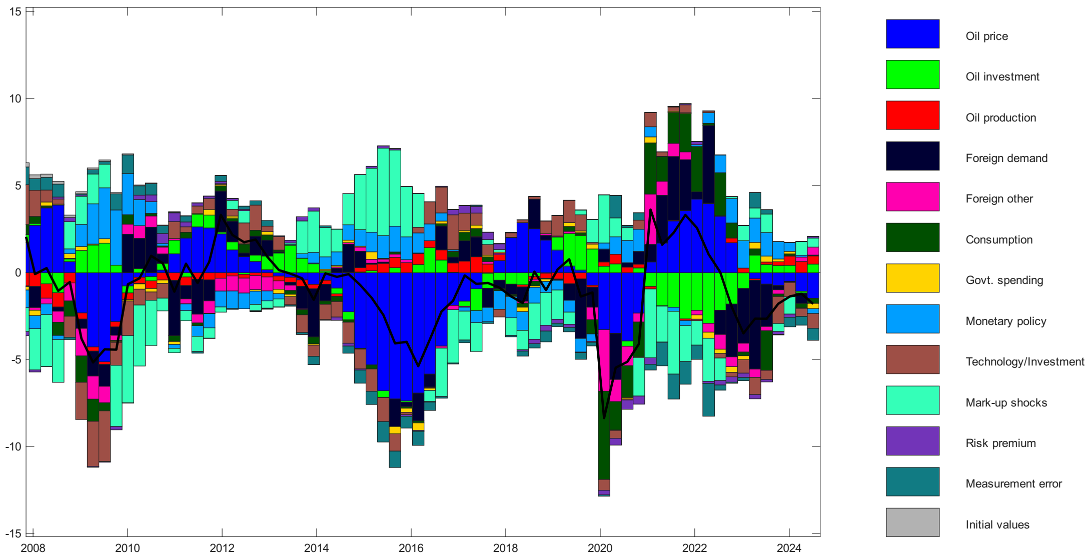
Figure 4: Impulse responses to an oil price shock in the DSGE model

two years.

In the mainland economy, both consumption and investment fall in response to the decline in activity offshore. The real exchange rate also depreciates as a result of two separate mechanisms. On impact, the oil price shock leads to a depreciation in the nominal exchange rate and a jump in CPI-inflation as foreign goods become more expensive. This leads to an increase in the nominal interest rate despite the decline in mainland GDP. Over time, the hump-shaped response in the real exchange rate is due to consumers borrowing from abroad to smooth consumption through the downturn. This leads to a decline in net foreign assets, and an associated hump-shaped response in the risk-premium. A fall in the oil price thus leads to a depreciation of the real exchange rate even though we have not modeled it as a function of oil prices directly.

5.2 Results for recent business cycles in Norway

The historical decomposition in Figure 2 showed that the decline in oil prices starting mid-2014 and continuing through 2015 was an important driver of the downturn in the Norwegian economy during that period. Figure 5 shows a shock decomposition of mainland GDP from the estimated DSGE model. As in the structural VAR, the DSGE model implies that oil price shocks contributed significantly to the decline in mainland GDP-growth in that period.



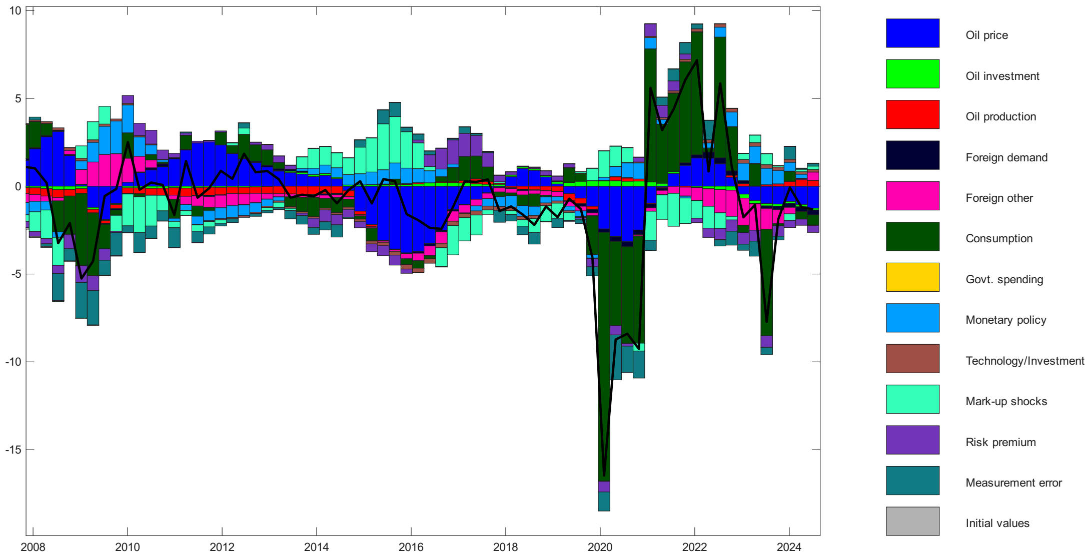
Note: The figure shows the historical shock decomposition of year-on-year growth in mainland GDP implied by the estimated model in deviation from its trend component. The bars represent the contribution of different structural shocks, while the black line shows the data.

