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Tittel *:	How big are multipliers related to public and private oil investments in Norway?
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Executive summary

In this thesis, we estimate Keynesian investment multipliers related to public and private oil investment in Norway, employing a structural vector autoregressive (SVAR) approach. Our baseline SVAR model is composed of four endogenous variables: Investment in oil, investment net of oil (mainland investment), GDP and the interest rate. We use quarterly data from 1985Q1 to 2021Q4. We assume that oil investment reacts with a lag to the other variables in the system, applying a recursive identification scheme. This is based on the notion that investment in oil tends to be driven by multi-year strategies and is therefore predetermined in relation to the other variables in the system within the quarter. Our resulting multiplier estimates are consistently above one, ranging from 1.24 to 4.43 depending on model specification and the time frame considered. This suggests that GDP increases more than in proportion to an increase in oil investment. Public and private investment in oil do not appear to crowd out private investment. These results are robust to different model specifications.

Acknowledgement

This thesis completes our master's degree at BI Norwegian Business School. The work has been carried out during the spring 2022. We would like to express special thanks to our supervisor Jamie Cross for valuable guidance and feedback throughout the process. We would also like to thank our family and friends for their support.

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1 Introduction

In this thesis, we aim to quantify the relationship between oil investment and output in Norway. Since production started on the Norwegian continental shelf in the early 1970s, the oil sector has been one of the key drivers of growth. Bjørnland et al. (2019) attributes much of the favorable effects of oil on growth in Norway to domestic investment in the oil sector. In the early days of the boom, foreign companies dominated exploration and the development of oil fields - however, as a result of deliberate policies requiring national participation and Norway's basis as an industrial and shipping nation, domestic industries have successfully established themselves as service providers to oil related industries. Subsequently, these industries have gained experience and made technological advances that have been favorable for the overall economy.

Investment in the oil sector accounts for around 20 percent of total investment in the Norwegian economy, which is far more than any other industry (Norwegian Petroleum, 2022a). To assess the effects of those investments, we estimate Keynesian investment multipliers by employing a structural vector autoregressive (SVAR) model, following the work of Batini et al. (2021). Our SVAR is composed of four endogenous variables: Investment in oil, investment net of oil (mainland investment), GDP and the interest rate. We apply a Cholesky identification scheme by assuming that oil investment reacts with a lag to the other variables in the system. This is based on the notion that investment in the oil sector tends to be preceded by years of feasibility studies and geological screenings, followed by prolonged license applications. Temporary fluctuations in GDP are therefore unlikely to be strong determinants of oil investment decisions.

Our resulting multiplier estimates depend on model specification and the time frame considered, but are consistently above one for up to five years after the occurrence of the oil investment shock, ranging from 1.24 to 4.43 (a summary of our results is provided in Section A.4). This suggests that GDP increases more than in proportion to an increase in oil investment. As first proposed by Keynes

(1936), the investment multiplier may be larger than one because investment expenditures circle through the economy, increasing total employment beyond the primary employment required by the investment itself, and consequently real aggregate income that in turn increases aggregate demand. In this way, the increase in expenditure has a larger impact on the economy than the amount spent. On a more general note, given that a large part of investment in oil in Norway is public, our findings support earlier SVAR studies that estimate fiscal multipliers above one. This includes the seminal study by Blanchard and Perotti (2002), and several contributions issued after it. This is mainly explained by an increase in private consumption following public spending, and limited negative effects on private investment. In fact, our findings suggest that public and private investments in the oil sector do not appear to crowd out private investment at all. This stands in contrast to earlier studies on public investment (e.g., Perotti (2004a)) and the theoretical predictions of several conventional macroeconomic models.

The remainder of our thesis is structured as follows. Section 2 gives an overview of related literature on fiscal multipliers, which is characterized by two debates: (i) a theoretical debate and the study of transmission mechanisms of fiscal policy in model simulations, and (ii) the debate in the empirical literature, which concerns the identification of fiscal shocks. Section 3 presents our model and results. In section 4 we check robustness to results by addressing some issues commonly discussed in the SVAR literature, which may be applicable also to our analysis. Finally, in section 5, we provide our concluding remarks.

2 Fiscal multipliers

Note that our multipliers relate interchangeably to public and private investment in oil. Thus, our multipliers are Keynesian investment multipliers and not standard fiscal multipliers. Even so, a review of the vast literature available on fiscal multipliers are useful also for our purposes. Given that a large share of oil investment is public, much of the dynamics are the same as for fiscal spending. We also rely on the same methodology as used for the empirical estimation of fiscal multipliers. The following sections therefore give an overview of related literature on fiscal multipliers.

2.1 Terms and definitions

The multiplier effect describes the changes in a nation's total output that occur as a result of government spending:

$$\text{Spending multiplier} = \frac{\Delta \text{GDP}}{\Delta \text{Spending}}$$

For instance, a multiplier of 1.5 would indicate that a one dollar increase in government spending would result in a one and a half dollar's worth rise in output. A multiplier below one would indicate that part of the spending is crowded out on other components of output.

Government spending is an aggregate of different fiscal policy tools, chiefly investment, consumption and transfer payments. Public investment is often regarded as more effective than public consumption and transfer payments in boosting economic activity. This was clearly demonstrated during the Great Recession when policymakers around the world enacted fiscal stimulus packages to combat the decline in output - a common feature of these packages was that a significant share of spending were on investment (Boehm, 2020). The argument prevailing is that public investment directly improves the economy's productive capacity by increasing the marginal product of capital and labor, so that as time passes, the investment “pays for itself” (Perotti, 2004a). From a theoretical perspective, public investment can have two contrasting effects on economic activity. First, the need to finance an increase of public investment may imply more taxes or cause interest rates to rise following a higher demand for funds, hence crowding out private investment and consumer spending that would have otherwise taken place to a larger extent. Second, public investment may induce private investment and consumption by generating more favorable circumstances for economic agents (Alfonso and Aubyn, 2009).

Keynes (1936) developed the investment multiplier as an integral part of General Theory. The Keynesian investment multiplier determines the impact of investment, public or private or the sum of these, on aggregate employment and the general economy. Keynes proposed that the investment multiplier may be larger than one because investment expenditures circle through the economy: when investment increases, firms hire more workers and pay more suppliers, those suppliers pay their workers and suppliers, while the workers spend part of their increased income on goods and services, thus creating more demand. To meet this additional demand, firms would again have to hire more workers and pay more suppliers, and so it goes.

A few definitions are essential as there are various methods used to measure multipliers. In general, the definition of a multiplier is the ratio of a change in output to an exogenous and temporary change in a fiscal variable, but the effect will likely vary depending on the time horizon considered. We therefore focus on the two specific multipliers, as follows.

The *impact multiplier* measures the effect of spending at the time in which the spending shock occurs. It is defined as the ratio of the change in output (Y_t) to a change in government spending (G_t) at time t:

$$\text{Impact multiplier} = \frac{\Delta Y_t}{\Delta G_t}$$

The *cumulative multiplier* is applied to estimate the multiplier effect for a longer time frame, thus taking into account the lagged effects of the spending shock. It is defined as the ratio of the cumulative change in output to the cumulative change in government spending, for some time horizon T:

$$\text{Cumulative multiplier} = \frac{\sum_{t=0}^{T} \Delta Y_t}{\sum_{t=0}^{T} \Delta G_t}$$

(see Ilzetzki et al. (2010) and Spilimbergo et al. (2009) for definitions).

