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Macroeconomic and Industry Effects of Supply-Side Climate Policy

Dutch disease in reverse?

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DISCUSSION PAPERS

1014

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Abstract

Petroleum-producing countries face unique challenges in meeting global emissions targets. As global petroleum consumption declines, these nations must reallocate resources and phase out a historically profitable industry. This study examines Norway's economic transformation resulting from a significant downturn in the petroleum sector, akin to a reverse Dutch disease. Industries linked to petroleum, particularly those supplying factor inputs, must pivot to new markets, while other sectors may benefit from real exchange rate depreciation. Our findings indicate that long-term macroeconomic adjustments are modest, whereas short-term effects can be significant but are largely mitigated through standard fiscal and monetary policy measures.

Keywords: Petroleum industry, Green transition, Dutch disease

JEL classification: Q32 Q54 E60 F41

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Sammendrag

Artikkelen analyserer virkninger på norsk økonomi av at petroleumsvirksomheten fases ut for å bidra til å oppnå IEAs netto nullutslippsmål for klimagasser innen 2050. Vi bruker den makroøkonometriske modellen KVARTS i analysen. Modellen kobler olje- og gassektoren med den norske fastlandsøkonomien og inkluderer betydningen av regler i utformingen av finans- og pengepolitikken.

Vi finner at reduksjonen i petroleumsaktiviteten gir permanent lavere totalt BNP utover nedgangen i bruttoproduktet i petroleumsvirksomheten. Tilpasningene til lavere petroleumsinntekter og -produksjon har ringvirkninger som gir en svak nedgang også i BNP Fastlands-Norge på lang sikt. Aktiv pengepolitikk demper nedgangen i fastlandsøkonomien betydelig og leder til forbedret konkurranseevne i ikke-petroleumsrelaterte eksportindustrier og høyere industrisysselsetting.

Artikkelen bidrar til litteraturen ved å inkludere internleveranser mellom næringene gjennom en kryssløpsstruktur samtidig som vi tar hensyn til responser i penge- og finanspolitikken. I motsetning til tidligere studier som har brukt mer aggregerte modeller, gir vår tilnærming en detaljert analyse av hvordan nedgangen i petroleumsaktiviteten påvirker ulike næringer.

Sensitivitetsanalyser viser effekter av ulik penge- og finanspolitikk, samt betydningen av størrelsen på priselastisiteter i utenrikshandelen.

Resultatene belyser noen effekter av avkarbonisering i en liten, ressursrik og åpen økonomi med inflasjonsmål, og funnene kan være relevante for land med en stor ressurssektor som står foran en omstilling til lavere utslipp av klimagasser.

1 Introduction

Since the discovery of oil in the North Sea in 1969, the petroleum industry has played a crucial role in funding Norway's welfare state and contributing to its sovereign wealth fund. Today, the value added by petroleum exploration amounts to almost a quarter of Norway's GDP. Among countries where a significant portion of income stems from petroleum or other high CO2 footprint energy sources, the Norwegian government faces the challenge of designing policies aligned with the Paris Agreement. This agreement aims to limit the global temperature increase to 2 degrees Celsius, ideally no more than 1.5 degrees. Various studies, such as IEA (2021), suggest that achieving this temperature cap is possible by reaching net zero emissions (NZE) by 2050.

The literature discussing the NZE goal typically focuses on either demand policies or supply restrictions. Demand-side policies often involve CO2 taxes and energy efficiency measures to reduce fossil fuel demand, which can lower demand for fossil fuels, reducing crude oil prices, profitability, and exploration activities, as noted in IEA (2021). Alternatively, supply-side policies restrict fossil fuel supply to cut emissions, potentially driving up crude oil prices and reducing emissions, as indicated by Asheim et al. (2019). Lindholt and Wei (2023) and Lindholt (2023) examines a combination of demand-side and supply-side policies and show that very stringent policies and implementation of advancements in energy-saving technology are necessary to achieve NZE by 2050 for Norway. According to IEA (2021), investments in petroleum extraction should cease immediately, allowing only for the continued extraction from existing fields. No new projects or investments in current fields would lead to a gradual phase-out of petroleum extraction in Norway and by 2050 only minimal amounts of oil and natural gas should be extracted.

While Lindholt and Wei (2023) and Lindholt (2023) have studied the implications of changes in the petroleum industry in Norway as a result of NZE policies, to the best of our knowledge, no study has analyzed the economic impact to the Norwegian economy of such policies comprehensively. Our paper focuses on the economic transformation in Norway following the decline in the petroleum industry. In doing so, we take into account the input-output structure that allows us to trace the changes in the industry structure while accounting for changes in monetary and fiscal policies to estimate the effects on the total macroeconomy.

To comprehensively capture the effects of such a transition, we need an empirical framework that not only links the oil and gas sector with the Norwegian non-oil economy but also incorporates changes in fiscal and monetary policies. For this purpose, we use the multi-sector quarterly macroeconomic model of the Norwegian economy KVARTS, cf. Boug et al. (2023). The model includes a relatively large array of commodities destined for either export or domestic markets, making it detailed in its classification of both commodities and industries. Notably, our model integrates a comprehensive input-output structure derived from the National Accounts and employs various empirically validated behavioral equations for both firms and households based on economic theory and the cointegrated VAR methodology.

We demonstrate that the reduction in petroleum activity will lead to a permanent decrease in total GDP, while the impact on the mainland economy is significantly mitigated by improved competitiveness in non-petroleum export industries. This reversal of the

Dutch disease, combined with an expansionary monetary policy, lead to a depreciation of the real exchange rate and provide a boost to the traded sector. The outcomes align closely with the Dutch disease hypothesis, where increased petroleum activity traditionally crowds out other tradeable goods industries. Here, the reverse occurs. After the most dramatic reductions in manufacturing employment related to decreased petroleum activity have taken place, there is, in fact, reindustrialization occurring as a consequence of the lowered petroleum activities. For the private service industries, employment drops significantly in the short to medium term, but not in the long run.

Our paper integrates and extends various approaches from the economic literature. First, we contribute to the studies related to the economic impact of a permanent decline in windfall revenues for Norwegian economy, see Bergholt et al. (2023). Unlike Bergholt et al. (2023) that used a highly aggregated modeling approach, our model incorporates an input-output structure, enabling a detailed industry analysis of changes in petroleum activity.

Second we speak to large economic literature on the effects of natural resources on growth, engaging with the Dutch disease model, see e.g. van der Ploeg (2011), Corden and Neary (1982), van Wijnbergen (1984), and Krugman (1987). The Dutch disease model suggests that windfalls from resources like petroleum can cause macroeconomic shifts, appreciating the currency and reallocating labour to resource-intensive sectors, thus undermining other industries and leading to deindustrialization. Gylfason et al. (1999) and Torvik (2001) note this could result in a loss of manufacturing knowledge. However, studies by Cappelen and Eika (2020), Bjørnland and Thorsrud (2016), and Bjørnland et al. (2019) indicate that Norway may have mitigated or even reversed these effects, helped by greater labour market integration in Europe from 2004 onwards and positive spillovers from resource exploration. Our study explores a scenario in Norway where the phasing out of petroleum reverses the resource movement effect and reduce the spending effect.

A "green" transition of an economy involves technological changes that will affect both production and consumption of goods and services and lead to changes in industry structure, see e.g Kemp-Benedict (2018). Structural change in Norway relating to the green transformation will to a larger extent than in most OECD countries center around the effects of phasing out its petroleum industry. Exploration of crude oiI and natural gas resulted in one fifth of total CO2 emissions in Norway in 2022. Thus, phasing out the petroleum industry will significantly help reducing emissions in Norway by 2050. Our results highlight the effects decarbonization in a small resource rich open economy with inflation targeting, and the findings should be relevant to a number of similar countries with a big resource sector that experience a green transition.

The remainder of the paper is structured as follows. Section 2 puts the Norwegian oil industry in perspective by presenting some stylized facts and a theoretical framework for understanding how the reduction of petroleum windfalls may affect the overall economy. Section 3 describes the empirical framework and the reference path for the Norwegian economy. Empirical results are discussed in section 4, focusing on, among others, the effects of reduced petroleum activity on various industries and the general macroeconomy. In section 5 we show several sensitivity analyses focusing on the effects of monetary and fiscal policies, as well as the role of price elasticities of foreign trade. Section 6 concludes.

2 Norwegian Oil Industry

We start by introducing a stylized model, building on previous economic frameworks, to specifically examine the effects of phasing out the petroleum industry in Norway. This section establishes a theoretical foundation to understand the mechanisms driving these changes, focusing on how the 'spending effect' and 'resource movement effect' can reshape the structure of the Norwegian economy. Additionally, we discuss the interconnections between various sectors, as highlighted by Hungnes et al. (2022), emphasizing the influence of the oil and gas industry on the mainland economy.

2.1 A Stylized Model of the Impact of Reduced Oil Windfalls on the Domestic Economy

Starting with Corden and Neary (1982) and Corden (1984), a substantial body of literature has emerged, using the theory of Dutch disease to explain the effects of natural resource windfalls on non-resource sectors of the economy. In this section, we illustrate how the phasing out of the petroleum industry can affect different sectors of the Norwegian economy, using the Dutch disease framework. For this analysis, we use a stylized model based on the two-sector model from Rødseth (1979), which closely follows the approaches of Corden and Neary (1982) and Corden (1984). [1]

The two sectors in the private mainland economy produce,respectively, traded goods T and nontraded goods N . To simplify matters, we include only labour as input and assume the simplest production function in the non-traded goods industry

$$X_N = A_N * N_N \tag{1}$$

where A_N is a productivity term and N_N is employment. The price of the nontraded goods, P_N, is determined as a mark-up over marginal costs. The production function in the traded goods sector is specified as a CES function of labour, N_T, and capital which is assumed for simplicity to be fixed. With constant returns to both production factors, in line with the assumption in KVARTS, there will be decreasing returns to labour. Together with the assumption that the price of tradable goods, P_T is given by world prices, this determines output in the traded goods industry as:

$$X_T = A_T \times [\delta N_T^{-\rho} + (1-\delta) \times K_T^{-\rho})]^{\frac{1}{\rho}} \tag{2}$$

where A_T is a productivity term, and δ and ρ are share and distribution parameters respectively. In addition, there is an oil sector (B) that shares the resources (labour) with the mainland economy. For the oil sector we assume that both production and prices are exogenous.

Households' consumption of non-traded goods is a fixed budget share, e, of total consumption, C.

The total labour supply, NS, is exogenous:

[1] Boug et al. (2023) also use a similar stylized model to study the effects of changes in fiscal policy.

$$NS(1-U) = N_N + N_T + N_B + N_G \tag{3}$$

where N_G, N_N and N_T is employment in government, nontraded and traded sectors respectively. U denotes the endogenously determined unemployment rate. N_G is exogenous. Wage bargaining in Norway can be characterized as "pattern bargaining", see Calmfors and Seim (2013). Unions and employer federations bargain first at the aggregate industry level followed by local bargaining later in the year. The parties in the traded goods industry bargain first and set a "wage norm" which is then followed by other industries. The norm is determined in so that the wage share in the traded goods industry is roughly constant over the business cycle. Cyclical variations in the wage share are related to changes in unemployment in line with the empirical findings in Gjelsvik et al. (2020). The wage curve in traded sector is

$$W_T = sU^{\gamma} P_T \cdot \frac{X_T}{N_T} \tag{4}$$

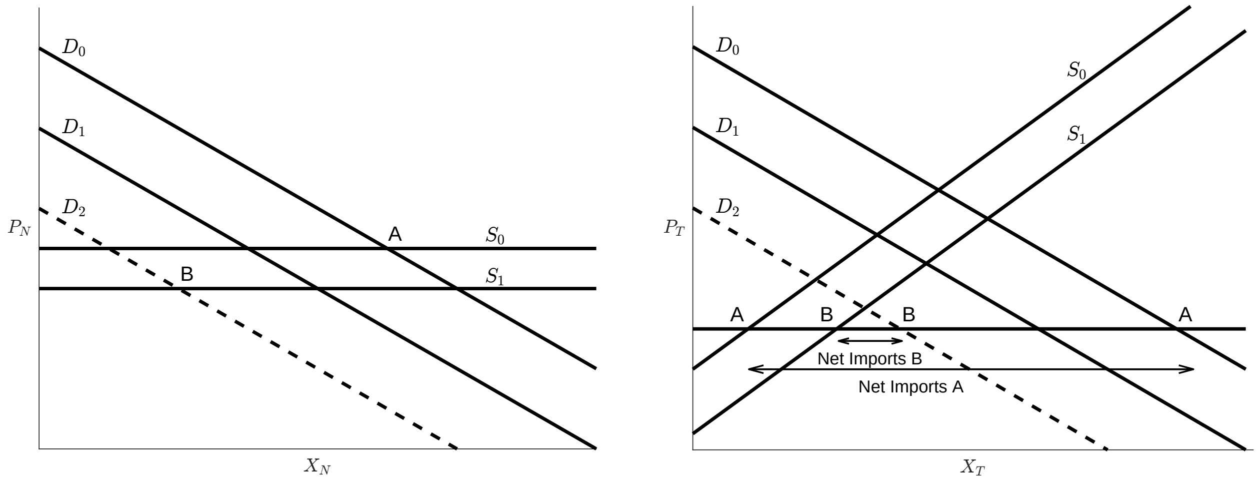
where sU^{γ} equals the wage share in the traded sector. The wage rate in the non-traded and government sector follows the wage rate in the traded goods sector in accordance with pattern bargaining in Norway. The real exchange rate defined as $\frac{P_N}{P_T}$. Households' disposable income is a sum of wage income, a share of operating surplus in the non-traded and traded goods industries and transfers from the government.

