NORA - A Microfounded Model for Fiscal Policy Analysis in Norway
PRELIMINARY AND INCOMPLETE

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Abstract

This paper describes a microfounded model for fiscal policy analysis designed by the Norwegian Ministry of Finance. The model is based on a relatively standard dynamic stochastic general equilibrium (DSGE) model of the type used in many central banks and international institutions. We modify the standard framework considerably to allow for a realistic analysis of the general-equilibrium effects of fiscal policy on the Norwegian economy. In particular, the model features wage bargaining between a union representing workers and firms in the tradable sector to capture the institutional framework for wage setting in Norway, a sovereign wealth fund–the Government Pension Fund Global (GPFG)–and related constraints on the use of resources from the GPFG for fiscal financing purposes, and a rich description of the fiscal authority in Norway and its interlinkages with the rest of the economy. We illustrate the properties of the model by comparing fiscal multipliers with those from existing models used for fiscal policy analysis in Norway, and present a number of fiscal policy simulations that illustrate typical use cases for the model.

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1 Introduction

This paper describes a model of the Norwegian economy designed for fiscal policy analysis, which we have named NORA (**NOR**wegian fiscal policy **A**nalysis model). The model is being developed by the Norwegian Ministry of Finance in collaboration with Statistics Norway and Norges Bank. The model described in this documentation is still work in progress, and is presented in the interest of transparency and to invite discussion about how the model should be further developed to make it a useful tool for fiscal policy analysis in Norway.

The model described in this documentation builds on an earlier version of the model published in 2018, see Frankovic et al. (2018). The main changes relative to the previous published version of the model include (i) the addition of a non-tradable sector, (ii) wage bargaining between a union representing workers and firms in the exposed sector to better capture the institutional framework for wage setting in Norway, (iii) the inclusion of the Government Pension Fund Global (GPFG) — the Norwegian sovereign wealth fund — and related constraints on the use of resources from the GPFG for fiscal financing purposes, (iv) a richer description of firms in the economy and the tax base for the corporate profit tax, and (v) a more elaborate treatment of the foreign economy, the oil price and its spillovers to the Norwegian mainland economy.

The model described in this paper belongs to the class of standard dynamic stochastic general equilibrium (DSGE) model of the type used in many central banks, including Norges Bank (Kravik and Mimir, 2019), and international institutions including the International Monetary Fund (Laxton et al., 2010) and the European Commission (Albonico et al., 2019). We modify the standard framework considerably to allow for a realistic analysis of the general-equilibrium effects of fiscal policy on the Norwegian economy. In particular the model includes a rich description of the fiscal authority in Norway and its interlinkages with the rest of the economy, which exceeds the level of detail found in most existing DSGE models.

The remainder of this documentation is organized as follows. Section 2 provides a short non-technical summary of the model followed by a longer more technical description of the main model elements. A detailed derivation of the model equations is provided in an Appendix. Section 3 describes the current calibration of the model and provides a comparison with Norges Bank's DSGE model NEMO, see Kravik and Mimir (2019).[1] Section 4 compares the magnitude of fiscal multipliers in our model and those in Statistics Norway's large-scale macroeconometric model MODAG/KVARTS (Boug and Dyvi, 2008) and assess the sensitivity of the multipliers to some key parameters in the model. The remainder of section 4 describes a number of fiscal policy simulations that illustrate typical use cases for the model, as well as an analysis of self-financing rates for different taxes. Section 5 concludes with a brief overview of the next steps in the modeling project.