In general, the literature relies on two main methods to derive fiscal multipliers. The first is model-based and concerns the study of transmission mechanisms and interactions of many microeconomic decisions in model simulations. The second is empirical and mainly based on the econometric estimation of SVAR models or narrative studies.

2.2 Theoretical overview

One of the most crucial assumptions of any model studying the transmission mechanism of fiscal policy is whether or not agents are forward-looking. Forward-looking consumers with rational expectations react to the expected changes of future variables in the current period while in the absence of forward-looking behavior, expected future changes have no effect on current period decisions. This section provides an overview of theoretical approaches distinguishing between models with or without a forward-looking behavior.

The key assumptions of Keynesian theory, as proposed by Keynes (1936), are price stickiness and that current consumption is solely based on current income, with no regard for expected future income. In standard Keynesian models, output is demand-determined and responsive to domestic fiscal policy implications. Increased government spending stimulates demand leading to an increase in output. As a result of growth in production, households' disposable income increases which in turn leads to increased consumption. Hence, expansive fiscal spending boosts production and consumption. By how much is determined by the households' marginal propensity to consume. Private investment decreases following an increase in the interest rate. However, the positive effects on consumption are likely to dominate the negative effects on investment, and it follows that the multiplier is above one (Ramey, 2019; Hebous, 2011).

Dynamic stochastic general equilibrium (DSGE) models have different implications than standard Keynesian theory. In DSGE models, consumers maximize lifetime expected utility subject to the lifetime budget constraint while firms maximize profits subject to the existing technology. Neoclassical and new Keynesian models, which are both fundamental DSGE models, vary significantly in two assumptions. Neoclassical models assume flexible prices and perfect competition. New Keynesian models imply monopolistic competition and sticky prices and wages, such that monetary policy matters in the short run and the effects of an increase in government spending are influenced by the monetary policy response.

Neoclassical models with variable labor supply and capital stock usually predict spending multipliers below one. The forward-looking consumer anticipates that an increase in government spending has to be financed by higher taxes in the future, and hence lowers consumption. An increase in government spending crowds out the private sector and reduces the real wage. Consumers then increase their labor supply to compensate for a reduction in expected future income, and production therefore increases as a result of households working more. Accordingly, private consumption falls and labor supply rises, however, the marginal product of labor decreases following a decrease in real wages. A common perception in the literature is that the neoclassical model is an inadequate framework for the study of fiscal multipliers, since it predicts multipliers that are substantially below the range found in empirical studies (Hall, 2009).

New Keynesian models combine neoclassical assumptions of forward-looking agents with Keynesian features of monopolistic competition and price stickiness. New Keynesian DSGE models predict multipliers both below and above one depending on model specifications, though the mechanism is entirely different from the standard Keynesian model. An additional government spending yields greater output and lower consumption, similar to neoclassical models. This is owing to the negative wealth effect of a fiscal expansion induced by households' forward-looking behavior in both types of models. In a new Keynesian set-up, the rise in labor demand caused by greater output, however, offsets the increase in the labor supply due to the negative wealth effect. Consequently, real wages increase in response to government consumption and investment shocks rather than decrease as in neoclassical models.

Furthermore, new Keynesian models predict that an increase in government spending crowds out private investment, as more government borrowing drives up interest rates. However, with interest rates near the zero lower bound, it is difficult to see how this could have happened (Stiglitz, 2011). Christiano et al. (2011) argue that when the economy hits the zero nominal interest bound, an increase in government spending has a positive effect on output, which boosts expected inflation. This in turn causes a decline in the real interest rate and the spending multiplier becomes large in such an economy. According to Hall (2009), in a model with an output multiplier of 0.9 in normal times, the multiplier raises to 3.9 when the zero bound of the nominal interest rate is strictly binding and the central bank loses its power to stimulate the economy to prevent deflation. Woodford

(2011) argues that the output response indicated by the new Keynesian model might be even less than that expected by neoclassical models under certain monetary policy assumptions. As a result, an empirical result of a multiplier less than one does not necessarily rule out the validity of the new Keynesian model.

In summary, the size of the government investment multiplier has been studied extensively in many literature using general equilibrium models. To estimate the impact of a particular fiscal policy, evidently, one must be aware of the macroeconomic model being used. Standard Keynesian usually predicts multipliers above one, whereas multipliers in new Keynesian models can be above or below one, depending on the exact specification of agents' preferences and the characteristics of the economy (Galí et al., 2007; Monacelli and Perotti, 2008). In neoclassical models, however, the multiplier is typically less than one (see, e.g., Aiyagari et al., 1992; Baxter and King, 1993; Ramey and Shapiro, 1998; Burnside et al., 2004; Ramey, 2011).

2.3 Empirical literature

Two main methodologies have been employed to the empirical estimation of fiscal multipliers: structural vector autoregressions (SVARs), and case studies of episodes with truly exogenous fiscal expansions (the narrative approach). On average, the narrative approach tends to estimate smaller multipliers relative to SVARs. There is a general agreement in the literature that multipliers are likely to vary greatly across countries and over time. Broadly speaking, two types of determinants are identified in the literature: country characteristics that determine the economy's response to government spending, and temporary economic fluctuations that make multipliers deviate from normal levels (Batini et al., 2014).

Vector autoregressive (VAR) models were first introduced by Sims (1980) as an alternative to large-scale macroeconometric models dominating in the 1970s, as the theoretical and empirical support for these models proved to be increasingly doubtful. Since then, VARs have come to be extensively used in macroeconomic research for a wide range of purposes. It provides a systematic way of capturing dynamics in multiple time series by relating the value of a variable to not only past values of itself, but also to current and past values of all other variables in the VAR system. The structural VAR (SVAR) uses economic theory to sort out contemporaneous relationships among the variables, which allows for correlations to be interpreted causally (Bjørnland and Thorsrud, 2015).

Blanchard and Perotti (2002) made the first major contribution to the SVAR literature for the study of fiscal policy. In an assessment of fiscal spending in the US, identification of structural shocks is facilitated by using quarterly data and assuming that it takes policymakers and legislators more than a quarter to respond to output shocks. Thus, government spending decisions are predetermined and do not react to shocks within the period. The study provided a foundation for much of the later literature and has been replicated in various forms. However, the existing range of multiplier estimates resulting from SVAR models varies considerably. Blanchard and Perotti (2002) find multipliers close to one, with positive effects on private consumption and negative effects on private investment following an increase in public spending. Other studies on the US estimate multipliers below one and even negative in the long run (Mountford and Uhlig, 2008) and larger than one (Fatás and Mihov, 2001). Perotti (2004b) estimate multipliers in the range of -2.3 to 3.7 based on five OECD countries.

The narrative approach seeks to identify exogenous fiscal shocks directly by going through budgetary documents and announcements. The objective is to identify changes to fiscal policy that are unrelated to current and expected economic conditions, and therefore can be treated as exogenous. On the tax side, Romer and Romer (2010) uses estimates of fiscal measures extracted from budget documents, while excluding the subset of tax measures taken in response to short-term macroeconomic fluctuations. On the spending side, a number of studies have used news about military spending as a measure of exogenous shocks. This is based on the notion that military spending is not driven by the state of the economy, rather, it is determined by wars and foreign policy. Similar to SVAR models, the range of spending multiplier estimates resulting from narrative studies varies greatly. Ramey and Shapiro (1998) find a multiplier close to one. Ramey (2011) estimates multipliers above one. Hall (2009), Barro and Redlick (2011), and Guajardo et al. (2014) estimate multipliers below one, however, the latter find that the cumulative multiplier reaches one after about two years. All studies are based on US defense spending for various sample periods.