While traditional Dutch disease literature concentrates on the effects of a booming resource sector, we focus on the economic transition resulting from phasing out the petroleum sector. Figures 1a and 1b illustrate the effects of decreasing oil and gas production on industry structure.

A decrease in oil and gas production reduces aggregate income through the contraction of the government sector and lower transfers to households. Reduced government spending decreases demand for both traded and non-traded goods, resulting in lower domestic production of non-traded goods and a decline in imports of traded goods. This is illustrated in Figures 1a and 1b, where the demand curve shifts from D_0 to D_1. Increased unemployment leads to lower wages and reduced marginal costs, causing the supply curves for both traded and non-traded sectors to shift downward from S_0 to S_1. As a result, prices for non-traded goods decline. Since the price of traded goods remains constant, the real exchange rate depreciates. This outcome is the inverse of the *spending effect* typically described in the Dutch disease literature.

In addition, the contraction of the oil sector will reallocate labor away from the petroleum industry, which is the opposite of the *resource movement effect* commonly discussed in the Dutch disease literature. This shift reduces household income further, leading to an additional decline in demand. Consequently, the demand curves shift from D_1 to D_2.

According to Corden (1984), there is also a labor movement effect between the traded (T) and non-traded (N) sectors due to changes in demand in the non-traded goods sector. However, in Norway, this effect is moderated by wage bargaining practices that ensure wage growth in the non-traded sector aligns with wage growth in the traded sector. As a result, increased profitability in the traded goods sector, driven by the depreciation of the real exchange rate, leads to upward pressure on wages, which helps mitigate the reduction



(a) Non-traded sector. **(b)** Traded sector.

Figure 1: Effects of decrease in activity in petroleum sector in the industry structure in non-traded (N) and traded (T) sectors.

in household income. Norway also distinguishes itself from many other resource-rich countries by depositing revenues from oil and gas into a sovereign wealth fund, using only the expected real return from this fund to cover fiscal budget deficits. This fiscal rule has reduced the relative importance of the spending effect in Norway, making the resource movement effect more prominent. Simultaneously, demand from the oil and gas sector has driven the development of technologically advanced industries in the mainland economy, which specialize in supplying goods and services to the petroleum industries. As shown by Bjørnland et al. (2019), learning-by-doing in these industries has created positive spillovers for the broader economy. When activity in the oil and gas sector will decline, the negative impacts of the spending effect are expected to be mitigated by the continued government revenue from the sovereign wealth fund. At the same time as the adverse effects from resource movements can have negative effects on the mainland economy.

The structure of employment in the economy will also significantly impacts the spending and resource movement effects. In Norway, employment in the private non-traded sector accounts for around 60 percent of total employment. The public sector employs around 30 percent, while only 10 percent of total employment is in the traded goods sector. Although only about 2 percent of total employment is directly within the oil and gas industry, other mainland industries have specialized on delivering services for the petroleum industry, and hence will be directly and indirectly affected by reduced demand in the oil and gas sector. A relatively small oil and gas sector in term of number of employees together with a closer integration of labour markets in Europe due to the Schengen agreement and the enlargement of the EU from 2004 and onwards, see Cappelen and Eika (2020), have led to a moderation of the resource movement effect for Norway so far. This emphasizes the importance of having an appropriate modelling framework that takes into account the Norwegian industry structure when analyzing the effects of phasing out the petroleum sector.

2.2 Input - Output Linkages

The extent to which the petroleum sector has spillovers to the rest of the economy depends on the inter-linkages in the economy, i.e., if other sectors also deliver output to the oil sector. Hungnes et al. (2022) have studied domestic industries supply to the petroleum industry and how much is imported, using input-output tables from the Norwegian national accounts to estimate the value added linked to these deliveries. As the authors show the direct deliveries of investment goods to the petroleum industry are primarily provided by the Manufacturing of machinery, Petroleum services, and Other private services, accounting for about 75 percent of direct deliveries. Table 1 in Appendix A illustrate this. More than 20 percent of direct delivery is imported (see column ”Direct delivery”), but taking the indirect effect into account the share of imports doubles (see column ”Value Added”). Most industries do not deliver goods and services directly to the petroleum sector to a great extent. However, they play a significant role as suppliers of inputs to other industries that make these direct deliveries. Examples of such industries include Real estate activities and Production of electricity. Another important way Norway deviates from other countries, is the fiscal policy rule. Since 1996 revenue from the sale of oil and gas is deposited into what is known as a savings fund, and from 2001 only the expected real return of the fund is drawn annually to finance public spending or tax cuts. Hence although oil and gas export has brought Norwegian households and government substantial wealth improvement, the mechanisms from the spending effect are much weaker if the income from oil and gas would result in higher public or/and private consumption as Norway produces oil and gas.

This illustrates the importance of taking into account spillovers between the industries, and why we emphasize the importance of modeling the oil sector jointly with the rest of the economy in the empirical analysis below.

Industry	Direct delivery (%)	Value added (%)
Agriculture, forestry and fishing	0.0	0.3
Manufacturing of Consumer goods	0.7	0.9
Manufacturing of industrial raw materials	0.3	0.3
Manufacturing of machinery	15.9	7.3
Construction	0.6	0.7
Production of electricity	0.2	0.6
International shipping services	0.1	0.1
Petroleum services	22.9	8.4
Wholesale and retail trade	1.0	4.0
Housing services	0.0	0.0
Real estate activities	0.0	1.5
Other private services	36.4	29.9
Government services	0.8	1.7
Net indirect taxes	-0.1	1.5
Imports	20.7	41.7
Total	**100.0**	**100.0**

Table 1: Deliveries to the Petroleum Sector's Investments in 2020. Percentage of Investments. Value added shows how industries are affected through Input-Output linkages. For more details see Hungnes et al. (2022).

3 Modeling Framework

We now analyse how phasing out the petroleum sector in Norway will affect the economy. To do so, we use the KVARTS multi-sector quarterly macroeconomic model of the Norwegian economy, cf. Boug et al. (2023). KVARTS is in particular useful to answer our main question as the model contains several types of industries, including oil and gas industry, various manufacturing industries, primary industry, construction, private service industries as well as public sector, cf the discussion of input-output effects earlier. The model also specifies a relatively large number of commodities that are delivered to the export market and/or the domestic market and contains a comprehensive input–output structure based on the National Accounts. In addition, KVARTS contains various empirically identified behavioral equations for both firms and households based on economic theory and the cointegrated VAR methodology. With a reasonable balance between theoretical consistency and empirical fit, we believe that the model is suitable for examining how a change in one industry will affect all the other industries in the economy. Below we give a brief overview over important mechanisms in KVARTS, that are in addition to those described in Section 2.1 and 2.2. For a more detailed model description we refer to A and Boug et al. (2023).

3.1 The model

The empirical basis in KVARTS is based on an input output core. There are 16 industries of which exploration of oil and natural gas is one. Each industry produces one or more goods using a KLEM production structure. The capital stock is a Cobb-Douglas aggregate of several capital goods while labour (hours worked) by industry is not disaggregated. Electricity and fuels enter as a CES energy aggregate. Other non-energy material inputs is a separate input and a Leontief aggregate of non-energy-commodities. The petroleum exploration sector has some specific capital goods not used in other industries (pipelines and platforms).

As described in Section 2, most output prices in domestic and foreign markets are based on mark-up pricing where marginal costs are based on the KLEM production system and the input-output structure. Hourly wage rates are determined by a wage bargaining system often called pattern bargaining where bargaining in the manufacturing industries sets a norm for wages in the other industries including the government sectors. Wage rates in manufacturing are mainly determined by producer prices and productivity in manufacturing and the rate of unemployment. Labour supply is determined by population by age and gender and participation rates depend on the disposable consumer real wage as well as on the unemployment rate to capture a so-called discouraged worker effect.

Household consumption is a function of household disposable real income, real wealth (financial and housing) and the after-tax real interest rate. The housing block includes the interaction between housing credit, interest rates, housing prices and investment/capital leading to a financial accelerator in the model. Foreign trade is mostly determined by the Armington approach. Imports as share of total use of each product depends on the ratio of import price to the domestic price for each product. Export volumes are related to relative Norwegian export prices to foreign competitive prices in common currency as well as foreign incomes. As is often found in aggregate studies the price elasticities of foreign trade are estimated to be moderate in absolute size. We return to the significance of these elasticities in the sensitivity analyses in Section 5. The exchange rate (the Krone Euro rate) combines Uncovered interest rate parity (UIP) and purchasing power parity (PPP) cf. Benedictow and Hammersland (2023).

The central bank policy rate is set according to a Taylor rule with an inflation target of 2 percent and an unemployment target equal to the historical average of just over 4 percent. The fiscal policy rule includes two terms. First there is a smoothing of the structurally and petroleum revenue adjusted central government budget deficit both to achieve annual figures and to secure that the deficit amounts to 3 percent of value of the state pension fund invested abroad. Another term allows for discretionary fiscal policy around the 3 percent rule depending on business cycle features in the short and medium run. The change in deficit is spread to expenditure changes and tax changes so that the government and household consumption changes by the same percentage point. By the end of 2023 the fund amounted to about four times Mainland GDP[2]. A more detailed presentation of

[2]Mainland GDP is defined as total GDP minus value added in the two industries Production and pipeline transport of crude oil and natural gas and International shipping services. Mainland GDP is the most commonly used aggregate output measure for the Norwegian economy both nationally and in OECD publications.

the model is given in appendix A.

3.2 Model simulations

To examine how a reduction in petroleum investment and production will affect the rest of the economy in KVARTS, we need a reference scenario for the Norwegian economy as our starting point. Based on this reference scenario, we can introduce an exogenous change in petroleum sector activity and analyze its effects on the rest of the economy.

Below we present a brief overview over the reference path, and a more detailed description can be found in B. In Section 3.2.2 we present the assumptions regarding the exogenous change in the petroleum industry.

3.2.1 The reference scenario

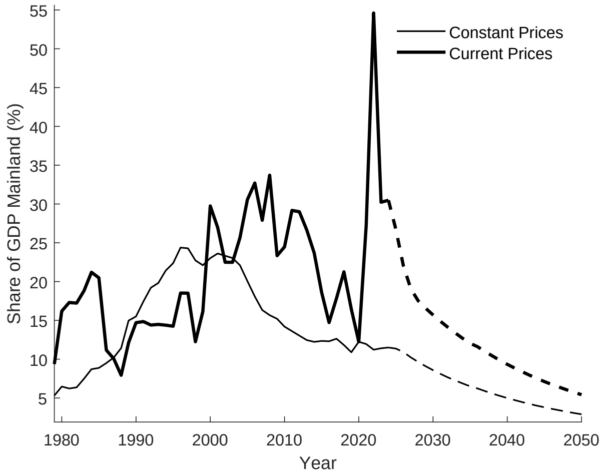
In 2023, value added in the petroleum industry was roughly a third of Mainland GDP, slightly higher than the average for the period 2000-2020 (see figure 2a). Looking at this share in current 2020 prices, we first notice the enormous terms of trade gains for Norway due to the war in Ukraine. However, these gains are not assumed to persist, and prices for oil and natural gas have decreased markedly, with crude oil prices expected to fall further until 2026 according to future prices as of early 2024. Thereafter, we assume its real value to remain roughly unchanged until 2050. The price of natural gas, however, is expected to remain higher in the future than before the war in Ukraine. Regarding production in physical terms, our reference scenario for the petroleum industry is based on the Norwegian Petroleum Directorate (2023)[3].

The gross production according to the directorate's "expected scenario" and assumptions regarding the use of labour, capital, and material inputs, shown in figure 2b, form the basis for our estimate of value added in figure 2a. This figure shows the value added in petroleum industry relative to the mainland GDP, demonstrating the relative size of the petroleum industry in Norway. As evident from figure 2a, the size of the petroleum industry is expected to decline substantially over the coming decades, with a larger relative decline due to underlying growth in Mainland GDP.