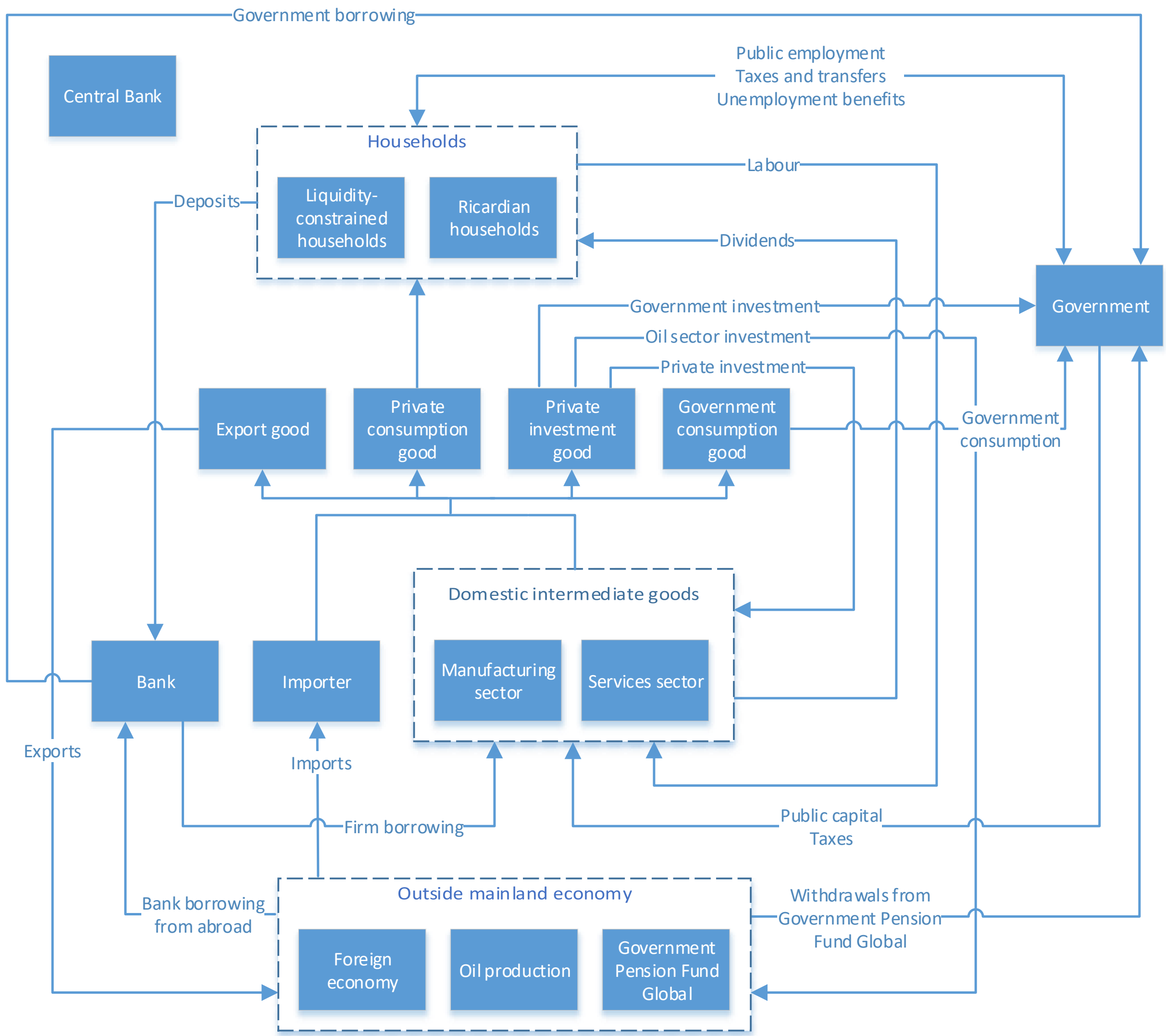
2 The model

Figure 1 provides a graphical overview of the model presented in this documentation. The model belongs to the class of small open economy DSGE models of which Justiniano and Preston (2010) or Adolfson et al. (2007) are prominent examples. The economy described by this model is assumed to have strong trade and financial linkages with the rest of the world, but is sufficiently small to not affect the world economy itself. Shocks to foreign variables are transmitted to the domestic economy through movements in the real exchange rate, the return on foreign bonds and the demand for exports.

Consistent with most analysis of the Norwegian economy the model described in this documentation focuses on developments in the mainland economy, i.e. excluding the off-shore oil sector. The production and taxation of the off-shore oil sector is not modeled. However, we include interlinkages between the off-shore oil sector and

[1] A complete estimation of the model will be presented at a later stage.

Figure 1: Graphical overview of the model



the mainland economy in the form of the oil sector's demand for domestically-produced investment goods.[2]

There are two types of households in the economy. First, an infinitely-lived utility-maximizing (Ricardian) household each period chooses how much to spend and how much to save in bank deposits in order to achieve a smooth consumption profile. The Ricardian household earns labor income from employment in domestic firms and the government, interest on bank deposits, dividend payments and capital gains resulting from ownership of domestic firms, and receives unemployment benefits and other public transfers.

Unlike the Ricardian household, the liquidity-constrained household is unable to smooth consumption across periods, and instead consumes its entire income net of taxes, consisting of labor income, unemployment benefits, and other public transfers, each period. The inclusion of the liquidity-constrained household can be justified by arguing that a share of households do not have access to financial markets, choose their consumption path on the basis of simple rules of thumb rather than rational expectations about the future, or are myopic/impatient. The liquidity-constrained household is included to add realism to the aggregate effects of changes to fiscal policy

[2] Government revenues from petroleum activities in Norway are assumed to be transferred in their entirety to the wealth fund and do therefore not have a direct impact on the mainland economy.

(notably the sensitivity of consumption to current income), and help overcome the Ricardian equivalence (i.e. that the timing of tax increases does not matter for household decision making) that typically characterizes this class of models, see Galí et al. (2007).

A novel feature of our framework is how we model wage formation and unemployment. Consistent with the institutional framework for wage bargaining in Norway (the so-called "frontfag" model), we assume that wage negotiations in the exposed sector of the economy sets the norm for wage growth in the rest of the economy. An important purpose of the frontfag model, which builds on the so-called main-course theory developed by Aukrust (1977), is to preserve the competitiveness of the exposed sector and to ensure a high level of employment. In particular, we assume that wages are set during Nash bargaining between a labor union aiming for a high level of wages and an employer organization aiming for high profits in the exposed sector. High unemployment is assumed to weaken the bargaining position of unions and lead to lower wage claims. The result is a negative relationship between the level of real wages and unemployment which is often referred to as the "wage curve", see Blanchflower and Oswald (1989, 2005). Labor force participation is modeled in a reduced-form fashion responding to the after-tax wage and the unemployment rate. The discrepancy between labor demand and labor force participation gives rise to unemployment in the model. Hence, household members in the model can either be employed, unemployed, or outside the labor force.