According to Batini et al. (2014), the narrative approach constitutes a methodological improvement upon traditional measurement of fiscal shocks. However, as emphasized by Ramey (2019), while the military-build up application may work well for US data, it is not necessarily applicable to other countries. Most nations either do not experience a significant change in military spending, or they experience large fluctuations that are accompanied with war related destruction of capital assets, which leads to confounding effects. This makes the narrative approach impractical for the estimation of spending multipliers in other countries, unless an alternative narrative record to identify government spending shocks is detected.

3 Empirical analysis

We use the SVAR approach as in Blanchard and Perotti (2002) and elsewhere since it serves the purpose of our thesis. Officially available historical data does not allow us to construct a valid narrative series for oil investment shocks.

3.1 Model specification

3.1.1 Variables and lags

At the minimum, the computation of multipliers requires the inclusion of GDP and the relevant spending variable, which in our case is investment in oil. We use base GDP, as opposed to mainland GDP, for the reason that we want to assess the effects on the entire Norwegian economy. Following Batini et al. (2021), we also add investment net of oil (mainland investment), given that this is the direct counterpart to oil investment in the economy, and the interest rate. Thus, our VAR system consists of four endogenous variables: Investment in oil (S_t), mainland investment (I_t), gross domestic product (GDP_t), and the interest rate (R_t). The vector of endogenous variables reads as:

$$Y = [S_t \quad I_t \quad GDP_t \quad R_t]$$

Having specified the model, the selection of an appropriate lag length is crucial. On the one hand, including too many lags in relation to the number of observations may result in poor and inefficient coefficient estimates. On the other hand, employing a too short lag order might omit some valuable information and residuals can easily become autocorrelated. To determine the proper lag length, one can apply economic theory or a statistical information criteria such as the Akaike and Baynes information criterion tests (AIC and BIC tests). For our model, two lags is the overall best performer in the AIC and BIC tests (see Section A.1). A common practice is to choose a relatively large lag length a priori, and thereafter check robustness to results by re-estimating the model with a shorter lag length. Following this practice, we choose four lags for our baseline model, since this is a common choice for quarterly data. Thereafter, for robustness, we re-estimate the model with two lags (see Section 6.1).

3.1.2 Data description

We use quarterly data from 1985Q1 to 2021Q4. The sample reflects the longest period in which data for all three variables is available. A detailed overview of data coverage and sources is provided in the Appendix (see Section A.5). All series are transformed in real terms using the GDP price deflator.

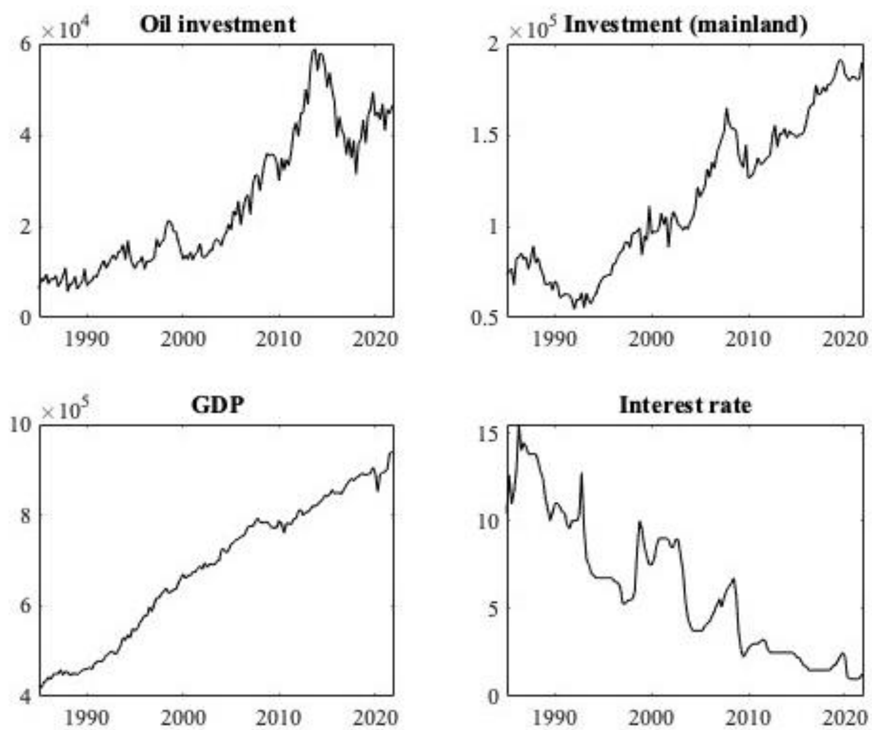

Figure 1: Raw data plots

Most macroeconomic variables are both growing and fluctuating over time. This gives rise to the statistical problem of decomposition: empirical studies of business cycles condition on how one chooses to separate the cyclical (stationary) component from the trend (non-stationary) component. The Hodrick-Prescott (HP) filter, first proposed by Hodrick and Prescott (1981), is commonly used for this purpose. Given T observations on variable y_t, the HP filter extracts a stochastic trend, g_t, which for a given value of λ moves smoothly over time and is uncorrelated with the cycle. The filter can be obtained as the solution to the following problem:

$$\min_{\{g_t\}_{t=-1}^{T}} \left\{ \sum_{t=1}^{T} (y_t - g_t)^2 + \lambda \sum_{t=1}^{T} [(g_t - g_{t-1}) - (g_{t-1} - g_{t-2})]^2 \right\}$$

The smoothness of the filtered series is determined by the choice of λ. If $\lambda = 0$, g_t would just be the observed series, y_t: there is no cycle and all data points are attributed to the long run trend. On the other extreme, if $\lambda \to \infty$, the trend will be perfectly log-linear and all of the variability in the data will be attributed to the cycle. The HP filter is applied to GDP to extract its cyclical component. The smoothing parameter λ is set to 1600, which is common practice for quarterly data (Bjørnland and Thorsrud, 2015). We are aware that there are shortcomings to this method. An alternative filter suggested by Hamilton (2018) is therefore applied for robustness (see Section 4.2). Regardless, for consistency, we follow Batini et al. (2021) and use the conventional HP filter for our baseline model.

3.2 Identification

3.2.1 Identification scheme

We start with a reduced form VAR(p) of p lags, which in general terms can be written as:

$$y_t = \mu + A_1 y_{t-1} + A_2 y_{t-2} + \cdots + A_p y_{t-p} + e_t \qquad (3.1)$$

where y_t is a (K×1) vector of endogenous variables, A denotes a (K×K) coefficient matrix, μ is a (K×1) vector of intercept terms, and e_t is a (K×1) vector of error terms which are assumed to be Gaussian white noise errors with properties $e_t \sim$ i.i.d.N(0,$\sum_e$). Without loss of generality, we base the computations that follow on a three-variable VAR(1) model and drop the constant term to simplify notations. Hence, our reduced form VAR can be expressed as:

$$y_t = A_1 y_{t-1} + e_t \tag{3.2}$$

Or written out in matrix form as:

$$\begin{bmatrix} y_{1,t} \\ y_{2,t} \\ y_{3,t} \end{bmatrix} = \begin{bmatrix} \alpha_{11} & \alpha_{12} & \alpha_{13} \\ \alpha_{21} & \alpha_{22} & \alpha_{23} \\ \alpha_{31} & \alpha_{32} & \alpha_{33} \end{bmatrix} \begin{bmatrix} y_{1,t-1} \\ y_{2,t-1} \\ y_{3,t-1} \end{bmatrix} + \begin{bmatrix} e_{1,t} \\ e_{2,t} \\ e_{3,t} \end{bmatrix} \tag{3.3}$$

To identify structural parameters from the reduced form model, we apply a Cholesky identification scheme, which relies on the algebraic result of the Cholesky decomposition. As first proposed by Sims (1980), identification is then facilitated by assuming a recursive structure for how the shocks affect the variables in the VAR system.