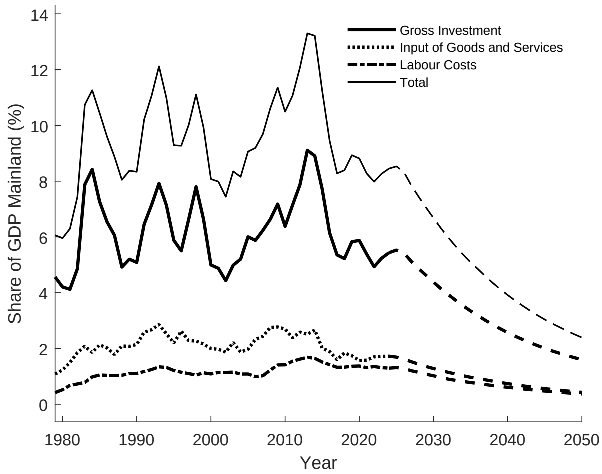
Figure 2b shows the assumed costs in the petroleum industry until 2050 as a share of Mainland GDP in current prices. While this industry currently uses resources amounting to about 8 percent of Mainland GDP, the assumed reduction in production will lower this share to less than 3 percent of Mainland GDP by 2050. Thus, the importance of the resource movement effect will decrease to levels not seen since the first half of the 1970s, when Norwegian petroleum production began.

The model estimates income from petroleum production, tax revenues, and capital income for the government. The government budget surplus is accumulated in a fund invested abroad, with its value shown as a share of two GDP measures in figure 3a. Currently, the fund is just above 400 percent of Mainland GDP. The fiscal policy rule permits using 3 percent of the fund in the central government budget, which implies that the budget is currently balanced by using capital incomes from the fund amounting to 12

[3]The reference scenario in Lindholt (2023) is also roughly in line with these assumptions.



(a) Value added in petroleum industry as a share of GDP Mainland. 2020 constant prices and current prices between 1979-2050, in percent.



(b) Gross investments, input of goods and services, and labour costs in the petroleum industry as a share of GDP Mainland, 1979-2050. In percent.

Figure 2: Comparison of value added in the petroleum industry and gross investments, input of goods, and labour costs as shares of GDP Mainland.

percent of Mainland GDP. This can be regarded as an estimate of the spending effect of petroleum in Norway. Since around 2015, the spending effect from petroleum has been larger than the resource movement effect. Our estimate of the fund's value from 2024 to 2050 suggests that while the spending effect will increase somewhat, it will remain quite stable in the long run. Further details on the reference scenario are presented in appendix B.

3.2.2 Alternative scenario

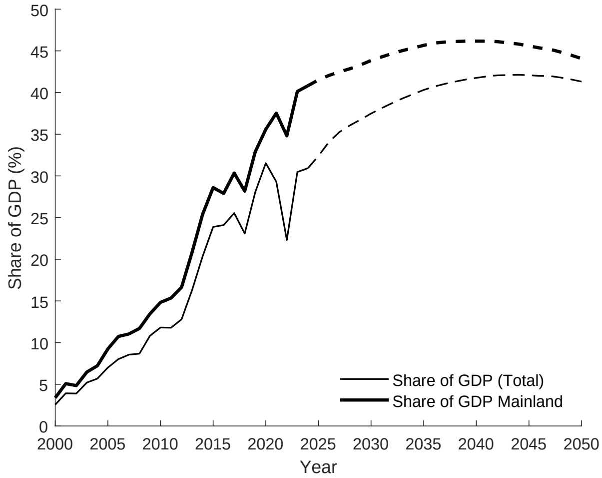
Our assumptions regarding the petroleum industry are based on studies by Lindholt and Wei (2023) for a global analysis of the IEA's net zero emission scenario IEA (2021) and Lindholt (2023) for an analysis of the consequences of the NZE scenario for the Norwegian petroleum industry. We implement the policy from 2026 onwards. Some existing projects currently in the planning or investment phase will be allowed to be completed, but from 2028 onwards, no further capacity building will take place. Current fields in operation will be allowed to continue as long as they remain profitable. Gross investment in the petroleum industry will not be zero from 2028, as the industry will need to dismantle existing installations. However, these investments will be small, as shown in 3b. The drop in investment from 2026 to 2028 will amount to nearly 5 percent of Mainland GDP in 2028 compared to the investment level in the reference scenario.

Figure 3c shows total output of crude oil and natural gas in million tons of oil equivalents in both the reference and alternative scenarios. As evident from the figure, there is a substantial decline in production in the reference scenario, with output more than halved by 2050 compared to current levels. In the alternative scenario, output is very small by

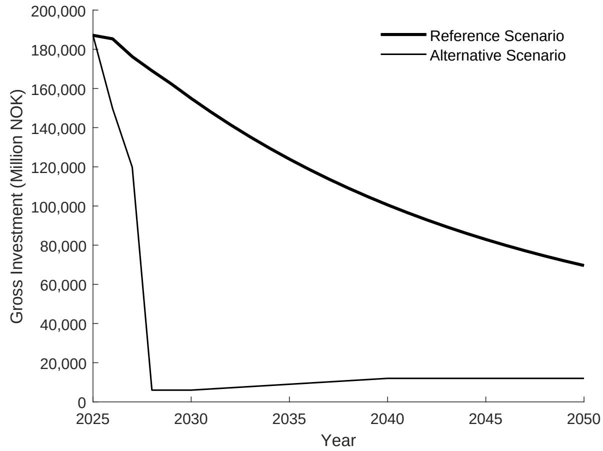
2050, but note that even if no new capacity is installed from 2028 onwards, there will still be profitable production from existing fields in 2050, in line with Lindholt (2023). Production of crude oil is falling somewhat more than natural gas in both scenarios.

Total resource costs as a share of Mainland GDP in the reference and alternative scenarios are shown in figure 3d. In 2028, the demand change – i.e., the difference between the alternative scenario and the reference scenario – equals more than 5 percent, which is a significant change compared to standard economic fluctuations in the Norwegian economy during normal business cycles. However, referring back to 2b, this shock is quite similar to what occurred between 2014 and 2017, showing that large shocks in resource demand from the petroleum industry have happened before. Notice that the difference between the two curves in figure 3d is largest in 2028 and reduces to 2 percent of Mainland GDP by 2050. Thus, our alternative scenario implies a large drop in resource costs (more than 5 percent of Mainland GDP in 2028) that gradually reduces to about 2 percent by 2050, indicating a permanent, but not constant, negative shock that diminishes over time.

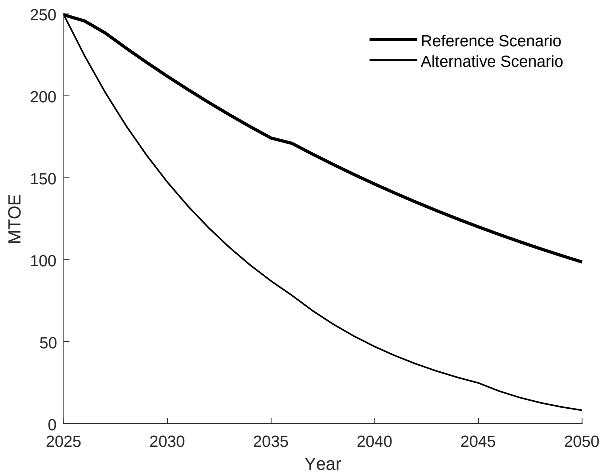
We assume no change in the global real oil price between the two scenarios. Lindholt and Wei (2023) estimate a dramatic increase in the crude oil price following a supply-side-driven cut in crude production. Lindholt (2023) finds that petroleum revenues in Norway change only moderately as a result. Other studies, such as IMF (2022), also find an increase in the crude oil price due to lower oil supply. On the other hand, IEA (2021) finds a significant reduction in the real crude price if demand-side policies are implemented to achieve global emission targets by 2050. Our choice of an unchanged price makes it easier to understand the various effects driving our results. We assume that the price of natural gas follows the crude oil price. If the crude oil price were to increase in line with Lindholt and Wei (2023), Norway would earn much higher incomes from petroleum production than we assume. This is shown in Lindholt (2023). This would significantly reduce the need for adjusting fiscal policies to meet the fiscal policy rule in our alternative scenario. If, however, the IEA-crude price were to be the consequence of the NZE-policies, a much larger fiscal adjustment would be needed than in our alternative.



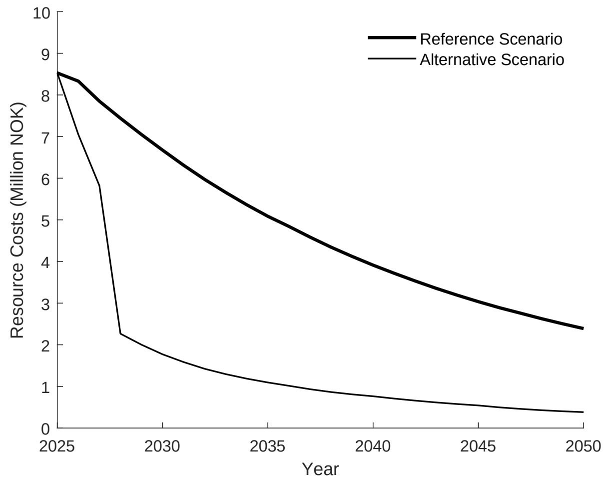
(a) Norwegian Oil Fund as a share of Total GDP and GDP Mainland, 2020-2050. In percent.



(b) Gross investment in Petroleum, Mill. NOK in 2020-prices.



(c) Production of crude oil and natural gas in mtoe.



(d) Resource costs in the petroleum industry. Share of Mainland GDP in percent.

Figure 3: Overview of the SPU share of GDP - and investments, production, and resource costs in the petroleum industry.

4 Empirical Results

We now study the effects of a national policy that prohibits further development of Norwegian capacity to produce crude oil or natural gas. To that end, we focus on the annualized impulse responses, estimated as the difference between the reference and the alternative scenario. Below we present the results based on active monetary and fiscal policies. In Section 5 we also discuss the effects when monetary and fiscal policies are passive.

4.1 Aggregate macro-effects

We start by examining the impact of reduces petroleum activity on the aggregate macroeconomy. Figure 4a displays the impacts of the reduction in petroleum activity on total GDP and its main components, while figure 4b shows these effects for Mainland GDP.

It is evident that total GDP significantly decreases in the initial years following the drop in oil activity. The investment component, by assumption, experiences the most substantial decline. A reduction in oil and gas exports follows decreased investments in exploration, but net exports are also impacted by a significant drop in imports of equipment tied to petroleum investments. The initial drop in the Mainland GDP is substantially less and gradually fades out due to reduced investment impacts and an increase in net exports from the mainland economy, stemming from improved cost competitiveness.

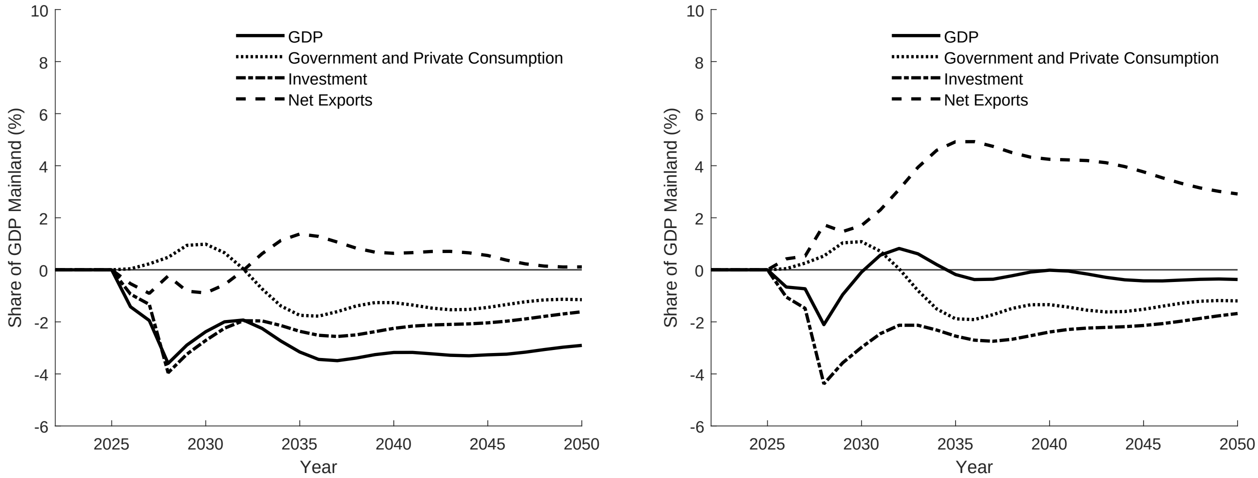
As discussed in Section 2.2, one effect of the petroleum industry using fewer resources is the resource movement effect, where increased unemployment leads to a decrease in wages. This leads to increased exports and reduced imports. However, the influence on mainland exports will diminish over time as the resource movement effect, though permanent, gradually lessens. By around 2040, the macroeconomic effects become minimal.

With lower activity and higher unemployment, consumer prices will drop relative to the reference scenario, prompting the central bank to reduce interest rates concurrently with a depreciation of the exchange rate, as shown in Figures 6a and 6b. Lower interest rates will help soften the decline in mainland investment and household consumption. Fiscal policy changes, including reductions in household tax rates and increases in government spending, will serve as discretionary stimuli, enhancing total consumption during the initial phase.