The production side of the economy differentiates between firms in the manufacturing and service sector of the economy. Manufacturing sector firms are typically more exposed to competition from abroad, both from imported goods and from their reliance on exports, while firms in service sector are typically more sheltered from foreign competition. Firms in the service and manufacturing sector use labor and capital to produce an intermediate good that is bundled with imported goods to make different types of final goods. These intermediate good firms face a choice between paying out dividends to Ricardian households or investing in fixed capital that is used in production.[3] Investment can either be financed through retained profits (equity) or borrowing from banks (debt). Firms that produce the intermediate good have market power because they produce differentiated goods that are imperfect substitutes, thus allowing them to set prices as a markup over marginal cost. Similarly, importers reprocess a homogeneous foreign good into a differentiated imported intermediate good that they sell at a price equal to their marginal costs (the world price) plus a markup. The output of domestic intermediate good firms and imported goods are bought by firms in a perfectly-competitive final good sector that bundle them into private consumption, government consumption and investment goods that differ in their composition and degree of substitutability across inputs. Finally, a monopolistically-competitive exporter combines intermediate domestic and imported goods to produce a differentiated export good that is sold on the world market at a price set in foreign currency as a markup over marginal cost. We assume that domestic intermediate goods firms, importers, and exporters face price adjustment costs so that an increase in marginal costs does not immediately result in an increase in prices. Domestic intermediate goods firms additionally incur adjustment costs when varying the level of investment.

Compared to most other DSGE models, the model described in this documentation includes a relatively disaggregated description of government spending and taxation in Norway. In particular, households pay a flat tax on their total (ordinary) income, a shareholder tax on dividends, a surtax on labor income and transfers, social security contributions, as well as a value and a volume-based tax on their consumption expenditure. Firms pay taxes on their profits net of deductions as well as social security contributions. The government in the model also receives an exogenous stream of funding from an offshore sovereign wealth fund, the Government Pension Fund Global (GPFG) to capture the fact that a significant portion of government spending in Norway is financed by such transfers. Taxes and withdrawals from the GPFG are used to finance government expenditures, consisting of unemployment benefits, purchases of goods and services from the private sector, government

[3] Most DSGE models assume, for simplicity, that households invest in fixed capital that they subsequently rent out to firms. Our more realistic depiction of the investment process allows us to more accurately describe the effect of tax changes on investment.

employment, and public investment. The model allows for the possibility that public capital increases private sector productivity. Monetary policy is assumed to follow a simple Taylor rule.

The remainder of this section provides an in-depth technical presentation of the main model elements. Further details of the mathematical derivations can be found in the Appendix.

2.1 Households

Following Mankiw (2000) and Galí et al. (2007), we assume that the economy is populated by a share $(1-\omega)$ of Ricardian households, denoted by superscript r, and a share $\omega \in [0,1)$ of liquidity-constrained households, denoted by superscript l. The Ricardian household chooses current consumption with a view to maximize its lifetime utility, while liquidity-constrained households simply consume all available income net of taxes.

2.1.1 Ricardian household

Lifetime utility The preferences of the Ricardian household are assumed to be additively separable in consumption (C_t^r) and utility-providing public goods (G_t^u).[4] Expected lifetime utility of the Ricardian household at time 0, denoted by U_0, is given by

$$U_0 = E_0 \sum_{t=0}^{\infty} \beta^t \left[\exp(Z_t^U) \frac{(C_t^r - H_t)^{1-\sigma}}{(1-\sigma)(1-h)^{-\sigma}} + \theta_G \frac{(G_t^u)^{1-\sigma}}{1-\sigma} \right] \tag{1}$$

The term G_t^u consists of government purchases $P_t^{cg} C_t^G$, government capital depreciation $P_t^i \delta_{KG} K_t^P$ and the government wage bill $W_t^G N_t^G$, see section 2.6.2 for further details.[5] The parameter σ is the inverse of the intertemporal elasticity of substitution and θ_G captures the relative weight of utility-providing public goods in the household's utility function. The term Z_t^U is a shock that increases households preference for consumption.[6]

We assume external habit formation in consumption, implying that the household derives utility from the difference between consumption today and a habit stock of consumption captured by $H_t = hC_{t-1}^r$. The term $(1-h)^{-\sigma}$ is added for convenience to ensure that the values of h only influence the dynamic properties of the model.[7]

Budget constraint The Ricardian household earns income from supplying labor, transfer payments by the government, dividends and capital gains resulting from ownership of domestic firms, and interest income on bank deposits. The sum of all these sources of income is referred to as household ordinary income (alminnelig inntekt) in the Norwegian tax code and is given by

$$\begin{aligned} OI_t^r = \; & \underbrace{LI_t^r}_{\text{labor income}} + \underbrace{UB_t(L_t - E_t)}_{\text{unemployment benefits}} + \underbrace{TR_t^r}_{\text{transfers}} + \underbrace{\frac{P_{t-1}}{P_t} DP_{t-1}^r (R_{t-1} - 1)}_{\text{return on deposits}} \\ & + \underbrace{(DIV_t^M + AV_t^M) S_{t-1}^{M,r} + (DIV_t^S + AV_t^S) S_{t-1}^{S,r}}_{\text{dividends and capital gains}} \end{aligned} \tag{2}$$

[4] In contrast to most DSGE models we do not include disutility of labor in the utility function, which typically is necessary to derive the wage-setting behaviour of households. Instead our wage formation model is based on Nash bargaining between a labor union and exposed sector firms, see section 2.3.