The next step is to derive the infinite moving average representation of our reduced form VAR, which describes y_t solely in terms of the entire history of the shocks. We assume that the VAR is stable. This will be the case if the eigenvalues of the companion form matrix are less than one in absolute value (see Section A.2), with the implication that the effect of shocks eventually dies out. The moving average can then be obtained using the lag operator, expressing equation (3.2) as:

$$A(L)y_t = e_t \tag{3.4}$$

Where A(L) is the lag polynomial that transforms an observation at time t backward one period in time. We obtain the reduced form moving average representation by multiplying equation (3.4) by the inverse $A(L)^{-1}$:

$$y_t = B(L)e_t = \sum_{j=0}^{\infty} B_j e_{t-j} \tag{3.5}$$

Where $B(L) = A(L)^{-1}$.

$\sum_e$ is not necessarily a diagonal matrix, which implies that the reduced form errors are likely to be correlated. To do a structural analysis, we need the endogenous variables expressed in a moving average representation where the residuals are orthogonal. To obtain this, we use the Cholesky decomposition. The Cholesky decomposition states that every positive definite symmetric matrix can be written as the product $\sum_e = PP'$ where P is the Cholesky decomposition of $\sum_e$. P will then be a lower triangular matrix, and P' is the conjugate transpose of P. Using this, equation (3.5) can be written as:

$$y_t = \sum_{j=0}^{\infty} B_j P P^{-1} e_{t-j} = \sum_{j=0}^{\infty} C_j v_{t-j} \tag{3.6}$$

Where $C_j = B_j P$ and $v_t = P^{-1} e_t$ so that:

$$E[v_t v_t'] = P^{-1} E[e_t e_t'](P^{-1})' = P^{-1}(PP')(P^{-1})' = I$$

Given that P is a lower triangular matrix, the components of the structural shocks, v_t, will be orthogonal. For our three-variable VAR(1) model, we can obtain (also using $C_0 = P$, which follows from $B_0 = I$):

$$\begin{bmatrix} y_{1,t} \\ y_{2,t} \\ y_{3,t} \end{bmatrix} = \begin{bmatrix} P_{11} & 0 & 0 \\ P_{21} & P_{22} & 0 \\ P_{31} & P_{32} & P_{33} \end{bmatrix} \begin{bmatrix} v_{1,t} \\ v_{2,t} \\ v_{3,t} \end{bmatrix} + B_1 P v_{t-1} + B_1 P v_{t-2} + \cdots \tag{3.7}$$

Equation (3.7) restricts the contemporaneous relationships between the shocks and the variables. In particular, each variable can only have an instant impact on the variables ordered after it. After one period, there are no further restrictions and all shocks can affect all variables. Hence, the variable ordered on top will only react to its own shock contemporaneously, and respond to shocks to the other variables with a lag. Conversely, the variable ordered at the bottom will react to all shocks contemporaneously (for a textbook reference, see Bjørnland and Thorsrud, 2015).

3.2.2 Identifying assumptions

Using the same notations as in (3.7), the following structural moving average is estimated for our SVAR:

$$\begin{bmatrix} S_t \\ I_t \\ GDP_t \\ R_t \end{bmatrix} = \begin{bmatrix} P_{11} & 0 & 0 & 0 \\ P_{21} & P_{22} & 0 & 0 \\ P_{31} & P_{32} & P_{33} & 0 \\ P_{41} & P_{42} & P_{43} & P_{44} \end{bmatrix} \begin{bmatrix} v_t^S \\ v_t^I \\ v_t^{GDP} \\ v_t^R \end{bmatrix} + B_1 P v_{t-1} + \cdots + B_1 P v_{t-4}$$

Oil investment is placed first, and thus assumed to be predetermined in relation to the other variables in the system. This is based on the notion that investment in the oil sector tends to be preceded by years of feasibility studies and geological screenings, followed by prolonged license applications. Equinor, the largest petroleum company in Norway in-which the government owns around 70 percent, estimates that the entire process from the initial screenings to production is likely to last for up to ten years. Once the field is developed, production can go on for several decades. Throughout this time, fields in production continue to require a substantial level of investment for maintenance and capacity expansion (Equinor, 2022. Details on particular projects can also be found in Equinor's annual reports). Thus, oil investment will be driven by multi-year strategies, and temporary fluctuations in GDP are unlikely to be strong determinants of oil investment decisions.

Mainland investment is placed second, assuming that it takes at least a quarter for investment to respond to shocks to output, consistent with the model of Batini et al. (2021). The interest rate is placed last, following a standard recursive structure for the study of monetary policy as proposed by Sims (1980), Christiano et al. (2001) and elsewhere. This implies that monetary policy affects GDP with a lag. The model is stable with a maximum eigenvalue of 0.9620 (see Section A.2).

3.3 Results

Having identified the oil investment shock, we can study its impact on the remaining variables by plotting the impulse response functions of our model, obtained from the moving average representation in (3.4) (see Section A.3 for calculations). An impulse response describes how a given (structural) shock affects a variable over time. In terms of our model, one can think of the impulse as the cause and its propagation as the effect over time (Bjørnland and Thorsrud, 2015). Figure 2 displays the impulse responses generated by a positive shock to oil investment.

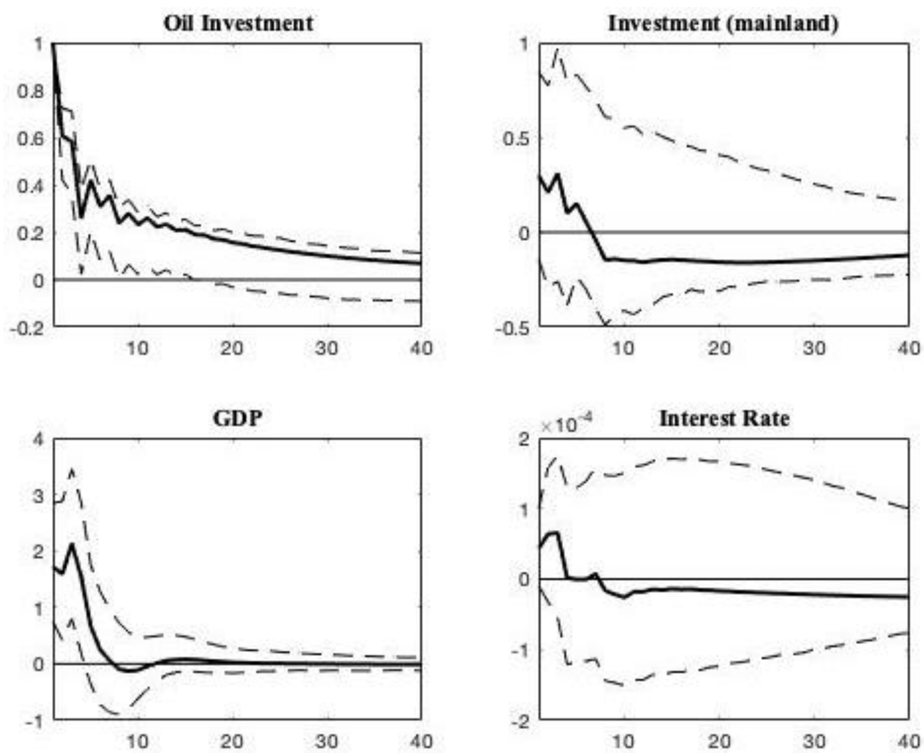

Figure 2: Impulse responses generated by an oil investment shock. The shock is normalized to an increase of one unit. The area between the two dotted lines indicates 95 percent confidence intervals.