In the long term, however, Mainland GDP and consumption will suffer from the spending effect discussed in section 2.1 that happens due to loss of revenues from the petroleum industry and a smaller "oil fund", resulting from diminished surpluses on the current account and the central government budget balance, as shown in Figures 5a and 5b. As government revenue decreases due to reduced oil and gas production, investment in the oil fund also declines, leading to a gradual decrease in its value in the alternative scenario.[4]

As shown in 6a, the significant decrease in petroleum investments results in a sharp reduction in the interest rate of more than 3 percentage points in 2028. Following this, the depreciation of the exchange rate, as illustrated in 6b, stabilizes after seven years at a level 5-6 percent lower than before. The permanent depreciation of the exchange rate is due to the initial increase in the price level caused by imported inflation, which influences wage

[4] In Section 5, we explore the effects of fiscal policy and exchange rate fluctuations on the value of the fund.



(a) GDP (Total).

(b) GDP (Mainland).

Figure 4: Comparison of GDP (Total) and GDP (Mainland).

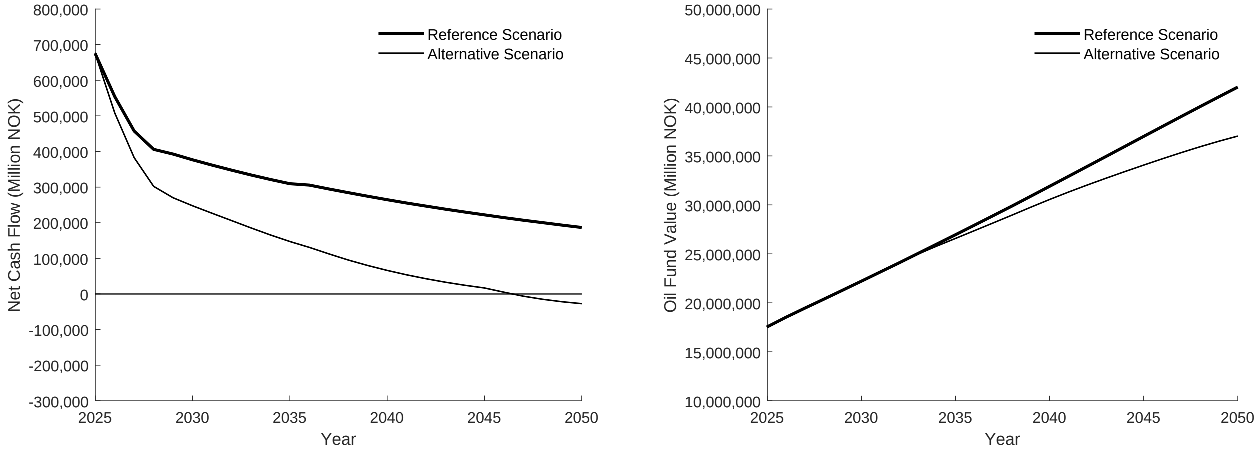
bargaining. This imported inflation, combined with the purchasing power parity (PPP) element in the exchange rate equation, leads to a sustained weakening of the krone.

The substantial reduction in petroleum investment results in an increase in unemployment, as depicted in figure 7. Initially, the unemployment rate rises by around 1 percentage point compared to the level in the reference scenario, but then gradually decreases as the central bank lowers the interest rate. Additionally, the aggregate labour participation rate drops by half a percentage point, influenced both by a discouraged worker effect and a decline in (after-tax) real wages.

In the long run, the effects on unemployment and participation rates are small, except for real wages, which remain lower than in the reference scenario. This is primarily due to a compositional effect: wages in the petroleum industry are typically higher than in the mainland economy, and the significant decline in this sector reduces the overall wage level. This wage adjustment also gradually impacts wage bargaining across several mainland industries, as the option of being employed in the relatively high-paying petroleum industry becomes less available, altering the bargaining power of employees.[5] The decline in the overall wage level contributes to reduction in private consumption.

Taken together, these results show that although mainland GDP is barely affected in the long run, consumption will be lower due to the spending effect. The resource movement effect, on the other hand, dies out, as depreciation of the exchange rate boosts the domestic export industries.

[5] To what extent wages in the petroleum industry are relatively high solely due to job attributes or partly because employees capture a share of the resource rent is not clear.



(a) Government net cash flow from petroleum.

(b) Government oil fund.

Figure 5: Government net cash flow from petroleum and Government oil fund in Reference scenario and the alternative scenario. Levels in Mill. NOK.

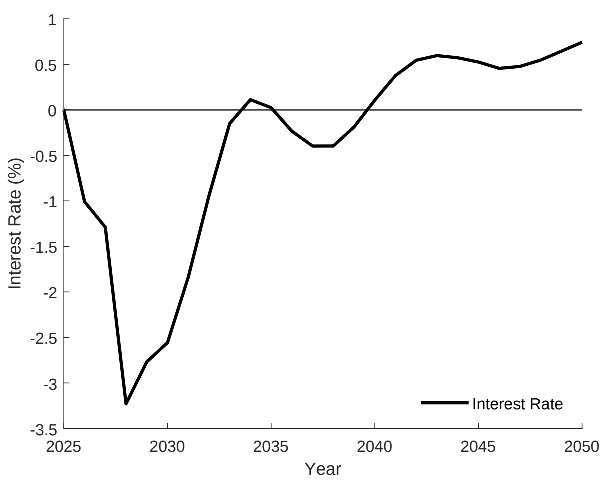
4.2 Employment effects at aggregate and disaggregate levels

Having seen how the reduction in petroleum activity affects the aggregate macroeconomy, we now turn to the change in the employment both at aggregate sector level as well as at more disaggregate industry level. To align our findings with the theoretical predictions discussed in section 2.1, we first examine how the traded, non-traded, and public sectors respond to the decrease in petroleum activity. Subsequently, we turn to the industry level, and analyze how employment varies within sectors.

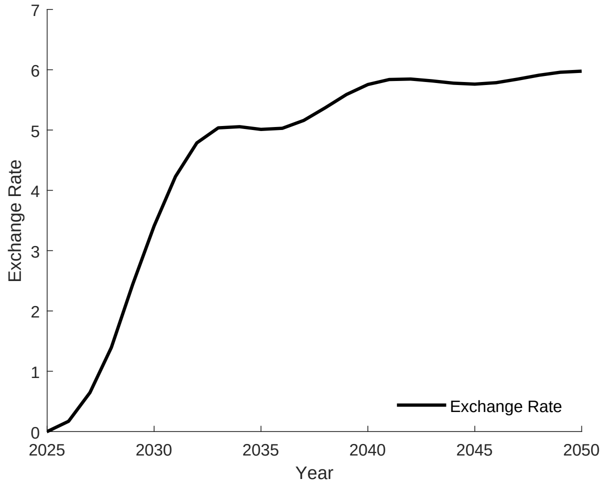
Figure 8 illustrates changes in total employment and employment by sector. Initially, total employment drops by around one and a half percent during the period of dramatic declines in petroleum investments. Over the longer term, a contractionary fiscal policy resulting from reduced petroleum income leads to lower employment in the public sector. Figure 8b highlights a decline in employment in the petroleum industry. However, since employment in this industry accounts for about one percent of total employment, its impact on the overall Norwegian economy is small. By 2050, there are only 1,000 employees left in that industry in the alternative scenarios.

Figure 8b also shows employment in manufacturing and in private mainland service industries. In Norway, there is considerable concern about how a rapid decline in the petroleum industry might affect manufacturing employment. This concern arises from potential impacts on regional labour markets and the critical role manufacturing employees play in Norway's system of wage bargaining. The effects on manufacturing employment are modest in a macroeconomic context.

The outcomes align closely with the Dutch disease hypothesis, where increased petroleum activity traditionally crowds out other tradeable goods industries. Here, the reverse occurs. After the most dramatic reductions in manufacturing employment related to decreased petroleum activity have taken place, there is, in fact, reindustrialization occurring



(a) Interest rate.



(b) Exchange rate.

Figure 6: Effects on the interest rate (in percentage points) and exchange rate (in percent) in the alternative scenario with policy rules. Deviations from the reference scenario.

as a consequence of the lowered petroleum activities. For the private service industries, employment drops significantly in the short to medium term, but not in the long run.

To better understand the aggregate employment effects outlined in our simulations, we go deeper into the specific impacts on various industries. Figure 9a illustrates the employment effects on traded goods industries. In the manufacturing sector, the machine industry, which is closely linked to the production of equipment used in the petroleum industry, experiences a significant initial drop in employment—5 percent compared to the baseline—due to the substantial decrease in petroleum activity. However, this decline is quickly offset within a few years by improved relative costs, which boost exports and reduce import shares of machinery, bringing output and employment back to baseline levels. Thus, even the part of manufacturing most closely linked to the petroleum industry sees only transient effects in the medium to long term.

Two other traded goods industries in Norway, primarily unrelated to the petroleum sector but heavily reliant on exports—the primary goods industry (mainly fishing and fish farming) and the manufacturing of metals and chemical semi-manufactured goods—benefit from improved competitiveness and increased exports while being minimally affected by the downturn in petroleum investments. Meanwhile, the manufacturing of consumer goods occupies a middle ground; it benefits from improved competitiveness but is also negatively impacted by the lower incomes and reduced activity in Norway, as indicated in Figure 4.

Figure 9b explores the employment effects across various service industries that represent the non-traded sector. Notably, government employment initially rises due to stabilization policies that increase government spending in response to the drop in petroleum investments. However, in the medium to long term, government employment decreases due to fiscal consolidation aligned with the fiscal spending rule. Employment in retail

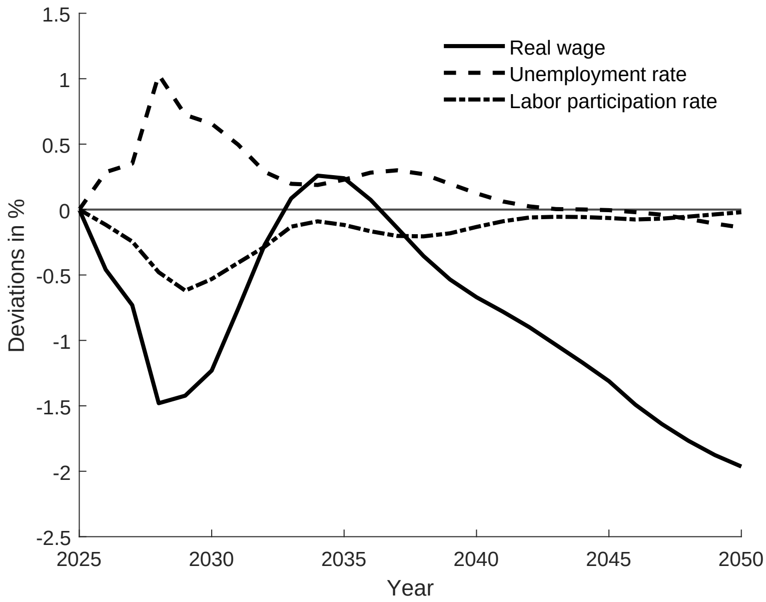


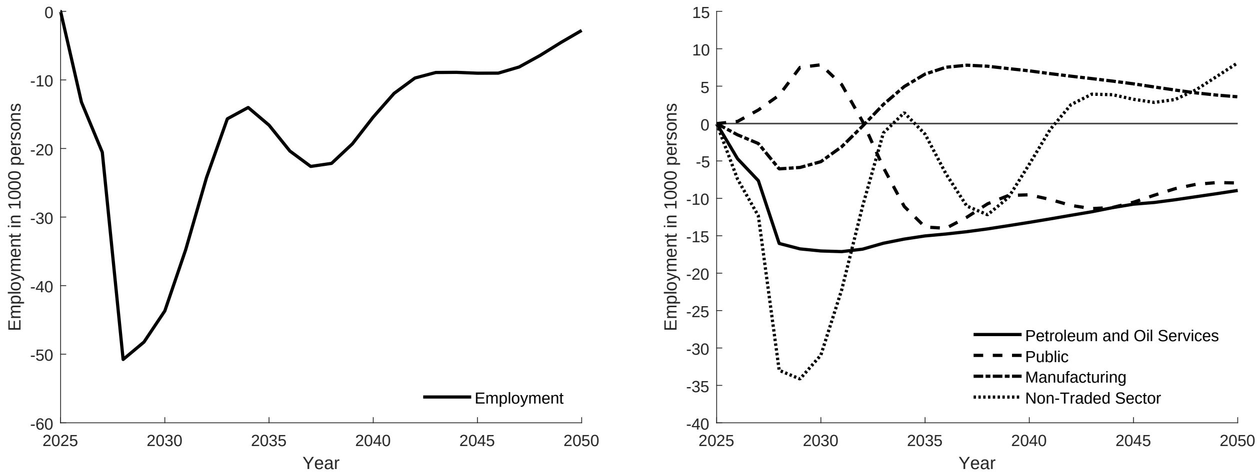
Figure 7: Effect on the consumer real wage, unemployment rate and labour participation rate. Deviations from reference scenario in per cent (changes in rates are in percentage points)

and wholesale trade mirrors the trends in government employment for similar reasons. A significant decline is also observed in business services, which parallels the drop in the machine industry, due to its composition of engineering services closely linked to petroleum investments. Nevertheless, this sector eventually benefits from improved cost competitiveness, given the significance of exports and imports of services.