[5] We assume that the households takes the amount of utility-providing public goods as given. Moreover, the additively separable nature of the utility functions implies that unlike other fiscal policy models including Akkaya et al. (2019) and Coenen et al. (2012) the amount of public goods does not affect the consumption-saving decision of the household.

[6] All shocks in the model are collectively discussed in section 2.9.

[7] Note that the household does not take into account that its current consumption level will affect the utility from future consumption. Note also that the external habits in our model differ quite substantially from deep habits (see Ravn et al. (2006)), where habits are formed on individual consumption goods, rather than on the aggregate composite consumption index.

Real labor income LI_t^r is given by

$$LI_t^r = W_t N_t^P + W_t^G N_t^G \tag{3}$$

where W_t is the real wage rate and N_t^P the number of hours worked in the private sector, both of which are taken as given by the household and will be discussed in more detail in the labor market section 2.2 and the firm section 2.5.3. The term $W_t N_t^P$ therefore represents real income from private-sector employment by the Ricardian household.

Given the importance of the public sector as an employer in Norway we follow Stähler and Thomas (2012) and Gadatsch et al. (2016) and assume that the Ricardian household can be employed in the public as well as the private sector. $W_t^G N_t^G$ denotes the Ricardian household's income from employment in the public sector, where the nominal government wage is given by W_t^G and total hours worked by N_t^G. We assume that government wages are proportional to private wages, i.e. $W_t^G = WG^m W_t$, where WG^m is a fixed parameter. The amount of hours worked in the public sector is determined by the government and will be discussed in the government sector section 2.6.2.

The variable UB_t captures unemployment benefits paid to the share of the household that is within the labor force L_t but is not employed, where E_t captures the share of the household in (private or public) employment. TR_t^r are lump-sum transfers to the Ricardian household. Dividends (per share) DIV_t^M and DIV_t^S are paid to the owners of firms in the manufacturing (denoted by superscript M) and service (denoted by superscript S) sector firms according to the amount of shares held at the end of the last period, $S_{t-1}^{M,r}$ and $S_{t-1}^{S,r}$. Real capital gains (per stock) in the manufacturing sector (and equivalently in the service sector) are given by $AV_t^M = \frac{P_t^{E,M} - P_{t-1}^{E,M}}{P_t}$, where $P_t^{E,M}$ denotes the nominal price of a share in the manufacturing firm and P_t the overall price level in the economy.[8] DP_{t-1}^r captures interest income on of bank deposits held at the end of the last period, which we convert into this period's value by dividing through by the inflation rate $\pi_t = \frac{P_t}{P_{t-1}}$. The gross nominal interest rate on deposits R_t is set by the monetary authority, which will be discussed further below.

The tax base for the household ordinary income tax is defined as follows

$$\begin{aligned} OI_t^{r,TB} = \quad & LI_t^r + UB_t(L_t - N_t) + TR_t^r + \frac{P_{t-1}}{P_t} DP_{t-1}^r (R_{t-1} - 1) - TD^{OI,H} \\ & + (DIV_t^M + AV_t^M - RRA_t \frac{P_{t-1}^{E,M}}{P_t}) S_{t-1}^{M,r} \alpha_t^{OI,H} \\ & + (DIV_t^S + AV_t^S - RRA_t \frac{P_{t-1}^{E,S}}{P_t}) S_{t-1}^{S,r} \alpha_t^{OI,H} \end{aligned} \tag{4}$$

The tax base for the ordinary income tax differs from actual ordinary income, see equation (2), due to two deductions. The first deduction $TD^{OI,H}$ represents an allowance on personal income. It is calibrated to ensure the correct value for the ordinary income tax base in steady state. A second deduction present in the Norwegian tax code applies to shareholder income in the form of a rate-of-return allowance on stocks RRA_t (skjermingsfradraget). This deduction has the effect that only the equity premium on stocks is taxed at the household level, while the return up to the after-tax return obtained on deposits is exempt from taxation. The return on bank deposits in Norway is close to riskless. We therefore refer to the return on bank deposits, which is equal to the component of the return on stocks that is exempt from taxation, as the risk-free return.

We can illustrate the role of the rate-of-return allowance by decomposing the total return on stocks into an

[8] Note that nominal (not real) capital gains are taxed. AV_t^M converts these nominal capital gains into real terms that we include in our model.

equity premium and a risk-free portion

$$\underbrace{\left(DIV_t^M + AV_t^M\right)}_{\text{Total return on stock}} S_{t-1}^{M,r} = \underbrace{\left(DIV_t^M + AV_t^M - RRA_t P_{t-1}^{E,M}/P_t\right)}_{\text{Equity premium}} S_{t-1}^{M,r} + \underbrace{\left(RRA_t P_{t-1}^{E,M}/P_t\right)}_{\text{Risk-free return}} S_{t-1}^{M,r}.$$

where RRA_t is a (net) rate-of-return allowance applied to the nominal value of stock holdings given by $P_{t-1}^{E,M} S_{t-1}^{M,r}$. For a more detailed exposition see appendix 6.6. Absent the rate-of-return allowance the risk-free return on equity would be taxed twice, both at the corporate and household level, thus introducing a tax-induced bias in favor of debt financing which is only taxed at the household level, see Sørensen (2005) for further details.