Given the recursive structure of the underlying model, GDP, mainland investment and the interest rate respond instantly to the oil investment shock. GDP increases considerably on impact and peaks after about three quarters. This suggests that oil investment has favorable effects on economic activity, though the effect falls relatively quickly. Within seven quarters, the effect on GDP has more or less died out. Mainland investment responds very little. This implies that (public and private) investment in the oil sector do not appear to crowd out private investment. If anything, there is a small positive effect.

Based on the impulse response functions depicted in figure 2, we compute the corresponding multipliers as reported in table 1. Recall that our multipliers relate interchangeably to both public and private investment in oil. Thus, our multipliers are Keynesian investment multipliers, and not standard fiscal multipliers.

Quarters	Oil investment multiplier
0	1.64
4	2.91
8	2.22
12	1.63
16	1.46
20	1.35

Table 1: Multiplier estimates from baseline model.

The impact multiplier is above one. This implies that GDP increases more than in proportion to the increase in oil investment at the time the shock occurs. In particular, when one additional NOK is invested in the oil sector, there is a 1.64 NOK worth increase in GDP on impact. However, as emphasized by Batini et al. (2021), focusing solely on the impact multiplier may be misleading because investment in the oil sector is often implemented over time, and the economy may only respond gradually. The favorable effects on GDP seem also to hold in the long run. The cumulative multiplier increases with horizon and reaches its peak four quarters after the shock, before falling gradually. After twenty quarters (five years), it is still well above one.

3.3.1 Discussion

As first proposed by Keynes (1936), the investment multiplier may be larger than one because investment expenditures circle through the economy, giving rise to an increase in total employment and real aggregate income that in turn increases aggregate demand. This argument relies on the assumptions that there is no change in the propensity to consume, and no associated offset through decreased investment in other directions. Then, the increase of total employment followed by an increase in investment will not be restricted to the primary employment required by the investment itself. Primary employment refers to employment directly employed on investment. In this context, that includes workers who are linked to value creation that takes place directly on the Norwegian continental shelf, such as oil exploration and production. This accounts for around 24,000 people. In addition, it is estimated that about 92,000 are indirectly employed in oil related industries as a result of demand for machinery, equipment, and the like. Moreover, another 89,000 are estimated to be employed as a result of spillover-effects from the oil sector, which occur when companies operating in oil related industries buy goods and services from companies not specialized in oil, e.g., wholesale and retail, hotels, restaurants, legal and accounting services, etc. (Norwegian Petroleum, 2022b). Thus, consistent with Keynes (1936), increased investment in the oil sector leads to an increase in total employment which is a multiple of primary employment. Real income then increases and households will wish to consume parts of their increased incomes. However, they will wish to consume a gradually diminishing proportion of it, and output will after a while stabilize at a new level.

Contrary to our findings, Batini et al. (2021) estimate Keynesian investment multipliers associated with oil, gas and coal combined to be well below one. This is explained by the fact that only a small share of the overall investment budgets in these sectors are used on hiring workers, whereas more is used on acquiring on- and offshore land, machines, supplies, etc. Moreover, they often rely on imports and economic activity taking place in other countries. There may be several reasons why our results contradict from those of Batini et al. (2021). First, our multipliers do not include coal. To our knowledge, there is no evidence that coal is less labor intensive than oil, but it implies that our estimates are not directly comparable to theirs. Second, their estimates are global and not based on data from Norway specifically, and there may be country differences. There is a general agreement in the literature that multipliers depend on a variety of country specific factors, such as financial development, openness to trade, and the exchange rate regime (Ilzetzki, 2010). In the context of oil and other natural resources, another crucial factor is the quality of institutions, as emphasized by Mehlum and Torvik (2006), among others. This is vital not only because weak institutions induce corruption as emphasized in previous literature, but also because weak institutions prevent the development of a domestic oil supply.

Our results are in line with Bjørnland et al. (2019) and Bjørnland and Thorsrud (2016). They find that the Norwegian oil sector stimulates domestic production and productivity. Bjørnland et al. (2019) find that increased oil activity in Norway tends to increase productivity in most domestic industries due to expertise and technological advances acquired by the oil sector, improving the productive capacity of the overall economy. Over the years, as the oil related industries gain more experience and become an increasingly important part of the economy, these productivity effects increase as well. Several papers have documented similar productivity spillover effects to the rest of the economy following oil booms, e.g., Alcott and Keniston (2018) find that total factor productivity is procyclical with local oil booms in the US, and that the productivity gains are broadly distributed across sectors.

On a more general note, since a large part of investment in oil is public, our findings are in line with previous SVAR studies that estimate fiscal multipliers above one. That includes the seminal study by Blanchard and Perotti (2002), and several studies issued after it. These results are mainly explained by an increase in private consumption following public spending, and limited negative effects on private investment. In fact, our findings suggest that public and private investments in the oil sector do not tend to crowd out private investment at all. This stands in contrast to earlier studies on public investment (by e.g., Perotti (2004a)) and the theoretical prediction of neoclassical and new Keynesian models.

4 Robustness

4.1 Shorter lag length

The baseline results are produced with four lags as this is common practice for quarterly time series. Given that AIC and BIC suggested two lags as a good fit for our data, we check whether our results are robust to a two-quarter lag structure. The model is stable with a maximum eigenvalue of 0.9544 in absolute terms. The resulting multiplier estimates are reported in table 2.

2-quarter lag structure	
Quarters	Oil investment multiplier
0	1.49
4	1.97
8	1.89
12	1.83
16	1.78
20	1.75

Table 2: Multiplier estimates with a two-quarter lag structure.

Relative to the baseline results, the impact multiplier is somewhat lower with a shorter lag length, though the estimates are very comparable. The cumulative multipliers remain lower than those in the baseline model until the 12^{th} quarter, where it is slightly higher and remains so until the 20^{th} quarter. However, all multipliers are consistently above one both in the short- and in the long term, which is consistent with the results and the conclusions drawn from the baseline model.

4.2 Alternative filter

Despite being widely applied in macroeconomic research, there are some well known shortcomings to the HP filter that we applied to our baseline model. In particular, Bjørnland and Thorsrud (2015) point to two problems: First, the filtered series will be sensitive to the choice of the smoothing parameter λ, and hence not robust to changes to λ. Hodrick and Prescott (1981) motivated their choice of $\lambda = 1600$ for quarterly time series based on the characteristics of US data, but this does not necessarily mean that it is a reasonable choice for other time series (say, GDP series for Norway). Second, there is an end-of-sample bias, which arises from the fact that the trend will be more responsive to transitory shocks at the end of the sample. Given these limitations, we check whether our results are robust to an alternative filter suggested by Hamilton (2018). The model is stable with a maximum eigenvalue of 0.9761. The resulting multiplier estimates are reported in table 3.