The construction industry experiences highly cyclical effects driven by fiscal and monetary policy responses. Initially, lower interest rates spur housing investments and construction activities, but in the longer term, the industry suffers from the general economic slowdown and reduced incomes. The construction industry is only moderately linked to the petroleum sector, the negative long-term effect is primarily driven by lower mainland investments. [6]

The results presented above show that the drop in petroleum activity has a mixed effect on the mainland industries. For industries supplying services and equipment to the oil and gas sector, the negative effect is prominent only in the short run. In the medium to long run, these industries, along with other export sectors, benefit from a lower exchange rate. On the other hand industries that have specialized on delivering goods and services to the domestic market suffer from lower domestic demand.

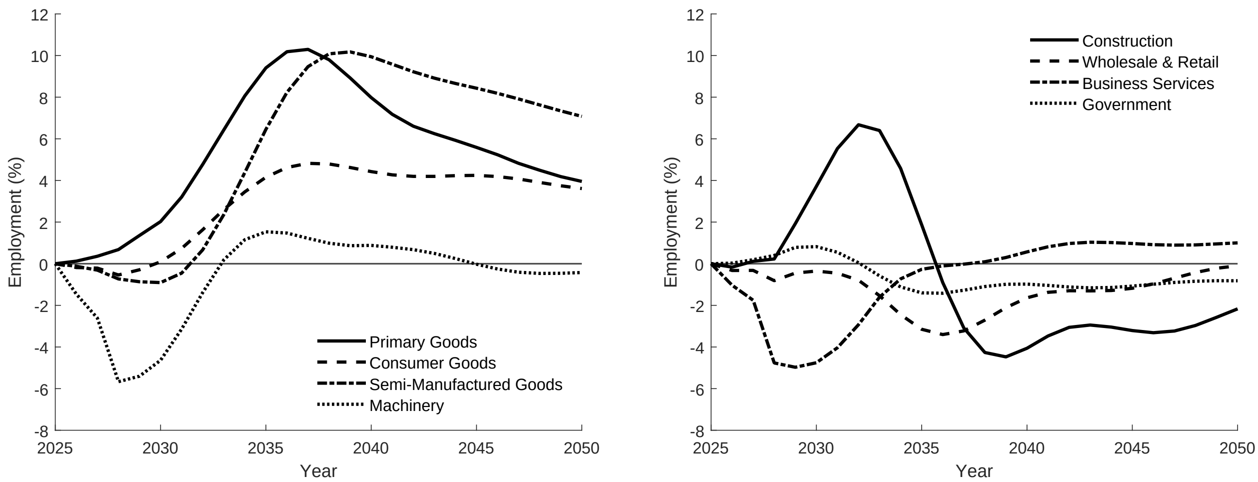
[6] The construction of oil platforms is part of manufacturing, not the construction industry.



(a) Total Employment.

(b) Aggregate Industry Employment.

Figure 8: Effects on total employment and for aggregate industries. Deviations in 1000 persons from reference scenario.



(a) Traded goods industries.

(b) Service industries.

Figure 9: Employment effects in percent deviation from baseline.

5 Robustness and sensitivity analysis

We next analyze sensitivity to key assumptions in our modeling framework. We comment briefly here, while details can be found in Appendix C. In particular, we analyze robustness to two dimensions. First, we analyze the effects coming from monetary and policy responses due to reduced petroleum activity. In particular, we simulate our model assuming passive monetary and fiscal responses at the same time as we assume an exogenous exchange rate. We show in Appendix C.1 that while depreciation of exchange rate is crucial for boosting activity in the traded sector, passive monetary policy leads to a bigger drop in private consumption in the short run and the negative effects for the non-traded private service becomes significantly larger.

Second, we analyze to what extend the choice of price elasticities of foreign trade shape our results. The canonical Dutch disease model usually invokes a small open economy (SOE) assumption where the tradeable goods industry faces given product prices on world markets. Higher domestic costs following higher resource exploration then drives down supply in traditional export industries and increases imports. In the simulations in Section 4 we have used relatively large price elasticises (in absolute value) in foreign trade to mimic the Dutch disease model by multiplying time series estimates by a factor of five. In Appendix C.2 we show the effects of *lower* price elasticities of foreign trade (in absolute value) compared to what we have shown so far. First we show the results of using the standard time series econometric values where the average aggregate export price elasticity for mainland products is -1.1. This fairly low value in absolute terms is in line with many econometric policy models as well as DSGE models. The figures in appendix C.2 show the simulation using this low value is symbolized as "1". The elasticities we have used in the model simulations presented earlier are symbolized as "5". We also include the results of using an intermediate level of the value of the price elasticities by multiplying the time series estimates by three. When price elasticities change, the mark-ups in the model also change. These changes are included in these simulations. We think there are two main results to notice from these simulations. First, as one would expect, higher price elasticities (in absolute value) result in lower negative effects on aggregate output, unemployment and prices of a cut in petroleum activity as non-oil exports increases more. Second, these results appears already when elasticities are multiplied by 3. From a modelling point of view, these results indicate that one does not need very large price elasticities anywhere near the SOE- assumption in order to get results that allows us to conclude that the long run macroeconomic effects are small or at least moderate in size.

6 Conclusions

Since the discovery of oil in 1969, Norway's petroleum industry has significantly supported its welfare state and lead to build up a sovereign wealth fund, accounting for nearly a quarter of its GDP today. As a significant petroleum producer, Norway faces the dual challenge of sustaining its economy while aligning with the Paris Agreement's climate goals. This requires a transition to net zero emissions (NZE) by 2050, a goal that demands both demand-side policies like CO_2 taxes and energy efficiency, and supply-side restrictions to decrease fossil fuel availability. In line with the assumptions in IEA (2021), Lindholt (2023) studies the impact of an immediate halt to new petroleum investments, forecasting that only existing fields will continue operating beyond 2026, leading to a drastic reduction in petroleum output by 2050.

We utilize the multi-sectoral macro-econometric model KVARTS-model to analyze these transitions and their broader economic implications. This model's detailed industry and commodity classifications allow us to precisely model the macroeconomic impacts of substantial industry shifts, such as those required under NZE scenarios. Our findings indicate that while the decline in petroleum activities will lead to a permanent reduction in Norway's total GDP and lower domestic consumption, the impact on the mainland economy will be less severe thanks to increased competitiveness. This may be seen as a study of Dutch disease in reverse, enhancing the performance of the traded sector due to depreciated exchange rates and expansionary monetary policies. We find that the real exchange rate depreciation stimulates non-oil industries to an extent that almost compensates for the loss of incomes that follows from phasing out the petroleum industry. Because the petroleum industry is a particularly profitable industry based on natural resources that is left idle, the loss in national income lowers consumption in the long run and this leads to spending effects that reinforces the resource movement effects.

Thus, our paper not only contributes to the discourse on economic adjustments required for decarbonization in resource-rich economies but also provides insights that could be applicable to other nations with similar economic structures. Our study offers a detailed analysis of how climate policy can impact the Norwegian economy, providing crucial insights that policymakers must consider when planning future economic and environmental strategies.

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Macroeconomic and Industry Effects of Supply-Side Climate Policy

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— Appendix—

A Overview of the multi-sector model

In this Appendix we give an overview of the full multi-sector model KVARTS to understand in more detail the main transmission channels of various shocks. We focus on the long-run properties of the model following closely the exposition in Boug et al. (2023), Section 3.

A.1 A policy model

The macro model KVARTS falls within the category of what Blanchard (2018) referes to as policy models, while Wren-Lewis (2018) and Fair (2021) classify it as a structural econometric models. The model consists of a system of equations built to make a reasonable balance between theoretical consistency and empirical fit for the purpose of various macroeconomic policy analyses.[1] KVARTS has been developed continuously since its first generation in the 1980s, see Biørn et al. (1987). All its behavioral equations have theoretical underpinnings, see Boug et al. (2023). Economic decisions in KVARTS are, just as in DSGE models, based on optimizing behaviour forming the long-run solution of the model. However, optimizing behaviour in KVARTS is usually imposed on a subset of variables at a time. The behavioral equations are mainly estimated using cointegrated vector autoregression (VAR) framework in line with Juselius (2006). The methodology underlying KVARTS involves applying econometric specifications that encompass several economic theories or rival models, see e.g. Bårdsen et al. (2005) and Hendry and Muellbauer (2018). Only equations with theoretical content that pass various empirical tests are included in

[1] KVARTS is also used for forecasting and counterfactual analysis on a regular basis. Several central banks use recently revised or developed macroeconomic models that, except from a comprehensive input-output structure, are similar in many ways to KVARTS. Examples include the Federal Reserve's FRB/US model, the Reserve Bank of Australia's MARTIN model, the Bank of Canada's LENS model, the European Central Bank's ECB-BASE model and the Bank of Japan's Q-JEM model, see Brayton et al. (2014), Ballantyne et al. (2020), Gervais and Gosselin (2014), Angelini et al. (2019) and Hirakata et al. (2019), respectively.

the model. In particular, since empirical tests have not supported forward-looking consumer behavior based on macroeconomic data, see Boug et al. (2023), such behavior is not included in the model. The expectation formation among economic agents is characterized by backward-looking behaviour which essentially mirrors the findings in Quaghebeur (2019) that adaptive learning behaviour replacing rational expectations in DSGE models fits the data much better. With a reasonable balance between theoretical consistency and empirical fit, KVARTS is suitable for the macroeconomic policies examined in this paper.

Overall, the production level is determined in the short run by the aggregate demand structure of KVARTS along the lines of the traditional Keynesian framework for an open economy with inflation targeting. The production level in the long run is mainly determined by the supply and production structure of the model. Still, the long-run solution of the model implies that aggregate demand conditions have effects on aggregate employment and production beyond the short and medium term. In the following, we describe the main blocks of the model and point out the various transmission channels of fiscal policy.

A.2 Supply and use

All blocks in the model are determined simultaneously, which implies that a change in one industry following a change in fiscal policy will possibly affect all the other industries of the economy. For each of the 38 products, there is a supply-and-use equation which, slightly simplified, is given by[2]

$$X + I = A + C + J + M + DS = A + D \tag{A.1}$$

where X is gross production, I is imports, A is exports, C is consumption, J is gross investments, M is intermediate inputs and DS is changes in total stocks, and where the subscript for each product is suppressed for notational convenience. Total domestic demand, D, is thus the sum of consumption, gross investments, intermediates and changes in total stocks. Aggregate consumption, gross investments and intermediate inputs are for each product given as a weighted sum across categories:

$$C = \sum_k d_{C_k} \cdot C_{k'} \quad J = \sum_a d_{J_a} \cdot J_{a'} \quad M = \sum_s d_{M_s} \cdot M_{s'} \tag{A.2}$$

where C_k is the consumer category k, J_a is the gross investment category a and M_s is the category s of intermediate inputs. The indices k, a and s run over 15 consumer categories, 8

[2] In this section, we drop time subscripts unless the dynamics of the equations warrant its inclusion.

investment categories and 16 industries, respectively. The symbols d_{C_k}, d_{J_a} and d_{M_s} denote fixed product specific coefficients with values taken from the National Accounts. Total imports are for each product split into the different demand categories by

$$I = DI \cdot \left(is_C \cdot C + is_J \cdot J + is_M \cdot M \right) \tag{A.3}$$

where $is_{C'}$ is $_J$ and is_M are activity-related import-shares for consumption, investments and intermediates, respectively, while DI is an index capturing the overall import share for a specific product. Below we describe how the different supply-and-use elements are determined, including the import share for each product.

Table A.1 shows how the industries in KVARTS map into these two main sectors, as well as a third non-traded goods sector, the government sector.

Non-traded goods sector	Traded goods sector	Government sector
Wholesale and retail trade	Agriculture, fishing and forestry	Local government
Other private services	Manufacturing of consumer goods	Central government
Real estate activities	Energy-intensive manufacturing	Defence
Power generation	Manufacturing of machinery	
Construction	Services related to oil and gas extraction	
Housing services		

Note: The petroleum and shipping industries are excluded here as we only consider mainland activities. In the actual model these industries are specified as two separate industries.

Table A.1: Mainland industries and sectors in KVARTS

A.3 Production and investment

All mainland industries share a common production technology but differ in terms of their input intensities. Production is modeled in a two-level setup. At the lower level, value-added, Y, is a constant elasticity of substitution (CES) function, F_Y, of capital, K, and the number of hours worked, H. At the upper level, gross production is a function, F_X, of value added, Y, and intermediates, M[3]. The two levels for each industry j can be summarized as

$$\begin{aligned} Y_j &= F_Y \left(K_j, H_j \right) \\ X_j &= F_X \left(Y_j, M_j \right) \end{aligned} \tag{A.4}$$

[3]The factor demand system is here slightly simplified as intermediates in KVARTS are further split into energy usage and other intermediate inputs.