The adjustment factor $\alpha_t^{OI,H} > 1$ increases the effective tax rate on the equity premium. The motivation behind this adjustment factor is to equalize the tax rate on the equity premium and the top marginal tax rate on labor income in order to remove any incentives for firm owners to shift their income from labor to equity income.[9]

Total direct taxes T_t^r paid by the Ricardian household are given by

$$T_t^r = \tau_t^{OI,H} OI_t^{r,TB} + (\tau_t^{LS} + \tau_t^{SS,H})(LI_t^r + UB_t(L_t - N_t) + TR_t^r - TD^{LS}) + T_t^{L,r}$$

where $\tau_t^{OI,H}$ is the household ordinary income tax rate , τ_t^{LS} is a labor surtax (trinnskatt) on labor income and transfers, and $\tau_t^{SS,H}$ is the rate of social security contributions (trygdeavgift).[10] The term TD^{LS} captures a deduction to the tax base of the labor surtax and social security contributions. Similar to the ordinary income tax base, the deduction is chosen to match the empirical value of the tax base for the labor surtax and social security in the steady state. The term $T_t^{L,r}$ represents other lump-sum taxes. For ease of exposition it is useful to define $\tau_t^W = \tau_t^{OI,H} + \tau_t^{LS} + \tau_t^{SS,H}$ as the overall effective tax rate on labor income and $\tau_t^D = \alpha_t^{OI,H}\tau_t^{OI,H}$ as the overall tax rate on dividend and capital gains income.

The household's budget constraint (in nominal terms) is given by

$$\begin{aligned} &P_t DP_t^r + P_t^{E,M}(1+F_t^S)S_t^{M,r} + P_t^{E,S}(1+F_t^S)S_t^{S,r} = P_{t-1}DP_{t-1}^r + P_{t-1}^{E,M}S_{t-1}^{M,r} + P_{t-1}^{E,S}S_{t-1}^{S,r} \\ &+P_t OI_t^r - P_t T_t^r - P_t C_t^r(1+\tau_t^C + \tau_t^f) + \underbrace{P_t AVT_t^r + \Pi_t^{X,r} + \Pi_t^{F,r}}_{\text{other income and costs}} \end{aligned} \tag{5}$$

The left hand side of the budget constraint shows the household's asset position at the end of period t. Following the approach in Graeve and Iversen (2017) we introduce financial fees F_t^S associated with trading firm stocks. These fees result in a positive gap between the required return on equity and the required return on bank deposits, which we can interpret as an equity premium.[11] The right hand side shows the asset position at the end of period $t-1$ together with overall household income net of total direct taxes, consumption expenditures and other income and costs.[12] The term τ_t^C is a value-added tax (VAT) on consumption and τ_t^f are volume-

[9] We introduce this adjustment factor as it is a feature of the Norwegian tax code, even though there is no potential for income shifting in our model.

[10] In reality, the labor surtax is a progressive tax, dividing total labor income and transfers into four brackets on which progressively higher tax rates are applied. Our model does not differentiate between different income groups and we are therefore not able to capture the progressive nature of the labor surtax. Instead, we set the labor surtax rate to the effective (or average) rate paid by all workers in the economy. Statistics Norway's microsimulation model Lotte Arbeid is, by contrast, able to take account of the progressive nature of the labor surtax, see Dagsvik et al. (2008).

[11] In Graeve and Iversen (2017) financial fees are used to generate a gap between central bank and market forward rates. Similarly, Andrés et al. (2004) and Chen et al. (2012) use financial fees to generate term premia. In our model these fees can also be interpreted as a stand-in for an equity premium due to risk in the productivity of firms. However, modeling risk involves computationally burdensome solution and estimation methods. Hence, we resort to this relatively simple modeling device to generate an equity premium.

[12] Other income and costs consist of an asset valuation tax refund AVT_t, profits from exporting firms, and wage adjustment costs

based fees on consumption, where $\tau_t^f = f_t^C/P_t$ such that f_t^C is the nominal fee per consumption good. For reporting purposes we define the total (real) value of household savings as

$$SV_t^r = DP_t^r + P_t^{e,M} S_t^{M,r} + P_t^{e,S} S_t^{S,r}$$

where $P^{e,M} = \frac{P_{t-1}^{E,M}}{P_t}$ (and equivalently for the service sector) is the relative price of a share in the manufacturing firm to the consumer price index (the numeraire price in the economy).

Maximization problem of the Ricardian household To maximize lifetime utility in equation (1) subject to the budget constraint given by equation (5) we form the Lagrangian

$$\mathcal{L} = E_0 \sum_{t=0}^{\infty} \beta^t \Big(\left[\frac{\exp(Z_t^U)\,(C_t^r - H_t)^{1-\sigma}}{(1-\sigma)(1-h)^{-\sigma}} + \theta_G \frac{(G_t^u)^{1-\sigma_G}}{1-\sigma_G} \right] + \lambda_t \frac{1}{P_t} \text{[r.h.s of eq. 5 - l.h.s of eq. 5]} \Big)$$

where λ_t is the real shadow value of one unit of savings (or one unit of foregone consumption). For convenience, we define the compounded stochastic discount factor as $\Delta_{t,t+j} = \beta^j \frac{\lambda_{t+j}}{\lambda_t}$ and the one-period discount factor at time t as $\Delta_{t+1} = \Delta_{t,t+1} = \beta \frac{\lambda_{t+1}}{\lambda_t}$.