Alternative filter	
Quarters	Oil investment multiplier
0	2.27
4	4.13
8	4.43
12	4.06
16	3.81
20	3.71

Table 3: Multiplier estimates applying an alternative filter.

All multiplier estimates are considerably bigger than those produced from the baseline model, both on impact and in the long run. However, this does not change the implications and conclusions drawn from the baseline results.

4.3 Alternative specifications

A natural extension of our study would be to better control for other factors that may affect GDP. Mainland investment and the interest rate is included in the baseline model. In this section, we add and control for the exchange rate and oil revenue.

4.3.1 Adding exchange rate

In this specification, we have added the exchange rate to the baseline SVAR. The exchange rate (E_t) is placed last, which implies that it responds instantly to shocks to all other variables in the system. This is consistent with Bjørnland (2008), among others, and based on the fact that the exchange rate is a financial variable that is highly responsive to economic fluctuations. It is therefore likely that it will respond to all shocks within the quarter. This yields the following structural moving average:

$$\begin{bmatrix} S_t \\ I_t \\ GDP_t \\ R_t \\ E_t \end{bmatrix} = \begin{bmatrix} P_{11} & 0 & 0 & 0 & 0 \\ P_{21} & P_{22} & 0 & 0 & 0 \\ P_{31} & P_{32} & P_{33} & 0 & 0 \\ P_{41} & P_{42} & P_{43} & P_{44} & 0 \\ P_{51} & P_{52} & P_{53} & P_{54} & P_{55} \end{bmatrix} \begin{bmatrix} v_t^S \\ v_t^I \\ v_t^{GDP} \\ v_t^R \\ v_t^E \end{bmatrix} + B_1 P v_{t-1} + \cdots + B_1 P v_{t-4}$$

The model is stable with a maximum eigenvalue of 0.9894. Corresponding multipliers, as reported in table 4, are very comparable to those resulting from the baseline model. The impact multiplier and the cumulative multipliers are slightly lower until the 16th quarter, where it is slightly higher. All conclusions drawn from the baseline model persist.

Adding exchange rate	
Quarters	Oil investment multiplier
0	1.24
4	2.49
8	2.17
12	1.72
16	1.56
20	1.41

Table 4: Multiplier estimates from an alternative model specification including the exchange rate.

4.3.2 Adding oil revenue

In countries where oil revenue constitutes a large component of total government revenues, oil price fluctuations will have a direct impact on fiscal spending. To shield the fiscal budget and thereby the domestic economy from oil price fluctuations, Norway adopted a fiscal framework in 2001 known as "the fiscal rule". Under the fiscal rule, only the expected real return of the Government Pension Fund Global (GPFG), where the net cash flow from the oil industry is transferred to in its entirety, is drawn annually to finance government spending or tax cuts. The expected real rate of return of the GPFG was set at 4% at the inception of the rule and lowered to 3% in 2017 (Bjørnland and Thorsrud, 2018). The purpose of the spending rule is twofold: it ensures that the real value of the GPFG is preserved for the benefit of future generations, and it facilitates a gradual phasing in of oil revenues into the Norwegian economy (Norwegian Ministry of Finance, 2022).

In this specification, we have added oil revenue to the baseline SVAR. Oil revenue (OR_t) is placed second. Thus, it is assumed to more exogenous than oil investment, but predetermined in relation to the other variables. This yields the following structural moving average:

$$\begin{bmatrix} S_t \\ OR_t \\ I_t \\ GDP_t \\ R_t \end{bmatrix} = \begin{bmatrix} P_{11} & 0 & 0 & 0 & 0 \\ P_{21} & P_{22} & 0 & 0 & 0 \\ P_{31} & P_{32} & P_{33} & 0 & 0 \\ P_{41} & P_{42} & P_{43} & P_{44} & 0 \\ P_{51} & P_{52} & P_{53} & P_{54} & P_{55} \end{bmatrix} \begin{bmatrix} v_t^S \\ v_t^I \\ v_t^{GDP} \\ v_t^R \\ v_t^E \end{bmatrix} + B_1 P v_{t-1} + \cdots + B_1 P v_{t-4}$$

The model is stable with a maximum eigenvalue of 0.9661. The resulting multiplier estimates are reported in table 5. Relative to the baseline model, all estimates are slightly higher for all horizons. Even so, the results are very comparable, and all conclusions drawn from the baseline model persist also for this specification.

Adding oil revenue	
Quarters	Oil investment multiplier
0	2.19
4	3.30
8	2.41
12	1.87
16	1.70
20	1.61

Table 5: Multiplier estimates from an alternative model specification including oil revenue.

5 Conclusion

In this thesis, we have assessed the relationship between oil investment and output in Norway by computing Keynesian investment multipliers. This was done employing an empirical SVAR analysis. Our resulting multiplier estimates are consistently above one, ranging from 1.24 to 4.43 depending on model specification and time horizon. These results suggest that GDP increases more than in proportion to an increase in oil investment, and that crowding-in effects dominates any potential crowding-out effects.

Based on the literature available, we would point to two main reasons that may explain our results. First, investment in oil increases total employment in the economy through the dynamics suggested by Keynes (1936). This is supported by the fact that approximately 89,000 people in Norway are estimated to be employed as a result of spillover-effects from oil related industries, in addition to the 116,000 people directly or indirectly employed in the oil sector. Thus, the increase in total employment following an increase in oil investment is a multiple of the primary employment required by the investment itself. Second, as found by Bjørnland et al. (2019), increased oil activity in Norway tends to have productivity spillover-effects to other domestic industries due to competencies and technological advances acquired by the oil sector, increasing the value added per worker in the overall economy. Since oil investment tend to stimulate both production and productivity in the general economy, it follows that oil investment shocks can be capable of generating growth in output greater in magnitude than the investment itself.

The oil sector has contributed outstandingly to economic growth and to the financing of the Norwegian welfare state, as our results also imply. However, a transition to a low-carbon economy for the motive of environmental considerations and a lower global demand for crude oil will require a contraction of the oil sector. This is often depicted as being incompatible with job creation and economic progress. For future research, an interesting perspective could be how the major investments made in oil can take part in the green transition. Oil industries possess capital, technology and expertise that may provide a valuable foundation for low-carbon industries to be built upon, and there may be synergies to be leveraged between renewables and oil value chains. For instance, offshore infrastructure and the competence on how to operate in deep waters under harsh climate conditions could be an advantage in the development of an offshore wind power industry, and the processing plants on stream for oil could provide a basis for a large-scale hydrogen industry (Bjørnland et al., 2019).

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Appendix

A.1 Lag selection test

Inference in VARs depend crucially on the choice of lag length. One method of determining the lag length is to use information criterion functions. These evaluate the trade-off between increased model fit by including more lags, and increased parameter uncertainty as the model becomes larger (Bjørnland and Thorsrud, 2015). BIC and AIC tests are commonly used for this purpose, and can be derived by:

$$BIC(p) = \ln\left(\frac{SSR(p)}{T}\right) + (p+1)\frac{\ln(T)}{T}$$

and

$$AIC(p) = \ln\left(\frac{SSR(p)}{T}\right) + (p+1)\frac{2}{T}$$

As reported in table 6, BIC and AIC suggest two and nine lags, respectively, as the best fit for our data. However, two lags has the lowest AIC and BIC values on average, and is therefore the overall best performing lag-structure.