Firms minimize discounted costs, which gives the conditional demand for capital, number of hours worked and intermediates in each industry j as

$$
\begin{aligned}
K_j &= \frac{Y_j}{A_{Yj}} \cdot \left(\frac{1}{P_{K_j}}\right)^{\sigma_{LK}} \cdot \left[{P_{P_j}}^{1-\sigma_{LK}} + W_j^{1-\sigma_{LK}}\right]^{\frac{\sigma_{LK}}{1-\sigma_{LK}}} \\
H_j &= \frac{Y_j}{A_{Yj}} \cdot \left(\frac{1}{W_j}\right)^{\sigma_{LK}} \cdot \left[{P_{Kj}}^{1-\sigma_{LK}} + W_j^{1-\sigma_{LK}}\right]^{\frac{\sigma_{LK}}{1-\sigma_{LK}}} \\
M_j &= \frac{X_j}{A_{Xj}} \cdot \left(\frac{1}{P_{Mj}}\right)^{\sigma_{YM}} \cdot \left[{P_{Mj}}^{1-\sigma_{YM}} + {P_{Yj}}^{1-\sigma_{YM}}\right]^{\frac{\sigma_{YM}}{1-\sigma_{YM}}}
\end{aligned}
\tag{A.5}
$$

where σ_{LK} denotes the elasticity of substitution between capital and labour, σ_{YM} denotes the elasticity of substitution between intermediates and value added, P_{Kj}, W_j and P_{Mj} denote the user cost of capital, the hourly wage rate and the price of intermediates in industry j, respectively, P_{Yj} is the price of value added in industry j, A_{Yj} is the TFP parameter for value added and A_{Xj} is the TFP parameter for gross production. The factor demand set-up in (18) builds on the studies in Hungnes (2011) and von Brasch et al. (2021).

The user cost of capital in industry j, P_{Kj}, is defined as a function of the nominal interest rate on corporate credit, r, the depreciation rate in industry j, δ_j, and the investment price in industry j, $P_{I,j}$:[4]

$$
P_{Kj} = \left(r + \delta_j\right) \cdot P_{I,j} \tag{A.6}
$$

Investment J in industry j in period t, $J_{j,t}$, is determined by the capital accumulation equation, which states that gross investment equals net investment plus replacement for fixed capital goods:

$$
J_{j,t} = K_{j,t} - K_{j,t-1} + \delta_j \cdot K_{j,t-1} \tag{A.7}
$$

where depreciation is geometric and depreciation rates for fixed capital, δ_j, vary across industries due to different capital asset compositions across industries, see Barth et al. (2016).

A.4 Housing

The housing market in KVARTS is modelled as an interplay between house prices and credit. The inverted demand function for real housing, K_H, is given by

[4]Note that here we ignore corporate taxes as we do not consider changes in such taxes in Section 5.

$$P_H = F_P(D, DY, K_H, RR) \tag{A.8}$$

where P_H denote real house prices, D and DY represent real household debt and real disposable income, respectively, and RR is the real after-tax interest rate.[5] Real house prices are decreasing in the housing stock, and increasing in real household debt, real disposable income, and the real after-tax interest rate. Real household debt is in turn determined by

$$D = F_D(P_H, DY, K_H, RR) \tag{A.9}$$

as banks are more likely to provide more mortgage if households have more collateral, higher income or face a lower interest rate. For the inverted demand function A.8, a one percentage point increase in the real after-tax interest rate leads to about 6 per cent lower real house prices after 10 years. When also considering the reciprocal relationship between house prices and household borrowing, as given by the system A.8 and A.9, a one percentage point increase in the real after-tax interest rate leads to about 8 per cent lower real house prices after 10 years. Further empirical and theoretical properties of the housing market, both short- and long-run, are outlined in Boug et al. (2024).

In contrast to the case of factor demand for capital in A.3, housing capital is determined according to the q-theory of investments given by

$$J_H = F_{J_H}(P_H, C_H) \tag{A.10}$$

where J_H is housing investments and C_H represents real construction costs. The functional form of F_{J_H} is such that a 1 per cent increase in housing prices or a 1 per cent decrease in construction costs leads to a 1 per cent increase in housing starts. Hence, a proportional increase in construction costs and housing prices will have no long-run effect on the supply of new houses. In this framework, the relative price of house prices and construction costs represents the q-ratio. Housing capital is in turn determined by the investment accumulation in A.7. Housing investments as well as the part of business investments in dwellings and constructions mainly lead to increased activity in the construction sector listed among the non-traded goods sectors in Table A.1.

[5] In KVARTS, RR is based on the nominal interest rate on mortgage credit, which is linked to the key policy rate set by the central bank through a one-to-one relationship with the money market rate, see Hungnes (2015)

A.5 Imports and exports

Each imported good is assumed to be a variety of a composite domestically produced good. Each user minimizes the costs of consuming a composite good, as in Dixit and Stiglitz (1977). For manufactured goods, the import share is a CES-function of the domestic price, P_D, and the corresponding import price, P_I, for each product:

$$DI = F_I\left(P_I/P_D\right) \tag{A.11}$$

Hence, developments in the indices for product specific import shares depend on the relative prices of domestically produced and imported product varieties. For non-competitive imports, domestic production is zero or negligible and imports are given by demand.

Total exports are also assumed to be variants of the corresponding domestically produced goods and are modelled using the Armington demand approach[6]:

$$A = F_A\left[(P_A/P_W)\cdot E, D_W\right] \tag{A.12}$$

where the export price, P_A, relative to world market prices for similar goods, P_W, in local currency captures price effects and where E is an aggregate of the main exchange rates of relevance for Norwegian exports. The function of exports, F_A, is multiplicative and homogeneous of degree zero in export and world market prices measured in a common currency. The world demand indicator, D_W, reflects developments in imports for Norway's main trading partners, see Boug and Fagereng (2010).

A.6 Consumption

Non-housing consumption, C, is modelled in a three-stage procedure. At the highest level, aggregate consumption is a log-linear function of real disposable income, DY, and real wealth, HW, and the real after-tax interest rate, RR :

$$C = F_C(DY, HW, RR) \tag{A.13}$$

where the consumption function, F_C, is homogeneous of degree 1 in income and wealth. The estimated aggregate consumption function is obtained from a cointegrated VAR system, see Jansen (2013) and Boug et al. (2021). At the next level, consumption is spread over non-durable consumption, transportation vehicles and other durable consumer goods us-

[6]Note that for exports of crude oil and natural gas, gross domestic production is exogenous, and exports are determined by (A.1.

ing a dynamic linear expenditure system based on the Stone-Geary utility function. At the lower level, expenditure on non-durable consumer goods is spread further in accordance with the Almost Ideal Demand System, see Deaton and Muellbauer (1980).

A.7 Basic and purchaser prices

Prices are determined as mark-ups over marginal costs, where the latter is derived by minimizing the input cost per unit, given the production function. The producer price in every industry is determined by maximizing real profits, given that producers face a downward-sloping demand curve for their products on both domestic and export markets. Products are generally assumed to be imperfect substitutes. Domestic product prices may therefore differ from prices set by foreign competitors. Domestic producers take foreign prices into account in their price setting in line with theories of monopolistic competition. In each industry, producer prices for domestic goods and exports (excluding taxes) are the product of a mark-up, m, and marginal costs, MC. Hence, basic prices or producer prices excluding taxes, P_b, are determined as

$$P_b = m \cdot MC \tag{A.14}$$

Standard theory states that the mark-up is a function of relative prices and total expenditure. We simplify and let each industry mark-up be a function of the relative price, P_F/P_b :

$$m = m_0 \cdot \left(\frac{P_F}{P_b}\right)^{m_1} \tag{A.15}$$

where P_F is the competing foreign price and m_0 and m_1 are parameters that determine the degree of price-taking behaviour. Inserting the expression for the mark-up in the price equation gives

$$P_b = m_0^{1/(1+m_1)} \cdot P_F^{m_1/(1+m_1)} \cdot MC^{1/(1+m_1)} \tag{A.16}$$

where the mark-up is decomposed into a function of the parameters m_0 and m_1 and the competing foreign price, P_F. If $m_1 = 0$, the mark-up is constant and the price equals marginal cost multiplied by m_0. If, on the other hand, m_1 approaches infinity ($m_1 \to \infty$), then the export price or the price in domestic markets for each good equals the competitor's price, P_F. Accordingly, there is price-taking behavior and output (gross production) is determined by supply (small open economy case). Such price-taking behavior is the case in the petroleum industry, where the crude oil price is completely exogenous in the model and all prices are equal (except for some short-run differences). Generally, the degree of price taking behavior is large across the traded goods sectors in the model. In contrast, the degree of mark-up pricing is relatively high in the non-traded goods sectors. In the standard case with mark-up pricing, output in each industry is determined by a weighted sum of the demand categories in the model. The empirical properties of the price equations are outlined in Boug et al. (2017).

In addition to domestic price setting, foreign prices and taxes are essential in determining purchasing consumer prices. For each demand component, a purchasing price index is determined according to the structure in the National Accounts. The purchasing price index for consumer prices, P, which is created for separate consumption categories, such as food, electricity and housing, and then aggregated across these categories, is used below as an example. We suppress for notational convenience the index denoting the particular consumption category and write

$$P = \sum_{p} a_p \cdot \left(1 + VAT_p\right) \cdot \left[\left(1 + \tau_p^{ET}\right) \cdot P_{Hp} + b_p \cdot P_{ETp} + c_p \cdot P_{TMp}\right] \tag{A.17}$$

where the subscript p now is introduced to denote a specific product in a given consumption category. The squared bracket is a weighted sum of a composite product specific price index, P_{Hp}, which is taxed at the excise tax rate, τ_p^{ET}, excise taxes based on unit of sales[7], P_{ETp}, and trade margins, P_{TMp}. The value added tax rate is denoted by VAT_p, and applies to all prices. Both value added tax rates and excise tax rates vary across products[8].

The composite product specific price index, P_{Hp}, is a weighted average of domestic product prices, P_{bp}, and foreign product prices (import prices), P_{Fp}, both measured in domestic currency:

$$P_{Hp} = \left(1 - is_p \cdot DI_p\right) \cdot P_{bp} + \left(is_p \cdot DI_p\right) \cdot P_{Fp} \tag{A.18}$$

where is_p is the import share and DI_p is defined in A.11. Import prices are mostly exogenous in foreign currency, although for some goods, there are pricing-to-market effects in the model, see Benedictow and Boug (2013).

The weights a_p, b_p and c_p, which are calibrated constants based on the National Accounts for a given base year, denote the input-output coefficients[9], the share of excise tax in total

[7]Subsidies are defined as negative excise taxes.

[8]There are three VAT rates in Norway (12, 15 and 25 per cent). Since a given product in a consumption category is taxed at different rates, VAT_p are average rates and do not equal to the official VAT rates. Fuels, electricity, alcohol, tobacco and nearly all cars are heavily excise taxed, while most goods and consumer categories are hardly excise taxed at all.

[9]The input-output coefficients are defined as: $a_{jp} = \frac{\text{Basic value of product } p \text{ in industry } j}{\sum_j \text{Market value of product } p \text{ in industry } j}$ where we have

prices in the base year and the share of the trade margins in total consumer prices for each consumption group in the base year, respectively. The weights sum to unity by

$$\sum_p a_p \cdot \left(1 + VAT_p\right) \cdot \left(1 + \tau_p^{ET} + b_p + c_p\right) = 1 \tag{A.19}$$

which means that the consumer price index for product p in A.17 can be interpreted as a weighted average of net prices and excise taxes. The input-output coefficients measure the share of basic values (the amount receivable by the producer from the purchaser of a unit of a good or service) at market values (the price consumers pay). Due to consumption taxes and trade margins, they sum to less than unity, i.e. $\sum_p a_p < 1$.

A.8 The exchange rate and the Taylor role

The macroeconomic model also contains an exchange rate equation based on a combination of the purchasing power parity (PPP) and the uncovered interest rate parity (UIP), which links the Norwegian krone to the euro according to the relationship:

$$E = F_E\left(P/P^*, R/R^*\right) \tag{A.20}$$

where E is the nominal exchange rate, P is the domestic consumer price index, R is the key policy rate set by the central bank[10] and P^* and R^* represent the corresponding foreign (euro area) variables. The exchange rate thus allows for deviation from relative PPP. This deviation is captured by the interest rate differential, R/R^*, which is based on the fact that the balance of payment constraint implies that any imbalances in the current account have to be financed through the capital account. Shocks that force the real exchange rate away from PPP must be captured through the movements in interest rates, since they reflect expectations of future purchasing power, see Bjørnland and Hungnes (2006)[11]. The interest rate setting of the central bank is captured by a Taylor-type rule of equation based on inflation, $\Delta \ln P$, and the unemployment rate, U :

$$R = F_R(\Delta \ln P, U) \tag{A.21}$$

dropped the industry subscript j above for notational convenience.

[10]The money market rate, which replaces R in the actual model, is historically closely related to the key policy rate.