The first-order condition for ***deposits*** (further details of the derivations can be found in appendix 6.1) is given by

$$\lambda_t = \beta E_t \left[\frac{\lambda_{t+1}}{\pi_{t+1}} (1 + (R_t - 1)(1 - \tau_{t+1}^{OI,H})) \right] \tag{6}$$

To a first-order approximation (and assuming perfect foresight so that we can drop the expectations operator) this implies that the the Ricardian household discounts the future with the after-tax return on their deposits $1/\Delta_{t+1} = (1 + (R_t - 1)(1 - \tau_{t+1}^{OI,H}))$.

The first-order condition for ***consumption*** is given by

$$\lambda_t = \frac{\exp(Z_t^U)(C_t^r - H_t)^{-\sigma}}{(1 + \tau_t^C + \tau_t^f)(1-h)^{-\sigma}} \tag{7}$$

Hence, consumption is allocated in such a way that marginal utility of consumption (the right-hand side of equation (7)) equals the shadow value of one additional unit of savings. Combining equations (7) and (6) yields the well-known Euler equation

$$\frac{\exp(Z_t^U)(C_t^r - H_t)^{-\sigma}}{(1 + \tau_t^C + \tau_t^f)} = \beta E_t \left[\frac{\exp(Z_{t+1}^U)(C_{t+1}^r - H_{t+1})^{-\sigma}}{(1 + \tau_{t+1}^C + \tau_{t+1}^f)} \frac{1}{\pi_{t+1}} (1 + (R_t - 1)(1 - \tau_{t+1}^{OI,H})) \right]$$

which under certainty equivalence simplifies to

$$\left(\frac{C_{t+1}^r - H_{t+1}}{C_t^r - H_t} \right)^{\sigma} = \beta \frac{(1 + \tau_t^C + \tau_t^f)}{(1 + \tau_{t+1}^C + \tau_{t+1}^f)} \frac{1 + (R_t - 1)(1 - \tau_{t+1}^{OI,H})}{\pi_{t+1}}$$

Hence, a higher real after-tax return on deposits encourages the Ricardian household to increase savings and defer consumption till the future while a higher VAT rate in the future encourages the Ricardian household to

γ_t^W. The asset valuation tax refund is a pragmatic solution to the fact that capital gains in our model are (unlike in the real world) realized every period. Because the firm share price is forward looking it reacts strongly to shocks that hit the economy, imply that capital gains taxes can be very volatile. To avoid this we redistribute capital gains tax revenue back to the Ricardian household in a lump-sum fashion. Because the Ricardian household maximizes expected lifetime utility and is assumed to have complete access to financial markets, temporary income movements caused by the asset valuation tax refund will not affect their decision-making process. Profits from monopolistically-competitive exporting firms are included to close the model, see section 6.10 for more details. Finally, the financial fees imposed on stock holdings are payed to an unmodelled financial intermediary whose profits $\Pi_t^{F,r} = P_t^{E,M} F_t^S S_t^{M,r} + P_t^{E,S} F_t^S S_t^{S,r}$ are redistributed lump-sum to the Ricardian household.

bring consumption forward. Note, that the dynamics of *aggregate* consumption do not simply follow the Euler equation, but also depends on current income due to the presence of liquidity-constrained households that will be discussed in the next section.

The first-order condition for ***stocks*** is given by

$$P_t^{e,M} = \sum_{j=1}^{\infty} \frac{1}{R_{t+j}^e} DIV_{t+j}^M \tag{8}$$

where $R_{t+j}^e = \prod_{l=1}^{j} \frac{1-\Delta_{t+l}/\pi_{t+l}\tau_{t+l}^D(1+RRA_{t+l})}{\Delta_{t+l}(1-\tau_{t+l}^D)}$. Hence, the price of a stock is equal to the present discounted value of the stream of future dividends from that stock, where the discount factor is a function of the household's discount factor, the effective tax rate on dividends, and the rate-of-return allowance.[13]

2.1.2 Liquidity-constrained households

We model the liquidity-constrained household along the lines of Galí et al. (2007). The budget constraint (in nominal terms) is thus given by

$$P_t C_t^l (1 + \tau_t^C + \tau_t^f) = (1 - \tau_t^W)(P_t(W_t N_t^P + W_t^G N_t^G) + P_t UB_t(L_t - E_t) + P_t TR_t^l) \tag{9}$$

where the variables with superscript l are the liquidity-constrained equivalents of those already introduced for the Ricardian household with superscript r in the previous section. Hence total expenditures of the liquidity-constraint household consist of consumption expenditures, while their income is generated from employment in the public and private sector as well as unemployment benefits and other transfers from the government.