Figure 5: Shock decomposition of mainland GDP

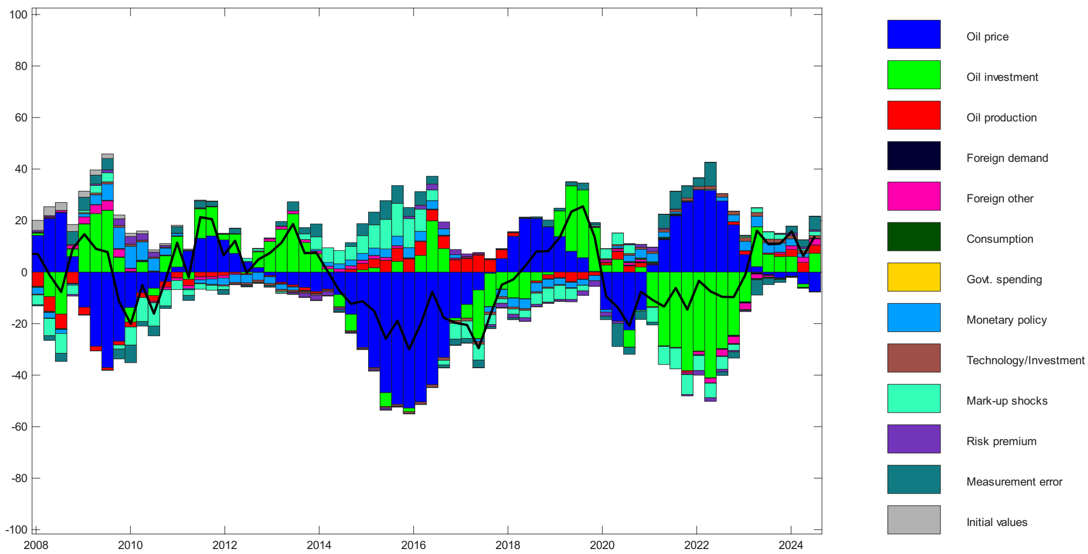
Turning to the COVID-19-pandemic starting in the first quarter of 2020, we see that the sharp downturn in mainland GDP in the Norwegian economy was mainly driven by the forced saving shock to consumption and a decline in economic activity among Norway's trading partners. But the contemporaneous decline in oil prices also contributed to the slowdown in mainland activity in Norway. This indicates that the mechanisms we normally think are important in driving business cycle fluctuations of small open economies should not be ignored even in the downturn that was clearly driven by the pandemic. It will be especially important to take these mechanisms into account if the aim is to compare differences in the response to the pandemic across countries, and to identify economic costs associated with different policies.

Figure 6a shows the shock decomposition of consumption in the model. The sharp drop in consumption during the pandemic is driven by the forced saving shocks. These should be interpreted as a combination of consumption dropping because of policy-driven shut-downs of economic activity that limited consumption possibilities and voluntary restrictions in consumption to avoid the risk of infection. Isolating these distinct mechanisms and their effects on consumption is not a goal in this paper. Instead the aim is to examine the importance of oil price shocks for fluctuations in economic activity in Norway, and to analyze the contribution of these shocks in the downturn during the pandemic. Even though the dynamics of consumption before and after the pandemic are clearly driven by the pandemic-specific shocks, the model indicates a small contribution also from the shocks to oil prices.

Figure 6b shows the shock decomposition of oil investment. Oil investment fell along with the declining oil price in 2014–2016, but then recovered prior to the onset of the pandemic. When the pandemic hit and oil prices again collapsed in 2020, oil investment fell again. However, when oil prices recovered after the pandemic and oil investment did not increase, the model interprets this as determined by a sequence of negative oil-investment-specific shocks. The decline in oil prices during the pandemic, and concerns about the economic consequences, led Norwegian politicians to introduce a stimulus policy for the oil industry as part of the government's pandemic response. The policy was specifically aimed at stimulating investment in the oil sector and is discussed further in Section 7.



(a) Consumption



(b) Oil investment

Note: The figure shows the historical shock decomposition of year-on-year growth in consumption (a) and oil investment (b) implied by the estimated model in deviation from its trend component. The bars represent the contribution of different structural shocks, while the black line shows the data.

Figure 6: Shock decompositions

6 Robustness

In this section we consider alternatives for some of the choices we made in modeling the resource sector. Specifically, we consider a version of the model where there is no accumulation of a sector-specific capital stock in the oil sector in Section 6.1, and a version where we do not transfer a substantial share of oil sector profits to an unmodeled sovereign wealth fund in Section 6.2.