[11]In addition to the interest rate differential and relative prices, the exchange rate equation in KVARTS also includes the ratio of the value of the oil and gas exports to the value of total Norwegian exports, the net flow of capital between Norway and the euro area countries, the Norwegian oil-specific share price index and the volatility of the US S&P stock market index, all reflecting the existence of a foreign exchange rate risk premium, see Benedictow and Hammersland (2023)

where the functional form of F_R holds the Taylor principle, so that the real interest rate is increased when inflation increases.[12]

A.9 Employment and wages

The employment block of the macroeconomic model consists of labour demand by industry, which can be aggregated to total labour demand, noting that employment in the government sector is exogenous. The total labour supply is disaggregated by age group (five age groups) and gender since participation rates vary substantially between groups and over time. To capture discouraged worker effects, we specify for each group a logit function relating labour supply in terms of the participation rate to the (marginal) real after-tax wage as well as the unemployment rate. The logit function, F_{YP}, by age group and gender generally reads

$$\ln\left(\frac{YP}{1-YP}\right) = F_{YP}[W \cdot (1 - TMW)/P, U] \tag{A.22}$$

where YP is the labour force participation rate, W is the (average) wage level and TMW is the (average) marginal tax rate on wage income. The implied aggregated supply elasticity is in line with the micro-econometric results in Dagsvik et al. (2013) and Dagsvik and Strøm (2006). The aggregate labour supply is found by multiplying the various participation rates by the size of the population in the corresponding group. Unemployment is merely the difference between the labour force (supply) and employment.[13]

The labour market is further characterized by large wage setters that negotiate on wages, given the price-setting behavior of firms, see e.g. Layard et al. (2005)) and Gjelsvik et al. (2020). Unions are assumed to have preferences for both wages and employment. Therefore, unions' bargaining power increases with low levels of unemployment, implying that the wage response is higher for a low level of unemployment than for a high level of unemployment. This non-linearity is captured in the specification of the wage curve for manufacturing:

$$\ln(W) + \ln(1+T) + \ln(H) - \ln(P_Y) - \ln(Y) = f(U) \tag{A.23}$$

where W is the wage level, H is hours worked, T is the payroll tax, Y is the volume of value added and P_Y is the value-added price index, such that the left-hand side equals

[12] Note that inflation in A.21 is measured by the consumer price index adjusted for tax changes and excluding energy products in the actual model.

[13] The model distinguishes between hours worked and employment. We abstract from this distinction here.

the wage share. This wage curve represents the outcome for wages in the manufacturing sector.[14] The wage level in the manufacturing sector is the norm for the wage level in the other sectors of the economy, a coordination system which was implemented to maintain a competitive exporting sector, see Aukrust (1977). This institutional setting is captured in the model by the wage level in the private sector (excluding the petroleum industry and manufacturing), W_{PR}, and the government sector, W_G, following the wage level in the exposed manufacturing sector, W_M :

$$\ln(W_i) = \omega_i \cdot \ln(W_M) \, ; i = PR, G \tag{A.24}$$

To sum up, our macroeconomic model includes an extensive input-output structure based on the National Accounts and detailed descriptions of firms' decisions on production, investments, employment, exports and imports; housing demand and supply; households' consumption and labour supply; price and wage formation across industries in addition to exchange rate determination. These are important transmission channels of fiscal policy in a small open economy, like the Norwegian. Finally, the model contains the central bank's decision on the key policy rate in line with inflation targeting in the conduct of monetary policy.

[14] Manufacturing here refers to manufacturing of consumer goods, energy-intensive manufacturing and manufacturing of machinery from A.1

B More on the reference scenario

Our reference scenario is based on a set of assumptions that are partly best guesses and partly stylized.[15] Population data are taken from a recent national population forecast with some minor recent updates. Labour force data are endogenous in the model as explained earlier. Assumptions regarding pensions and government spending on social services are based on two main sources. Pensions are taken from a microsimulation model (MOSART) based on the same population forecasts as mentioned above. Pensions and transfers to households amounted to close to 18 percent of Mainland GDP in 2023. Government expenditures for health and social services are based on the population forecast and assumptions regarding the number of clients and standards of the services taken from a model based on detailed statistics on the use of these services by gender and age. Military expenditures are assumed to increase and reach a target of 2 percent of nominal GDP by 2026-2050 in line with current NATO target. International transfers amounting to more than 1 per cent of total national income is also endogenous. Government expenditures on goods and services not related to activities with explicit policy targets, are adjusted so that with constant tax rates for indirect taxes (VAT etc.) and income taxes for household and companies, the government budget balance is in accordance with the fiscal policy rule mention earlier. This rule implies that the central government budget surplus including taxes on the petroleum sector are transferred to a fund that invests only in financial and real assets abroad. We will return to the size of the fund during our simulation period until 2050 below.

Based on the population forecast, Table A.2 shows that while the total population grows somewhat until 2050, the population in working age (15-74 years) hardly increases at all. This difference is due to the aging population in Norway. With hardly any growth in the work force there is little growth in the number of hours worked although the decline in employment in the petroleum industry will allow for some potential reallocation of labour from that industry to the mainland economy. Table 2 shows results from a simple growth accounting for the aggregate mainland economy. Here we see that the number of hours worked grow very little until 2050 and that labour productivity increases mainly due to an assumed growth in total factor productivity and capital deepening. From 1990 to 2022 the mainland economy grew at an annual rate of 1,5 percent. The decline in growth going forward is therefore not large compared to the previous decades and the lower growth rate is mainly due to lower growth in the number of hours worked and not labour productivity according to the model simulations.

Table A.3 also provide information on unemployment and the consumer real wage

[15] The scenario is based on Chapter 4 in Bjertnæs et al. (n.d.). Chapter 7 in Bjertnæs et al. (n.d.) include analysis of lower petroleum activities that although different from this paper resembles the present study.

growth. Unemployment is likely to increase somewhat from the current low levels (3,6 percent in 2023) due to the current recession and higher interest rates and after 2026 because of lower resource use in the petroleum industry as discussed above. But in the long run the unemployment rate is close to it historical average of four per cent from 2000-2023. The consumer real wage will grow in line with productivity growth according to the simulations.

	2023-2030	2031-2040	2041-2050	2023-2050
Mainland Norway GDP	1.5	1.1	1.1	1.2
Hours Worked	0.4	0.1	0.1	0.2
Labor Productivity	1.1	1.0	1.0	1.0
Real Capital per Work Hour	0.6	0.5	0.3	0.4
Total Factor Productivity	0.5	0.5	0.7	0.6

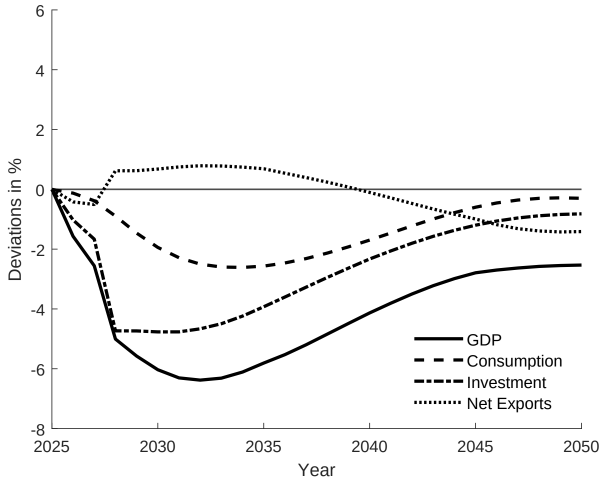
Table A.2: Growth Accounting for Mainland Norway's Economy, 2023-2050. Average Annual Growth in Mainland Norway's GDP in Percent, Contribution in Percentage Points.

	2023-2030	2031-2040	2041-2050	2023-2050
Total Population	0.5	0.4	0.2	0.3
Population (15-74 years)	0.3	0.0	-0.1	0.1
Employment Rate (level, %)	72.0	71.9	72.6	72.4
Labor Force	0.3	0.0	0.0	0.1
Employed Persons	0.4	0.1	0.0	0.2
Unemployment (level, %)	4.0	3.9	3.7	3.9
Consumer Real Wage	1.2	1.1	1.2	1.2

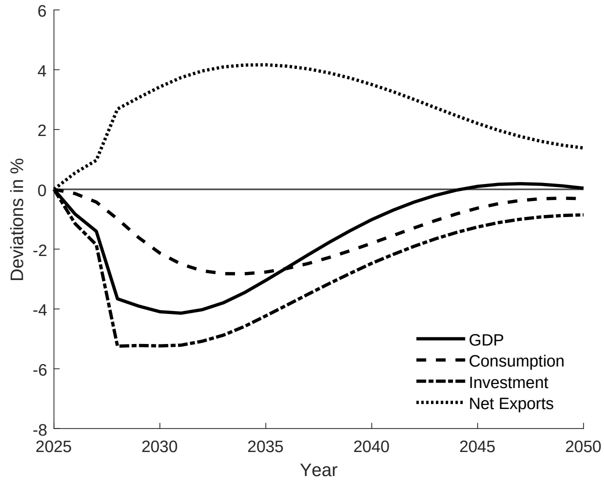
Table A.3: Population Development and Labor Market, 2023-2050. Average Annual Growth in Percent.

C Robustness

C.1 Passive monetary and fiscal policies and exogenous exchange rate

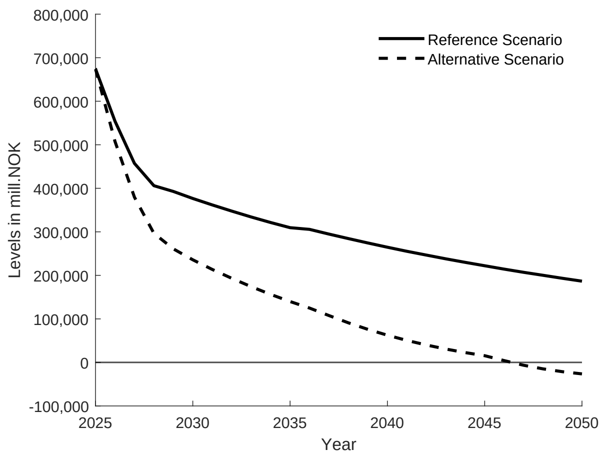


(a) GDP Total

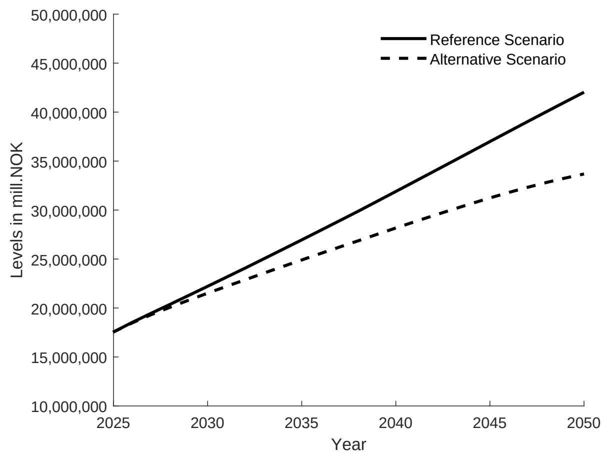


(b) GDP Mainland.

Figure A.1: Effects on GDP and GDP components of a reduction in petroleum investments without (alternative 1) and including (alternative 3) fiscal and monetary policy rules.



(a) Government net cash flow from petroleum.



(b) Government Oil Fund.

Figure A.2: Government net cash flow from petroleum and the Government Oil Fund in the reference scenario and two alternative scenarios. Values in million NOK.

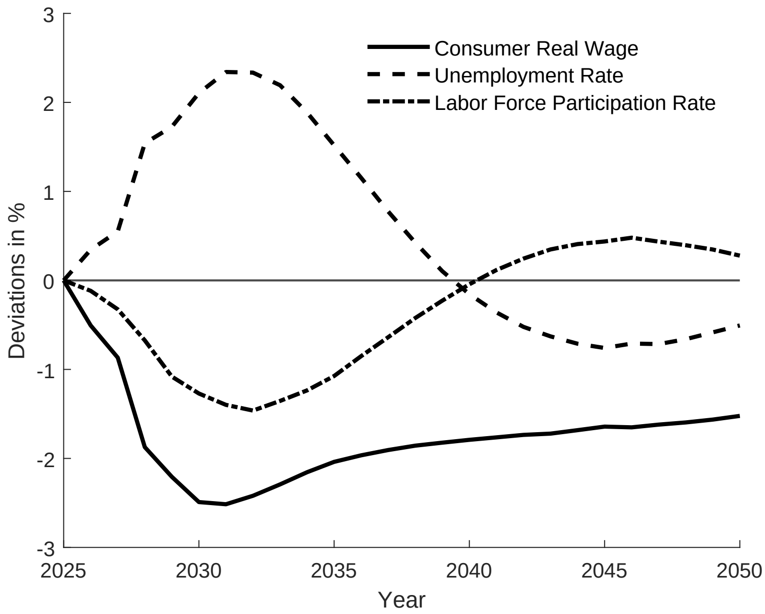
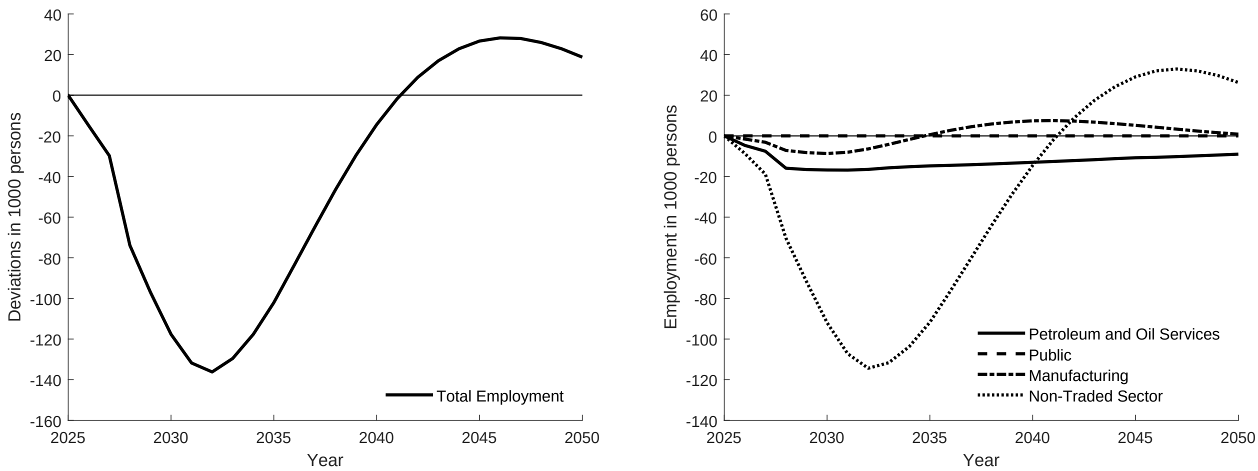


Figure A.3: Effect on the consumer real wage, unemployment rate and labour participation rate. Deviations from reference scenario in per cent (changes in rates are in percentage points).