2.1.3 Household aggregation

To conclude this section we define aggregate measures of household variables. Without loss of generality, we normalize the population size to 1. Recalling that $\omega \in [0, 1)$ is the share of liquidity-constrained households in the economy, we can calculate aggregate consumption and aggregate transfers from the government as

$$\begin{aligned} C_t &= \omega C_t^l + (1-\omega) C_t^r \\ TR_t &= \omega TR_t^l + (1-\omega) TR_t^r \end{aligned} \tag{10}$$

We furthermore assume that the total amount of hours worked in the private and public sector is proportional to the size of the household allocated across the two types of household.[14]

For those variables specific to the Ricardian household (e.g. deposits DP_t) we rescale by the share the Ricardian household in the overall population to arrive at an aggregate measure that can be used in the market clearing conditions

$$X_t = (1-\omega) X_t^r$$

for $X_t \in \{DP_t, T_t^L, S_t^M, S_t^S, \Pi_t^X, SV_t\}$.

[13]It is not possible in the model to separately identify both the price and the number of stocks, see Uribe and Schmitt-Grohé (2017) for more details. Without loss of generality we therefore normalize the number or stocks in the model to 1.

[14]Hence, total hours worked in the private sector by the Ricardian household amount to $(1-\omega)N_t^P$ and by the liquidity-constrained household to ωN_t^P, yielding overall hours worked in the private sector of N_t^P. The same logic applies to the public sector hours worked.

2.2 Labor market

Labor supply, employment and unemployment For simplicity we assume that the Ricardian and liquidity-constrained household have the same labor supply L_t, employment rate E_t and unemployment rate U_t. Labor supply, which we interchangeably refer to as labor force participation, follows directly the model of labor supply in Statistics Norway's large-scale macroeconometric model MODAG/KVARTS, see Boug and Dyvi (2008), which includes reduced-form processes for the participation rate of seven distinct population groups.[15,16] Participation rates in each population group j are a function of lags of the relevant participation rate, a positive function of lags of the real after-tax wage and a negative function of lags of the unemployment rates.[17] The latter captures the commonly-observed discouraged worker effect whereby workers who believe that their chances of finding a job are low in a recession (when unemployment is high) leave the labor force rather than incur the monetary and psychological costs of searching for a job, see Dagsvik et al. (2013). The reduced-form processes for participation rates take the form

$$L_t^j = f^j\left(U_{t-1,\dots,t-n}, (1-\tau^W_{t-1,\dots,t-n})W_{t-1,\dots,t-n}, L^j_{t-1,\dots,t-n}\right) \tag{11}$$

Since each group has its own process f^j the effects of unemployment and after-tax wages as well as the persistence in participation varies across population groups.[18] Total labor supply is then given by the sum of group-specific participation rates weighted by the relative size of the population groups

$$L_t = \sum_{j=1}^{7} w_j L_t^j + Z_t^L \tag{12}$$

where w_j capture the population weights for each subgroup. The variable Z_t^L denotes a shock to the overall labor force participation rate. It can be used to simulate population ageing (negative shock to the labor force) or immigration (positive shock). Note, that permanent shocks which result in a new steady-state after-tax wage rate and / or unemployment rate will result in permanent changes to the participation rate.

The number of hours worked per worker in the economy NpW_t is defined as the total number of hours worked in the private and the public sectors $N_t = N_t^P + N_t^G$ divided by the overall employment rate E_t

$$NpW_t = \frac{N_t}{E_t}.$$

Following Uhlig (2004) we assume that the employment rate (i.e. the extensive margin of labor supply) is a sluggish process that responds more slowly to economic shocks than hours worked per worker (i.e. the intensive margin of labor supply).[19] In particular, we rely on the following reduced-form relationship between the employment rate and the total number of hours worked in the economy

$$E_t = \rho^E E_{t-1} + (1-\rho^E) N_t / \overline{NpW}$$

where ρ^E captures the degree of persistence in the employment rate and $\overline{NpW}$ is the steady-state number of hours per worker. Hence, today's employment rate is a function of last period's employment rate, implying a certain sluggishness in the creation of new or destruction of old jobs. It is also a function of this period's labour

[15] In a previous version of the model (Frankovic et al., 2018) labor force participation and unemployment were modelled following Galí et al. (2012). This approach was found to generate large jumps in labor force participation and movements in unemployment at odds with the empirical findings in Norway and simulations from KVARTS, in particular following changes to labor taxes.

[16] Note, since the population size is normalized to one, L_t can be both considered the absolute number of people providing labor as well as the share of people in the economy providing labor, i.e. the participation rate.

[17] The seven population groups consist of 15-19 year olds, 20-24 year olds, female as well as male 25-61 year olds, female as well as male 62-66 year olds and 67-74 year olds.

[18] More details on the functional form and behaviour of the participation processes in the short- and long-run can be found in Gjelsvik et al. (2013).

[19] Uhlig (2004) assumes contract hours (rather than the employment rate) responds more sluggishly than actual hours worked. In that case it is productivity per contract hour that adjusts in the short-run rather than hours worked per worker as in our model. The modeling approaches are otherwise similar.

demand, which captures the number of workers that would be needed to satisfy the aggregate demand for hours if all workers worked the steady-state number of hours per worker $\overline{NpW}$. A shock that increases demand for hours N_t will therefore result in an immediate increase in hours worked per worker that will dissipate as the employment rate gradually adjusts.