Lags	BIC	AIC
1	27.43	27.23
2	27.38	27.00
3	27.66	27.09
4	27.84	27.09
5	27.78	26.83
6	27.98	26.83
7	28.27	26.93
8	28.34	26.81
9	28.47	26.75
10	28.68	26.77

Table 6: Results from BIC and AIC lag selection test for the baseline SVAR.

A.2 Stability of VARs

Following Bjørnland and Thorsrud (2015) notations, a VAR(p) model stated in equation (3.1) can be written in a VAR(1) form known as the companion form, which is accomplished as follows:

Consider the model:

$$Z_t = \Gamma_0 + \Gamma_1 Z_{t-1} + v_t \qquad \text{(A.2.1)}$$

Where we have defined:

$$Z_t = \begin{bmatrix} y_t \\ y_{t-1} \\ \vdots \\ y_{t-p+1} \end{bmatrix} = \begin{bmatrix} y_{1,t} \\ y_{2,t} \\ \vdots \\ y_{K,t} \\ \vdots \\ y_{1,t-p+1} \\ y_{2,t-p+1} \\ \vdots \\ y_{K,t-p+1} \end{bmatrix}, \quad \Gamma_0 = \begin{bmatrix} \mu \\ 0 \\ \vdots \\ 0 \end{bmatrix}, \quad v_t = \begin{bmatrix} e_t \\ 0 \\ \vdots \\ 0 \end{bmatrix}$$

Then the companion form of the VAR(p) model

$$y_t = \mu + A_1 y_{t-1} + A_1 y_{t-2} + \cdots + A_p y_{t-p} + e_t \qquad \text{(A.2.2)}$$

is as in equation (A2.1) or it can be expressed in matrix notation as below:

$$\begin{bmatrix} y_t \\ y_{t-1} \\ y_{t-2} \\ \vdots \\ y_{t-p+1} \end{bmatrix} = \begin{bmatrix} \mu \\ 0 \\ 0 \\ \vdots \\ 0 \end{bmatrix} + \begin{bmatrix} A_1 & A_2 & \dots & A_{p-1} & A_p \\ I & 0 & \dots & 0 & 0 \\ 0 & I & \dots & 0 & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & \dots & I & 0 \end{bmatrix} \begin{bmatrix} y_{t-1} \\ y_{t-2} \\ y_{t-3} \\ \vdots \\ y_{t-p} \end{bmatrix} + \begin{bmatrix} e_t \\ 0 \\ 0 \\ \vdots \\ 0 \end{bmatrix} \qquad \text{(A.2.3)}$$

Accordingly, the dimensions of the vectors Z_t, Γ_0 and v_t are $K_p \times 1$. A_j for j=1,2, …, p is K×K and Γ_1 is $K_p \times K_p$. In this case, Γ_1 is called the companion-form matrix.

For the VAR model to be covariance-stationary, the effect of the shocks must gradually die out. According to Lütkepol (2005)'s stationarity definition, a stable VAR process y_t is stationary for all t. In other words, if the VAR is stable, it is also stationary. This is valid if the eigenvalues of the companion matrix are all smaller than one in absolute value. The eigenvalues of the companion matrix Γ are those numbers λ for which $|\Gamma - \lambda I| = 0.$ In our study, the eigenvalues of the companion form matrix are smaller than one in absolute value for the baseline SVAR as reported in table 7. This suggests that our baseline model is stable and that we do not need to apply first differences of the variables to make the variables stationary.

Eigenvalues of the companion form
0.8007
0.5849
0.5273
0.5273
0.6497
0.6497
0.4016
0.4016
0.7809
0.7809
0.9620
0.9620

Table 7: Eigenvalues of the companion form for baseline model. The VAR is stable given that all eigenvalues are below one in absolute value.

A.3 Impulse response functions

Structural VAR applies restrictions that allow us to determine the impact of exogenous shocks on the variables in the system. Once the SVAR model is estimated, we can compute the impulse response functions in order to examine those impacts on the variables. Following Bjørnland and Thorsrud (2015) notations, the structural representation of a VAR model can be written in matrix format as:

$$\Psi\, y_t = \Phi\, y_{t-1} + \mathcal{E}_t \qquad \text{(A.3.1)}$$

Where

$$\Psi = \begin{bmatrix} \psi_{11} & \psi_{12} \\ \psi_{21} & \psi_{22} \end{bmatrix}, \quad y_t = \begin{bmatrix} y_{1,t} \\ y_{2,t} \end{bmatrix}, \quad \Phi = \begin{bmatrix} \phi_{11} & \phi_{12} \\ \phi_{21} & \phi_{22} \end{bmatrix}, \quad \mathcal{E}_t = \begin{bmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{bmatrix}$$

Since the parameters of the equations are not identifiable, we must proceed with the reduced form. To obtain the reduced form VAR, we multiply equation (A.3.1) by Ψ^{-1} which is assumed invertible:

$$y_t = \Psi^{-1}\Phi\, y_{t-1} + \Psi^{-1}\mathcal{E}_t = A_1\, y_{t-1} + e_t$$

$$\mathrm{A(L)}\, y_t = e_t \qquad \text{(A.3.2)}$$

Where

$$A_0 = \mathrm{I}, \quad A_1 = \Psi^{-1}\Phi, \quad A(L) = (I - A_1\mathrm{L}), \quad e_t = \Psi^{-1}\mathcal{E}_t$$

Hence, the reduced form errors e_t, are linear combinations of the structural errors $\mathcal{E}_t$, with covariance matrix:

$$\mathrm{E}\,[e_t\,, e'_t] = \Psi^{-1}\,\mathrm{E}\,[\mathcal{E}_t\mathcal{E}'_t](\Psi^{-1})' = \Psi^{-1}\Omega(\Psi^{-1})' \cong \sum e$$

Where Ω is the covariance of the structural errors, and Σe is the covariance matrix of the reduced form errors.

We can write the reduced form moving average representation in equation (A.3.2) in terms of the structural moving average representation in equation (A.3.3) by using $e_t = \Psi^{-1}\mathcal{E}_t$

$$y_t = A(L)^{-1}\, e_t$$

$$y_t = \mathrm{B(L)}\, \Psi^{-1}\mathcal{E}_t$$

$$y_t = B_0\Psi^{-1}\mathcal{E}_t + B_1\Psi^{-1}\mathcal{E}_{t-1} + B_2\Psi^{-1}\mathcal{E}_{t-2} + \cdots$$

$$\begin{bmatrix} y_{1,t} \\ y_{2,t} \end{bmatrix} = \begin{bmatrix} \psi_{11} & \psi_{12} \\ \psi_{21} & \psi_{22} \end{bmatrix}^{-1} \begin{bmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{bmatrix} + B_1\Psi^{-1}\mathcal{E}_{t-1} + B_2\Psi^{-1}\mathcal{E}_{t-2} + \ldots. \quad \text{(A.3.3)}$$

we can write equation (A.3.3) more compactly as below since B_0= I

$$\begin{bmatrix} y_{1,t} \\ y_{2,t} \end{bmatrix} = \begin{bmatrix} \theta_{11,0} & \theta_{12,0} \\ \theta_{12,0} & \theta_{22,0} \end{bmatrix} \begin{bmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{bmatrix} + \Theta_1\mathcal{E}_{t-1} + \Theta_2\mathcal{E}_{t-2} + \ldots$$