(a) Total Employment.

(b) Aggregate Industry Employment.

Figure A.4: Effects on total employment and aggregate industry employment. Deviations in 1,000 persons from the reference scenario.

C.2 Price elasticities of foreign trade

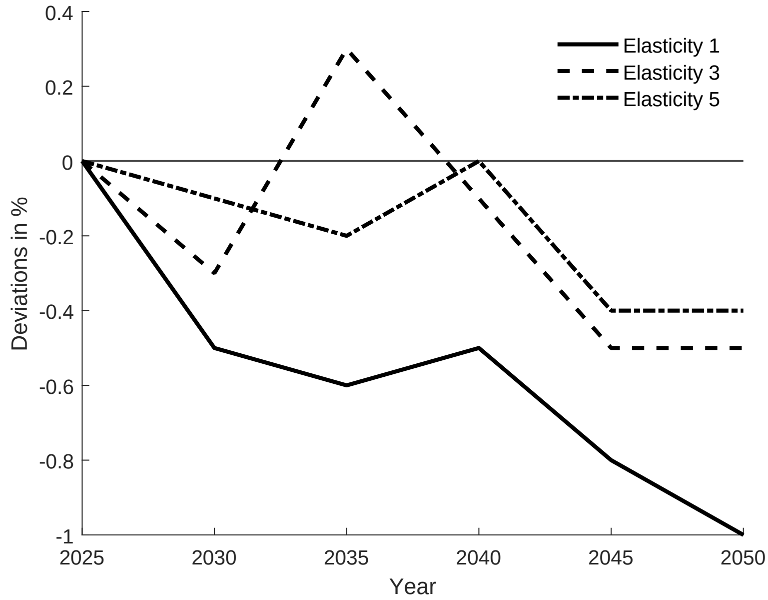


Figure A.5: Effects om Mainland GDP (MGDP) with varying elasticities in foreign trade. Deviations from reference scenario in percent.

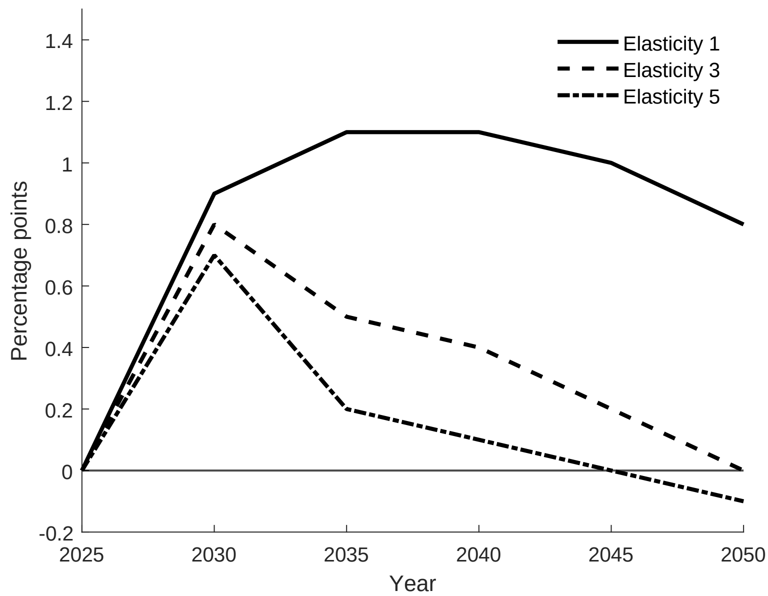


Figure A.6: Changes in the unemployment rate (UR) compared to reference scenario. Percentage points.

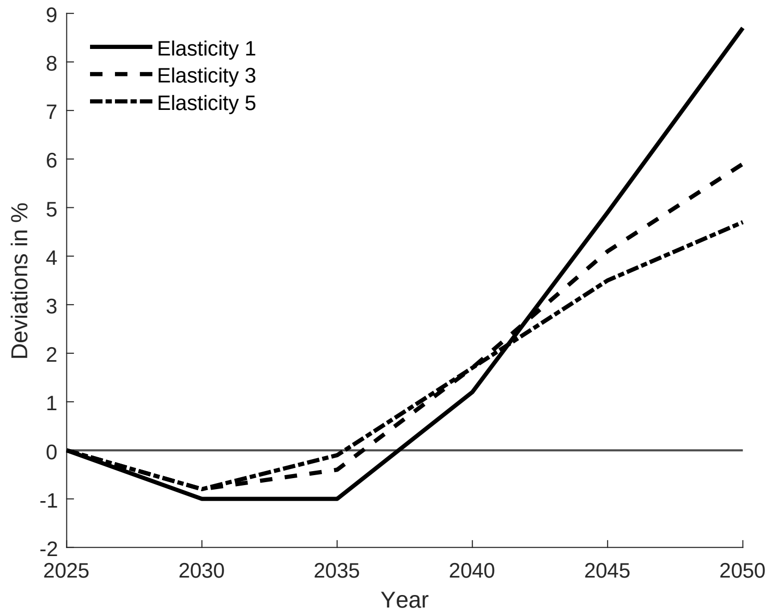


Figure A.7: Changes in consumer price level compared to reference scenario. Percent.

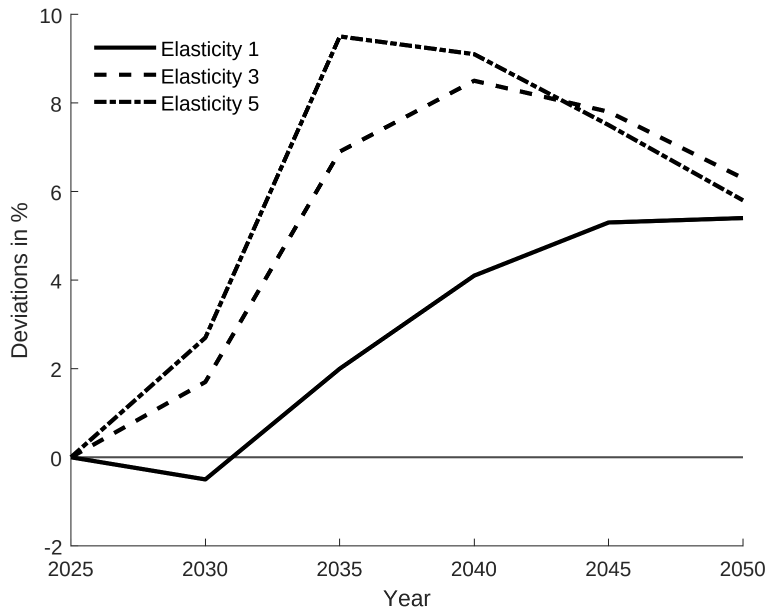


Figure A.8: Changes in non-oil exports compared to reference scenario. Percent. Percent.

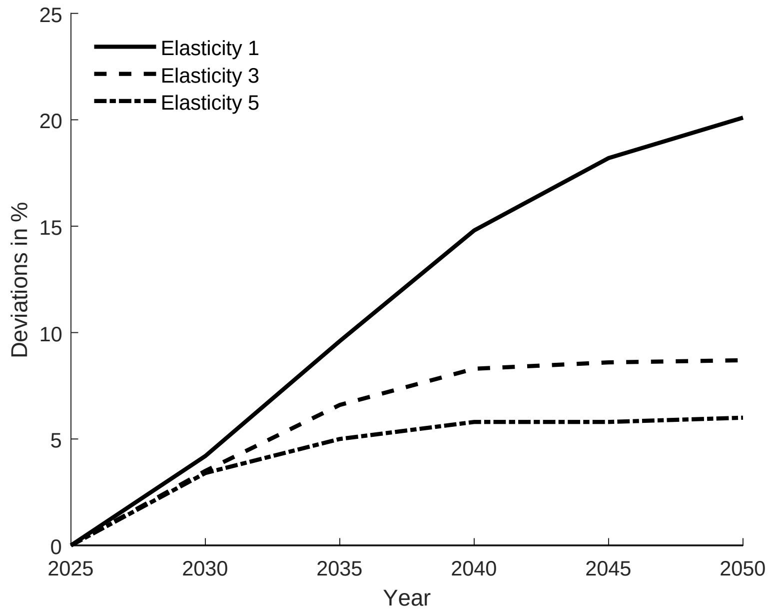


Figure A.9: Effects on the exchange rate compared to the reference scenario. Percent.

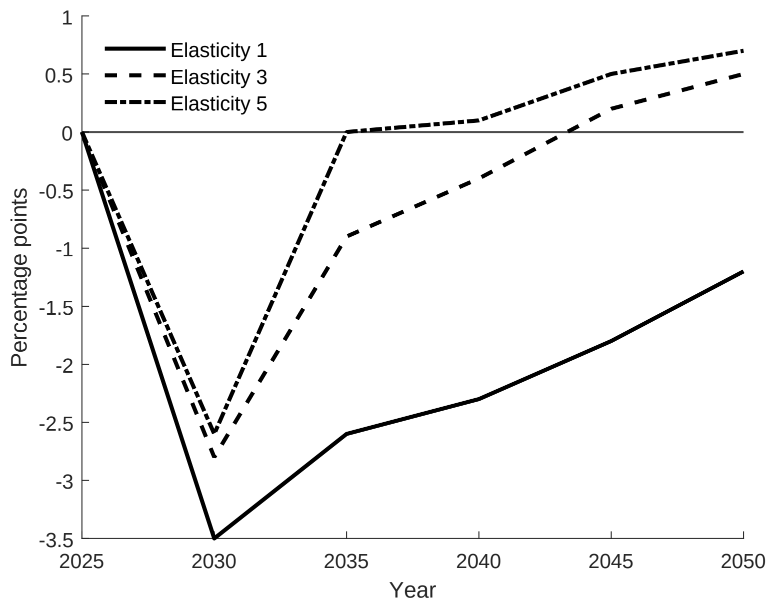


Figure A.10: Effects on the 3-m interest rate. Deviation from reference scenario. Percentage points.

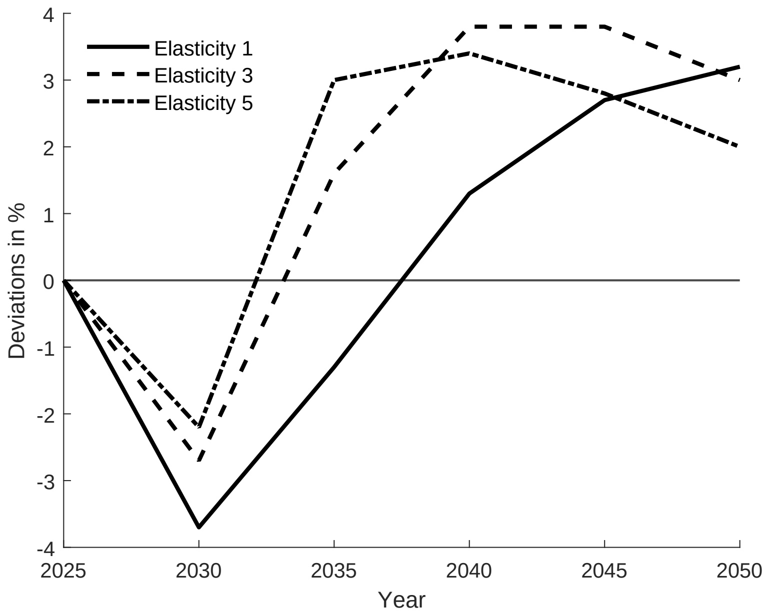


Figure A.11: Effects on employment in manufacturing compared to reference scenario. Percent.