6.1 No oil-sector-specific capital stock

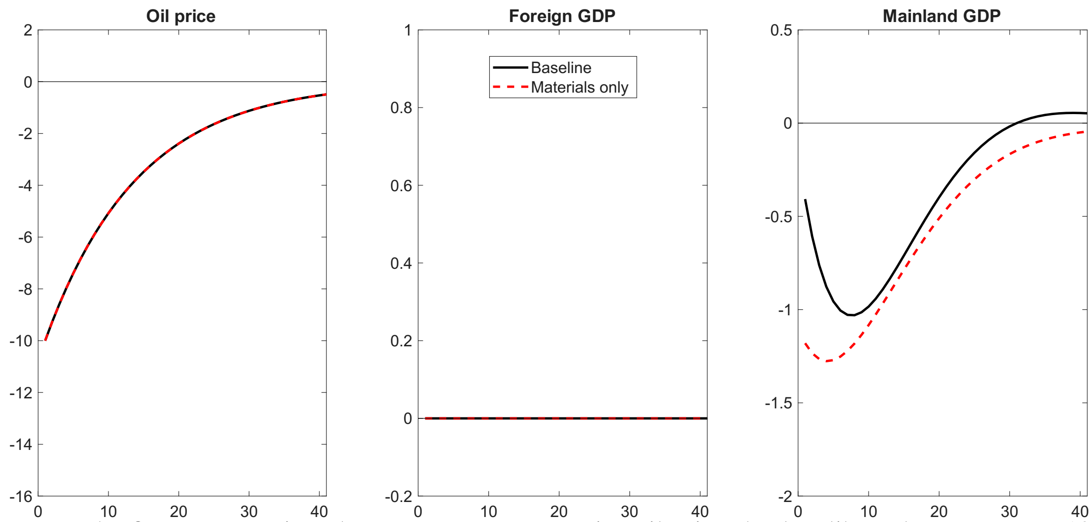
In our baseline model we developed a resource sector that demands materials from the mainland economy as an input in resource extraction, and also demands investment goods for the accumulation of a sector-specific capital stock. In a simpler model of the resource sector, Ferrero and Seneca (2019) label the demand for goods from the mainland as "materials" only. They can still capture the overall demand effect from the resource sector by calibrating their model to the overall flow of both materials and investment goods from the mainland to the resource sector. In this section, we consider a similar simplified version of our production function in the resource sector that ignores sector-specific capital.

In the alternative model, we set $\nu_k = 0$ in the production function in Equation (83). Oil extraction then demands only materials from the mainland economy. The steady-state share of "materials" in the production function is then calibrated as $\tilde{s}_m = s_m + s_{i,o} = 0.087$ from Table 1. That is, the model with the simpler production function captures the overall demand for goods from the mainland economy in the steady state, but it ignores the distinction between materials and investment goods.

Figure 7 shows that the dynamic properties of the alternative model are quite different from our baseline version. The figure plots the impulse response of mainland GDP in both models. When demand from the resource sector is not subject to the adjustment costs associated with capital accumulation, the immediate response to an oil price shock is much larger than in the structural VAR (Figure 1), and it does not follow the same hump-shaped pattern. Sector-specific capital accumulation that we include in the baseline model is, therefore, crucial to jointly match both the average demand for mainland goods from the resource sector in the steady state and the dynamic properties of this demand in response to oil price shocks.

6.2 No transfer of profits from the oil sector into a fund

In the baseline version of the model, we set the share of oil sector profits that are transferred to an unmodeled fund to $s_f = 0.78$ to match the tax rate firms in the petroleum sector face in Norway. However, as this approach is not standard, we investigate the implications in the model of setting $s_f = 0$ instead. With $s_f = 0$, all profits from the oil sector are transferred to the households. Again, note the equivalence result in Ferrero and Seneca (2019). They show that



Note: The figure reports impulse responses to a negative oil price shock calibrated to generate a 10 percent decline in the oil price on impact. Responses are expressed as percent deviations from steady state.

Figure 7: Impulse responses to an oil price shock in alternative versions of the DSGE model

"a sovereign wealth fund set up to invest oil revenues, [. . .], is irrelevant for the equilibrium allocation" (p. 961). In their baseline analysis, they therefore transfer oil profits directly to the households as we do when setting $s_f = 0$.

Table 4: Ratios to mainland GDP

Variable	Data	Model ($s_f = 0.78$)	Model ($s_f = 0$)
Consumption (C)	0.53	0.56	0.70
Investment (I)	0.21	0.21	0.21
Oil investment (I^o)	0.07	0.07	0.07
Government spending (G)	0.27	0.27	0.27
Mainland net exports (NX^d)	-0.04	-0.13	-0.27
Net exports (NX)	0.15	0.14	0.00

Note: The table reports selected steady-state ratios relative to mainland GDP in the model and the corresponding average ratios in the data. The columns labeled Model report steady-state values from the model under alternative assumptions for the parameter s_f.

Table 4 shows the implication in the steady state of the model of transferring oil sector profits to the households. In a stationary steady state where net foreign assets are equal to zero, Equation (55) implies that total net exports for the economy also have to equal zero. The result is that all oil exports finance mainland imports in the steady state. Hence, mainland net exports become much more negative than they are in the data. This leads to a large increase in consumption as households spend the oil profits that are transferred to them each period.

Therefore, we prefer the model with $s_f = 0.78$ when studying short-term business cycle fluctuations in Norway. For questions regarding the long-term sustainability of Norway's fiscal policy, however, a detailed model of the sovereign wealth fund would be required.

7 Discussion of the policy response to the oil price shock during the pandemic

As shown in Figure 5, our model indicates that oil price shocks during the first couple of quarters of 2020 contributed significantly to the downturn in the Norwegian economy. Norwegian policymakers were concerned about this effect at the time. Therefore, support for the oil industry was included in the set of policies that was implemented in response to the COVID-19 pandemic.

The oil industry support package was proposed by the Ministry of Finance in May 2020 (Finansdepartementet, 2020) and became law in June. The stated purpose was to improve the liquidity of oil companies after the pandemic-driven collapse in oil and gas prices, so that planned projects would not be postponed or canceled. The law improved the liquidity of oil companies by bringing tax deductions for investments forward in time, effectively lowering the short-term financing cost of investment.