Where we have defined $\Theta(L) = B(L)\Psi^{-1}$ so that,

$$\Theta_0 = \Psi^{-1}$$

$$\Theta_1 = B_1\Psi^{-1} = A_1\Psi^{-1}$$

$$\Theta_j = B_j\Psi^{-1} = {A_1}^j\,\Psi^{-1}$$

Θ_0 captures the initial impacts of structural shocks and determines the contemporaneous correlation between variables in the system. The restriction that the second shock in the system only affects the second variable $y_{2,t}$ of the system contemporaneously, can be easily found by assuming a lower triangular contemporaneous matrix Θ_0 , that is, $\theta_{12,0}$=0. This restriction implies a causal ordering that can be identified using the Cholesky decomposition which is

Ψ^{-1} = P, where P is the Cholesky decomposition of the reduced form covariance matrix Σe. Further, we can recover the structural shocks from the reduced form residuals with the restriction in place.

$$e_t = \Psi^{-1}\mathcal{E}_t$$

$$\mathcal{E}_t = \Psi\, e_t \equiv P^{-1}\, e_t$$

Having identified a structural model, we can now compute the impulse response functions interpreted as the impact of shocks on the variables in the system over time. In a structural model, the impulse is the cause, and its propagation is the effect across time.

The moving average representation stated in equation (3.5) implies that y_t can be expressed solely in terms of the entire history of the shocks. As a result, equation (3.5) contains the impulse responses to the system, which have been rewritten below and shifted s periods forward.

$$y_{t+s} = e_{t+s} + B_1 e_{t+s-1} + B_2 e_{t+s-2} + \cdots + B_{s-1} e_{t+1} + B_s e_t + B_{s+1} e_{t-1} + B_{s+2} e_{t-2} + \ldots$$

It should be noted that the impulse response analysis is carried out in terms of the MA representation where the residuals are orthogonal. The impulse responses in terms of the structural shocks, therefore, will be as following:

$$y_{t+s} = B_0\Psi^{-1}\Psi e_{t+s} + B_1\Psi^{-1}\Psi e_{t+s-1} + \ldots + B_s\Psi^{-1}\Psi e_t + \cdots$$

$$= \Theta_0\Psi e_{t+s} + \Theta_1\Psi e_{t+s-1} + \cdots + \Theta_s\Psi e_t + \cdots$$

$$= \sum_{j=0}^{\infty} \Theta_j\, \mathcal{E}_{t+s-j}$$

Where $\Theta_j = B_j\Psi^{-1}$ and $\mathcal{E}_t = \Psi\, e_t$

By writing out the matrices we have,

$$\begin{bmatrix} y_{1,t+s} \\ y_{2,t+s} \end{bmatrix} = \begin{bmatrix} \theta_{11,0} & \theta_{12,0} \\ \theta_{21,0} & \theta_{22,0} \end{bmatrix} \begin{bmatrix} \varepsilon_{1,t+s} \\ \varepsilon_{2,t+s} \end{bmatrix} + \begin{bmatrix} \theta_{11,1} & \theta_{12,1} \\ \theta_{21,1} & \theta_{22,1} \end{bmatrix} \begin{bmatrix} \varepsilon_{1,t+s-1} \\ \varepsilon_{2,t+s-1} \end{bmatrix} + \cdots$$

$$+ \begin{bmatrix} \theta_{11,s} & \theta_{12,s} \\ \theta_{21,s} & \theta_{22,s} \end{bmatrix} \begin{bmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{bmatrix} + \ldots$$

And the impulse responses can be found as:

$$\frac{\partial \Delta y_{1,t+s}}{\partial \varepsilon_{1,t}} = \theta_{11,s} , \quad \frac{\partial \Delta y_{1,t+s}}{\partial \varepsilon_{2,t}} = \theta_{12,s}$$

$$\frac{\partial \Delta y_{2,t+s}}{\partial \varepsilon_{1,t}} = \theta_{21,s} , \quad \frac{\partial \Delta y_{2,t+s}}{\partial \varepsilon_{2,t}} = \theta_{22,s}$$

The dynamic multiplier depends only on s which is the length of time separating the disturbance to the input ($\mathcal{E}_t$) and the observed value of output (y_{t+s})
The impulse response functions of the shocks will be the plots of $\theta_{ij,s}$ for i,j = 1, 2. These plots summarize how unit impulses of the shocks at time t influence the level of y at time t+s for different values of s. Hence, the element {i,j} of matrix Θ_s represents the impact of a shock j hitting the i-th variable of the system at time t (see Bjørnland and Thorsrud (2015) for details).

We can write the cumulative effect of a unit shock in each variable as the infinite sum of the impulse responses:

$$\Theta(1)= \begin{bmatrix} \sum_{s=0}^{\infty} \frac{\partial y_{1,t+s}}{\partial \varepsilon_{1,t}} & \sum_{s=0}^{\infty} \frac{\partial \Delta y_{1,t+s}}{\partial \varepsilon_{2,t}} \\ \sum_{s=0}^{\infty} \frac{\partial y_{2,t+s}}{\partial \varepsilon_{1,t}} & \sum_{s=0}^{\infty} \frac{\partial y_{2,t+s}}{\partial \varepsilon_{2,t}} \end{bmatrix} = \begin{bmatrix} \sum_{s=0}^{\infty} \theta_{11,s} & \sum_{s=0}^{\infty} \theta_{12,s} \\ \sum_{s=0}^{\infty} \theta_{21,s} & \sum_{s=0}^{\infty} \theta_{22,s} \end{bmatrix} = \begin{bmatrix} \theta_{11}(1) & \theta_{12}(1) \\ \theta_{21}(1) & \theta_{22}(1) \end{bmatrix}$$

A.4 Summary of results

Summary of results

	Impact	4 quarter	8 quarters	12 quarters	16 quarters	20 quarters
Baseline model	1.64	2.91	2.22	1.63	1.46	1.35
2-quarter lag structure	1.49	1.97	1.89	1.83	1.78	1.75
Alternative filter	2.27	4.13	4.43	4.06	3.81	3.71
Adding exchange rate	1.24	2.49	2.17	1.72	1.56	1.41
Adding oil revenue	2.19	3.30	2.41	1.87	1.70	1.61

A.5 Data coverage and sources

Variable	Explanation	Source
GDP	Gross Domestic Product for Norway	Statistics Norway
Investment in oil	Accrued investment costs related to exploration and field development in the oil sector in Norway	Statistics Norway
Investment (mainland)	Gross Fixed Capital Formation (GFCF) for mainland Norway	Statistics Norway
Oil revenue	Net cash flow from petroleum activities for Norway	Statistics Norway
GDP-deflator	GDP Implicit Price Deflator in Norway	FRED
Real exchange rates	Real Effective Exchange Rates Based on Manufacturing Consumer Price Index for Norway	FRED
Interest rate	Policy rate for Norway	Norges Bank

Table 9: Data coverage and sources.

All series were retrieved quarterly (1985Q1 to 2021Q4), except for the interest rate which was converted to quarterly using monthly data.