Figure 6b indicates that the oil price shocks during 2020 contributed to a decline in investment in the oil sector in our model. However, we have not modeled the effect on investment from the support package for the oil sector. The reason is that most of the effect of this package does not show up in the oil investment data in our sample period due to national accounts being recorded on an accrual basis. Even though the intention was to stimulate oil investment in the short term, the package mainly affected investment projects for which plans were submitted to the Ministry of Petroleum and Energy by January 1, 2022, and were approved before January 1, 2023. Existing investment projects submitted and approved by May 12, 2020, were explicitly excluded from the support package. This created a strong incentive to submit projects before the deadline and the investment value of these projects will be accrued in the national accounts over many years following that date.

In the business cycle report Economic Survey 3/2025 (Statistics Norway, 2025), it is argued that the support package implemented in 2020 did not affect oil investment until 2023–2024 (see Box 1). By this time international energy prices had recovered and increased substantially after the invasion of Ukraine in 2022. Hence, this policy does not seem appropriate to provide short term economic stimulus, despite our results that falling oil prices contributed to the downturn in the Norwegian economy during the pandemic and did so partly through affecting oil investments. However, it is possible that this policy prevented investments in the oil sector from falling even more than they did during the pandemic period.

8 Conclusion

In recent years there has been a debate about whether oil and gas reserves should be considered "stranded assets." Efforts to reduce carbon dioxide emissions to limit global warming may lead to a transition away from fossil fuels toward greener sources of energy. Such a transition could reduce the demand for petroleum products and lead to a sustained decline in the prices of oil and natural gas. In that case, price fluctuations would cease to be an important driver of economic activity among (former) petroleum exporters.

So far, there have been few signs that such a transition has had a significant impact on oil prices. The Russian invasion of Ukraine and the war in Iran resulting in the closing of the Strait of Hormuz both lead to surges in energy prices, with oil prices rising above $100 per barrel. Oil prices are, therefore, likely to remain an important driver of economic activity in petroleum exporting countries in the medium term.

This paper develops a small open economy model with a resource sector that takes the world resource price as given and demands materials and investment goods from the non-resource economy as inputs in resource extraction. Estimating the model using Norwegian data, we show that it captures the effects of oil price shocks on mainland economic activity that are broadly consistent with the empirical response in a simple structural VAR model. The results indicate that oil prices are an important driver of business cycle dynamics in Norway.

The model also includes a shock that captures the large fluctuations in consumption and economic activity during the COVID-19 pandemic. Even during this period, however, other mechanisms affecting business cycle dynamics remain important. Oil prices fell sharply during the pandemic, and the model indicates that this decline contributed to the downturn in the Norwegian economy. These findings suggest that studies comparing the economic effects of different pandemic responses across countries should take into account the structural features that shape their business cycles.

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A Derived model equations

A.1 Equilibrium conditions

Households Euler equation for consumption:

$$\beta R_t \mathbb{E}_t \left[\pi_{t+1}^{-1} \Xi_{t+1}^c\right] = \Xi_t^c. \tag{58}$$

Marginal utility of consumption:

$$\Xi_t^c = p_t^d \exp\left(Z_t^U\right) \frac{\left(C_t - hC_{t-1}\right)^{-\sigma}}{(1-h)^{-\sigma}}. \tag{59}$$

Foreign bond holdings:

$$\frac{R_t}{R_t^*} = E_t \left(\frac{\varepsilon_{t+1}}{\varepsilon_t}\right) \Upsilon_t. \tag{60}$$

Change in the real exchange rate:

$$\frac{RER_t}{RER_{t-1}} = \frac{\varepsilon_t}{\varepsilon_{t-1}} \frac{\pi_t^*}{\pi_t^C}. \tag{61}$$

Risk premium:

$$\Upsilon_t = \exp\left(-\epsilon_B \left(b_t^* - b_{ss}^*\right)\right) \exp\left(Z_t^{B*}\right). \tag{62}$$

Optimal investment:

$$\begin{aligned} \frac{1}{p_t^d} &= Q_t \exp\left(Z_t^I\right) \left[1 - \frac{\chi_I}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2 - \chi_I \left(\frac{I_t}{I_{t-1}} - 1\right) \frac{I_t}{I_{t-1}}\right] \\ &+ \beta \mathbb{E}_t \left[Q_{t+1} \frac{\Xi_{t+1}^c}{\Xi_t^c} \exp\left(Z_{t+1}^I\right) \chi_I \left(\frac{I_{t+1}}{I_t} - 1\right) \left(\frac{I_{t+1}}{I_t}\right)^2\right]. \end{aligned} \tag{63}$$

Optimal capital stock:

$$Q_t = \beta \mathbb{E}_t \left\{\frac{\Xi_{t+1}^c}{\Xi_t^c} \left[r_{t+1}^K + (1-\delta) Q_{t+1}\right]\right\}, \tag{64}$$

where $r_t^K \equiv R_t^K / P_t$.

Capital accumulation:

$$K_{t+1} = (1-\delta) K_t + \exp\left(Z_t^I\right) \left[1 - \Phi^d \left(\frac{I_t}{I_{t-1}}\right)\right] I_t. \tag{65}$$

Demand for domestic consumption goods:

$$C_t^d = (1-\alpha_m) \left(p_t^d\right)^{-\eta} C_t. \tag{66}$$

Demand for foreign consumption goods:

$$C_t^m = \alpha_m RER_t^{-\eta} C_t. \tag{67}$$

Consumer price index:

$$1 = \left((1-\alpha_m) \left(p_t^d \right)^{1-\eta} + \alpha_m RER_t^{1-\eta} \right)^{1/(1-\eta)}. \tag{68}$$

Consumer price inflation:

$$\pi_t^C = \left((1-\alpha_m) \left(\pi_t p_{t-1}^d \right)^{1-\eta} + \alpha_m \left(RER_t \pi_t^C \right)^{1-\eta} \right)^{1/(1-\eta)}. \tag{69}$$

Demand for domestic investment goods:

$$I_t^d = (1-\alpha_m) \left(p_t^d \right)^{-\eta} I_t. \tag{70}$$

Demand for foreign investment goods:

$$I_t^m = \alpha_m RER_t^{-\eta} I_t. \tag{71}$$

Optimal real wage:

$$\tilde{w}_t^{1+\phi\epsilon_N} = \frac{\epsilon_N}{\epsilon_N - 1} (1+\phi) \frac{f_t^{1,w}}{f_t^{2,w}} \exp\left(Z_t^W \right), \tag{72}$$

where $\tilde{w}_t = \tilde{W}_t / P_t$ is the optimal real wage and

$$f_t^{1,w} = \exp\left(Z_t^U \right) N_t^{1+\phi} w_t^{(1+\phi)\epsilon_N} + \beta \xi_W \mathbb{E}_t f_{t+1}^{1,w} \left[\left(\pi_{ss}^C \right)^{1-\omega_W} \left(\pi_t^C \right)^{\omega_W} \pi_{t+1}^{-1} \right]^{-(1+\phi)\epsilon_N}, \tag{73}$$

$$f_t^{2,w} = N_t \Xi_t^c w_t^{\epsilon_N} + \beta \xi_W \mathbb{E}_t f_{t+1}^{2,w} \left[\left(\pi_{ss}^C \right)^{1-\omega_W} \left(\pi_t^C \right)^{\omega_W} \pi_{t+1}^{-1} \right]^{1-\epsilon_N}. \tag{74}$$

Wage index:

$$w_t = \left[(1-\xi_W) \tilde{w}_t^{1-\epsilon_N} + \xi_W \left(\left(\frac{\pi_{t-1}^C}{\pi_{ss}^C} \right)^{\omega_W} \left(\frac{\pi_t}{\pi_{ss}^C} \right)^{-1} w_{t-1} \right)^{1-\epsilon_N} \right]^{\frac{1}{1-\epsilon_N}}, \tag{75}$$

where $w_t = W_t / P_t$ is the real wage.

Production of domestic goods Production:

$$Y_t\left(i\right)=\exp\left(Z_t^Y\right)\left(K_t\left(i\right)\right)^{\alpha}\left[N_t\left(i\right)\right]^{1-\alpha}-FC. \tag{76}$$

Capital demand:

$$r_t^K=\Xi_t^Q\left(i\right)\alpha\exp\left(Z_t^Y\right)\left(K_t\left(i\right)\right)^{\alpha-1}\left[N_t\left(i\right)\right]^{1-\alpha}. \tag{77}$$

Real marginal cost:

$$\Xi_t^Q=\frac{\left(r_t^K\right)^{\alpha}\left(w_t\right)^{1-\alpha}}{\alpha^{\alpha}\left(1-\alpha\right)^{1-\alpha}\exp\left(Z_t^Y\right)}, \tag{78}$$

with real marginal cost $\Xi_t^Q\equiv\frac{\lambda_t^Q}{P_t}$.

Domestic reset price equation:

$$\tilde{\pi}_t=\frac{\epsilon_D}{\epsilon_D-1}\frac{f_t^{1,p}}{f_t^{2,p}}\pi_t, \tag{79}$$

where $\tilde{\pi}_t=\tilde{P}_t/P_{t-1}$ is reset price inflation and

$$f_t^{1,p}=\Xi_t^Q\exp\left(Z_t^P\right)Y_t+\beta\xi_P\mathbb{E}_t\frac{\Xi_{t+1}^c}{\Xi_t^c\pi_{t+1}}\left(\pi_{ss}^{1-\omega_P}\pi_t^{\omega_P}/\pi_{t+1}\right)^{-\epsilon_D}f_{1,t+1}^p, \tag{80}$$

$$f_t^{2,p}=Y_t+\beta\xi_P\mathbb{E}_t\frac{\Xi_{t+1}^c}{\Xi_t^c\pi_{t+1}}\left(\pi_{ss}^{1-\omega_P}\pi_t^{\omega_P}/\pi_{t+1}\right)^{1-\epsilon_D}f_{2,t+1}^p. \tag{81}$$

Domestic inflation:

$$\pi_t=\left[\left(1-\xi_P\right)\tilde{\pi}_t^{1-\epsilon_D}+\xi_P\left(\pi_{ss}^{1-\omega_P}\pi_{t-1}^{\omega_P}\right)^{1-\epsilon_D}\right]^{1/(1-\epsilon_D)}. \tag{82}$$

Resource sector Production:

$$Y_t^o=A_o\exp\left(Z_t^{Y,o}\right)M_t^{\nu_m}\left(K_t^o\right)^{\nu_k}. \tag{83}$$

Capital accumulation:

$$K_{t+1}^o=\left(1-\delta_o\right)K_t^o+\exp\left(Z_t^{I,o}\right)\left[1-\Phi^o\left(\frac{I_t^o}{I_{t-1}^o}\right)\right]I_t^o. \tag{84}$$

Demand for materials in the resource sector:

$$M_t=\nu_mY_t^op_t^{o*}\frac{RER_t}{p_t^d}. \tag{85}$$

Optimal investment:

$$1 = Q_t^o \exp\left(Z_t^{I,o}\right)\left[1 - \Phi^o\left(\frac{I_t^o}{I_{t-1}^o}\right) - \Phi'^o\left(\frac{I_t^o}{I_{t-1}^o}\right)\frac{I_t^o}{I_{t-1}^o}\right] + \beta\mathbb{E}_t\left\{Q_{t+1}^o \frac{\Xi_{t+1}^c}{\Xi_t^c}\exp\left(Z_{t+1}^{I,o}\right)\Phi'^o\left(\frac{I_{t+1}^o}{I_t^o}\right)\left(\frac{I_{t+1}^o}{I_t^o}\right)^2\right\}. \quad (86)$$

Capital demand:

$$\mathbb{E}_t\left[\beta\frac{\Xi_{t+1}^c}{\Xi_t^c}\left\{\nu_k p_{t+1}^{o*}\frac{RER_{t+1}}{p_{t+1}^d}\frac{Y_{t+1}^o}{K_{t+1}^o} + Q_{t+1}^o\left(1-\delta_o\right)\right\}\right] = Q_t^o. \quad (87)$$

Real oil price in foreign currency:

$$p_t^{o*} = \left(p_{t-1}^{o*}\right)^{\theta_{p,o}}\exp\left(E_t^{p,o}\right). \quad (88)$$

Government institutions Taylor rule:

$$R_t = R_{ss}\left(\frac{R_{t-1}}{R_{ss}}\right)^{\rho_R}\left(\left(\frac{\pi_t^C}{\pi_{ss}^C}\right)^{\psi_\pi}\left(\frac{GDP_t^d}{GDP_{ss}^d}\right)^{\psi_Y}\right)^{1-\rho_R}\exp\left(Z_t^R\right). \quad (89)$$

Government spending:

$$G_t = G_{ss}\exp(Z_t^G), \quad (90)$$

$$G_t^d = (1-\alpha_m)\left(p_t^d\right)^{-\eta}G_t, \quad (91)$$

$$G_t^m = \alpha_m RER_t^{-\eta}G_t. \quad (92)$$

Market clearing

$$C_t^d + I_t^d + G_t^d + Y_t^x + M_t + I_t^o = Y_t \quad (93)$$

Capital market clearing

$$K_t^{tot} = K_t + K_t^o \quad (94)$$

National accounts Trade balance for the mainland economy:

$$NX_t^d = p_t^d Y_t^x - RER_t\left(C_t^m + I_t^m + G_t^m\right). \quad (95)$$

GDP for the mainland economy (CPI deflated):

$$GDP_t^d = C_t + I_t + G_t + p_t^d M_t + p_t^d I_t^o + NX_t^d. \quad (96)$$

Trade balance for the total economy:

$$NX_t = NX_t^d + p_t^{o*} RER_t Y_t^o. \tag{97}$$

Overall exports:

$$X_t = p_t^d Y_t^x + p_t^{o*} RER_t Y_t^o. \tag{98}$$

Overall imports:

$$IM_t = RER_t \left(C_t^m + I_t^m + G_t^m \right). \tag{99}$$

GDP for the total economy (CPI deflated):

$$GDP_t = C_t + I_t + G_t + p_t^d I_t^o + NX_t. \tag{100}$$

Evolution of foreign assets

$$b_t^* = \frac{1}{p_t^d} NX_t - s_f \left(p_t^{o*} \frac{RER_t}{p_t^d} Y_t^o - M_t - I_t^o \right) + R_{t-1}^* \Upsilon_{t-1} b_{t-1}^* \frac{\varepsilon_t}{\varepsilon_{t-1}} (\pi_t)^{-1} \tag{101}$$

Foreign economy Export demand:

$$Y_t^x = \alpha_f \exp\left(Z_t^X\right) \left(\frac{RER_t}{p_t^d} \right)^{\eta_f} Y_t^*. \tag{102}$$

Foreign demand:

$$\beta^* \mathbb{E}_t \left[\frac{R_t^*}{\pi_{t+1}^*} \exp\left(Z_{t+1}^{Y*}\right) \left(Y_{t+1}^*\right)^{-\sigma^*} \right] = \exp\left(Z_t^{Y*}\right) \left(Y_t^*\right)^{-\sigma^*}. \tag{103}$$

Foreign new Keynesian Phillips curve:

$$\pi_t^* = \pi_{ss}^* \left(\frac{\mathbb{E}_t \pi_{t+1}^*}{\pi_{ss}^*} \right)^{\beta^*} \left(\frac{Y_t^*}{Y_{ss}^*} \right)^{\frac{(\sigma^*+\varphi^*)(1-\xi^*)(1-\beta^*\xi^*)}{\xi^*}} \exp\left(Z_t^{\pi*}\right). \tag{104}$$

Foreign Taylor rule:

$$R_t^* = R_{ss}^* \left(\frac{R_{t-1}^*}{R_{ss}^*} \right)^{\rho_{R*}} \left(\left(\frac{\pi_t^*}{\pi_{ss}^*} \right)^{\psi_{\pi*}} \left(\frac{Y_t^*}{Y_{ss}^*} \right)^{\psi_{Y*}} \right)^{1-\rho_{R*}} \exp\left(Z_t^{R*}\right). \tag{105}$$

A.2 Normalization of shocks

Before estimation, we normalize a few of the shocks so that it is easier to interpret the estimated standard deviations. Specifically, the normalized intertemporal preference shock, η_t^b, COVID-specific forced saving shock, η_t^{FS}, investment-specific shock, η_t^I, wage mark-up shock, η_t^W, price mark-up shock, η_t^P, oil investment shock, $\eta_t^{I,o}$, and foreign demand shock, $\eta_t^{Y^*}$, are defined as follows:

$$\eta_t^b \equiv \frac{(1-h)}{\sigma(1+h)} Z_t^b, \tag{106}$$

$$\eta_t^{FS} \equiv \frac{(1-h)}{\sigma(1+h)} Z_t^{FS}, \tag{107}$$

$$\eta_t^I \equiv \frac{1}{(1+\beta)\chi_I} Z_t^I, \tag{108}$$

$$\eta_t^W \equiv \frac{1-\xi_W-(1-\xi_W)\beta\theta_W\xi_W}{\xi_W(1+\beta)} Z_t^W, \tag{109}$$

$$\eta_t^P \equiv \frac{(1-\beta\xi_P)(1-\xi_P)}{\xi_P(1+\beta\omega_P)} Z_t^P, \tag{110}$$

$$\eta_t^{I,o} \equiv \frac{1}{(1+\beta)\chi_o} Z_t^{I,o}, \tag{111}$$

$$\eta_t^{Y*} \equiv \frac{(1-\theta_{Y*})}{\sigma^*} Z_t^{Y*}. \tag{112}$$

B Bayesian estimation

This appendix describes the data we use in the estimation of the model and how we map these series to model variables. It also presents results for the posterior distributions for the parameters of all the shock processes in the model.

B.1 Observables and measurement equations

In the Bayesian estimation of the model we use data for the following model variables: $\{GDP^d, C, I, I^o, G, X, W, \pi^C, R, RER, Y^o, p^{o*}, Y^*, \pi^*, R^*\}$. The sources we use are listed in Table 6. All the series are quarterly and demeaned for the period 1995Q1 to 2024Q4.

For the following series, we use nominal, seasonally adjusted series from Statistics Norway that are deflated with CPI: $\{GDP^d, C, I, I^o, G, X\}$. We take the log-difference of each series and map it to the growth rate of the corresponding variable in the model. For these series, we also allow for measurement error which is calibrated to explain up to 10 percent of the variation in each series. For I^o we take the price of the domestic composite intermediate good relative to CPI into account when mapping the data to the model variable.

The wage series is an index for earnings in the manufacturing sector from the OECD. We use the nominal wage index, seasonally adjust it, and deflate with CPI to obtain data for the real wage in the manufacturing sector. This corresponds with Norway's centralized wage bargaining framework, where the wage negotiated for the manufacturing sector also determines wage growth in the rest of the economy. The log-difference of the series is mapped to the growth rate of the real wage in the model, taking the price of the domestic composite intermediate good relative to CPI into account.

For the inflation variables $\{\pi^C, \pi^*\}$, we construct gap-variables equal to inflation relative to the inflation target. We use the inflation target in Norway for both variables.[16] The gap-variables from the data are mapped to inflation relative to the steady state in the model.

For the short-term nominal interest rates $\{R, R^*\}$, we construct gap-variables equal to the interest rate relative to an estimate of the neutral real rate. We use estimates for the neutral real rate in Norway from Norges Bank for both variables.[17] The gap-variables from the data are mapped to interest rates relative to the steady state in the model.

The real exchange rate series is the inverse of the broad real effective exchange rate index for Norway from the Bank for International Settlements. The nominal index is constructed as a trade-weighted average of bilateral exchange rates, and the real index adjusts the nominal one with relative consumer prices. Production in the oil-sector is measured as offshore economic activity in Norway which consists of the value added in the oil and gas sectors and in ocean transport. Thus, the sum of the measure of production in the oil sector and mainland GDP is equal to Norway's total GDP. The real oil price is the price of Brent Crude deflated with US CPI both obtained from the Federal Reserve Economic Data database. Economic activity among Norway's trading partners is constructed as an export-weighted average of real GDP among Norway's most important trading partners. Those trading partners and the export-weights we use are listed in Table 5. The same weights are used to construct trade-weighted measures of inflation and the nominal interest rate for Norway's trading partners. For the series $\{RER, Y^o, p^{o*}, Y^*\}$, the log-difference is mapped to the growth rate of the corresponding variable in the model.

Table 5: Export weights

Country	Weight	Country	Weight
Eurozone	0.50	United States	0.11
Sweden	0.15	Denmark	0.08
United Kingdom	0.12	Poland	0.03

Note: Fixed country weights are averages across 1999Q1–2019Q4.

[16]The inflation target in Norway was 2.5 percent from the introduction of inflation targeting in March 2001 until it was reduced to 2 percent in March 2018. For data prior to 2001, we construct the gap relative to the average level of inflation.

[17] Norges Bank publishes regularly updated estimates of the neutral real interest rate interval in the reports accompanying its policy rate decisions, which are issued four times a year. With Figure 1.4 in Inflation Report 3/2005, Norges Bank provided the estimated interval spanning the time period 1996–2008 (projected rate for 2005–2008). Since 2005, the estimate has been lowered multiple times and Figure 4.B in Monetary Policy Report 2/2024 provides the estimates for the time-period 2005–2024. The last estimate was provided in Monetary Policy Report 2/2025 when it was increased slightly. We use the midpoint of the estimated interval.

Table 6: Observables and data sources

Variable	Series	Source	Transform.
GDP^d	Mainland Norway GDP (market value)	SSB	Δ log
C	Household consumption (incl. NPISH)	SSB	Δ log
I	Mainland gross fixed capital formation	SSB	Δ log
I^o	Oil-related gross investment[a]	SSB	Δ log
G	Government consumption	SSB	Δ log
X	Total exports	SSB	Δ log
W	Manufacturing earnings index	OECD	Δ log
π^C	Core CPI inflation[b]	SSB	gap
R	3-month nominal interest rate (NIBOR)	Macrobond	gap
RER	Broad real effective exchange rate index	BIS	Δ log
Y^o	Production in the oil-sector[c]	SSB	Δ log
p^{o*}	Real oil price[d]	FRED	Δ log
Y^*	Trade-weighted GDP of trading partners	OECD	Δ log
π^*	Trade-weighted inflation of trading partners	OECD	gap
R^*	Trade-weighted nominal interest rate of trading partners	OECD	gap

Notes: All series are quarterly and demeaned. "Δ log" denotes log-differences. "gap" denotes deviations from a reference level (inflation target for π^C and π^*, and an estimated natural real rate for R and R^*).
Sources are: Statistics Norway (SSB), Organisation for Economic Co-operation and Development (OECD), Bank for International Settlements (BIS), Federal Reserve Economic Data (FRED).
[a] Oil-related, or offshore, investment is gross investment in (i) oil and gas extraction and pipeline transport, and (ii) ocean transport.
[b] Core CPI is the Norwegian CPI adjusted for tax changes and excluding energy products.
[c] Offshore oil-sector activity is proxied by value added in oil and gas activity and ocean transport.
[d] Real oil price constructed as Brent crude oil price divided by the US CPI.

B.2 Posterior distributions of shock parameters

Table 7 contains results for the posterior distributions of the parameters in the shock processes in the model.

Table 7: Posterior distributions: shock processes

Parameter	Description	Post. mean	Post. mode	10th pct.	90th pct.
μ^{FS}	MA coefficient of COVID shock	-0.65	-0.60	-0.85	-0.44
Persistence of shocks					
θ_b	Consumption preference shock	0.21	0.20	0.06	0.36
θ_G	Government spending shock	0.27	0.19	0.09	0.44
θ_I	Efficiency of investment shock	0.15	0.13	0.05	0.25
θ_{I^o}	Efficiency of oil-investment shock	0.12	0.06	0.04	0.20
θ_P	Cost-push shock	0.20	0.14	0.07	0.33
$\theta_{p,o}$	Oil price shock	0.93	0.93	0.91	0.94
θ_W	Wage setting shock	0.11	0.10	0.03	0.19
θ_X	Foreign demand for exports	0.62	0.73	0.39	0.85
θ_Y	Productivity shock	0.45	0.41	0.23	0.67
θ_{Y^o}	Oil-sector productivity shock	0.92	0.93	0.88	0.96
θ_{B^*}	Risk premium shock	0.85	0.86	0.78	0.92
θ_{Y^*}	Foreign activity shock	0.83	0.85	0.78	0.88
θ_{π^*}	Foreign cost-push shock	0.83	0.95	0.71	0.989
Standard deviations of shock innovations					
σ_b	Consumption preference shock	0.45	0.44	0.36	0.54
σ_{FS}	Forced saving shock	2.66	2.30	1.71	3.57
σ_G	Government spending shock	1.19	1.19	1.01	1.37
σ_I	Efficiency of investment shock	2.07	2.38	1.77	2.37
σ_{I^o}	Efficiency of oil-investment shock	6.47	6.67	5.60	7.32
σ_P	Cost-push shock	1.04	1.02	0.90	1.17
$\sigma_{p,o}$	Oil price shock	14.53	14.35	12.97	16.06
σ_R	Monetary policy shock	0.16	0.16	0.14	0.18
σ_W	Wage setting shock	0.52	0.52	0.45	0.59
σ_X	Foreign demand for exports	5.01	5.12	4.26	5.74
σ_Y	Productivity shock	0.49	0.24	0.12	0.89
σ_{Y^o}	Oil-sector productivity shock	2.91	2.96	2.59	3.23
σ_{B^*}	Risk premium shock	0.23	0.20	0.16	0.31
σ_{R^*}	Foreign monetary policy shock	0.10	0.11	0.09	0.11
σ_{Y^*}	Foreign activity shock	0.36	0.28	0.24	0.48
σ_{π^*}	Foreign cost-push shock	0.13	0.14	0.10	0.17

Note: Posterior moments are based on draws from the posterior distribution. The table reports the 90 pct. highest posterior density intervals.