The number of household members that are unemployed is given by $L_t - E_t$ (as the population size is normalized to 1). A more commonly used measure of unemployment that we will use for the remainder of this paper relates the number of unemployed to the number of people in the labor force

$$U_t = \frac{L_t - E_t}{L_t}$$

Note that unlike most other DSGE models we do not model the utility value of being unemployed and not working. Our model is therefore silent on whether unemployment is voluntary or involuntary.

2.3 Wage formation

The institutional framework for wage bargaining in Norway is based on the so-called "frontfag" model ("frontfagsmodellen") whereby wage negotiations in the exposed sector of the economy sets the norm for wage growth in the rest of the economy.[20] An important purpose of this model is to preserve the competitiveness of the exposed sector and ensure a high level of employment by avoiding excessive wage claims relative to productivity, see inter alia NOU (2013:13) (Holden III Committee). Bjørnstad and Nymoen (1999), for example, show that high wage rarely occur during periods of low profitability in the exposed sector, while periods of high profitability result in higher wage claims. Moreover, Gjelsvik et al. (2015) find empirical support for the fact that the sheltered sector follows wage settlements in the exposed sector.

The role of the exposed sector in setting the norm for wage growth in small open economies was analysed by Aukrust (1977) in the so called main-course theory ("hovedkursteorien"), which lays the foundation for the frontfag model. Aukrust demonstrated that the sustainable level of nominal wage growth in small open economies is determined by productivity growth in the exposed sector and the growth in the world market price of exported goods. Wage growth exceeding this level will weaken the competitiveness of exposed sector firms, reduce activity and labor demand, and eventually lead to a moderation of wage growth. Since the sheltered sector of the economy competes for workers from the same pool as the exposed sector, wage growth in the sheltered sector will follow the norm set in the exposed sector.

Hoel and Nymoen (1988), Nymoen and Rødseth (2003) and Forslund et al. (2008) have developed formal models of the frontfag model in which wages are set through bargaining between workers and firms. In these models, which have been developed both for the Norwegian and Scandinavian context, workers are represented by a union that acts in their interest by aiming for a high level of wages, while exposed-sector firms are represented by an employer organization aiming for high profits. The economic environment is assumed to affect wage formation by changing the bargaining position of the parties. In particular, high unemployment will weaken the union's bargaining position and lead to lower wage claims, while a tighter labor market (low unemployment) makes it necessary for firms to pay higher wages in order to recruit workers. The resulting negative relationship between unemployment and the level of real wages, which is often referred to as the "wage curve", has been shown to be a robust feature of labor markets across a wide range of countries, see Blanchflower and Oswald (1989, 2005).

We build on this literature and model wage formation in Norway as Nash bargaining over wages between a union representing all workers in the economy and an employer organization representing firms in the exposed sector, which in our model is proxied by the manufacturing sector. We assume that the payoff function of the

[20] The frontfag model is sometimes referred to as the Scandinavian or Norwegian model of inflation, see Bårdsen et al. (2005) for further details.

union is a utility function that increases with worker's pre-tax real wages.[21] The union's reference utility, which can be thought of as their outside option in the event an agreement is not reached, is assumed to fall with the unemployment rate.[22,23] We will show later that a higher level of unemployment decreases wage claims by the union. The payoff function of the employer organization representing firms in the exposed sector is assumed to be given by the monetary value of profits in the manufacturing sector, which ceteris paribus is falling with the level of wages. The reference utility of firms is set to zero on the assumption that failure to reach an agreement implies no production and zero profits.

The real wage W_t^{NB} that corresponds to the Nash bargaining solution can be found by maximizing the following Nash product

$$W_t^{NB} = \arg\max_W [V(W) - v_0(U_t)]^\gamma [\Pi_t^M(W)]^{1-\gamma} \tag{13}$$

where $V(W)$ captures the payoff function of the union, v_0 denotes the union's reference utility, and the payoff function of firms equals profits in the manufacturing sector Π_t^M. The parameter γ changes the importance of the union's payoff function in the Nash product and thus their bargaining power. The payoff function of unions has the same functional form as the households utility function over consumption in equation (1) and is given by

$$V(W) = b^N + \frac{W^{1-\sigma^N}}{1-\sigma^N} \tag{14}$$

where σ^N determines the curvature of the utility function while b^N is a constant that ensures a positive value of V at relevant wage levels. The payoff function in equation (14) increases with the wage level $V_w > 0$ while gains at higher level of wages are valued less in utility terms $V_{ww} < 0$. Manufacturing sector profits will be defined in section 2.5.3. The union's reference utility is given by

$$v_0 = v^U \log(U_t) + Z_t^V$$

where $v^U < 0$ is a parameter that determines the importance of unemployment for the reference utility and hence the negotiated wage. We take the logarithm of unemployment given evidence by Blanchflower and Oswald (1989, 2005) that the wage curve becomes flat at relatively high levels of unemployment. The term Z_t^V captures a shock to the reference utility of the union which implies a vertical shift in the wage curve.

Solution and characterization The Nash bargaining solution can be found by taking the derivative of the Nash product in equation (13) with respect to the real wage and setting the resulting term to zero. The resulting first-order condition is given by

$$\frac{(W_t^{NB})^{-\sigma^N}}{V(W_t^{NB}) - v_o(U_t)} = \frac{1-\gamma}{\gamma} \frac{(1+\tau_t^{SS,F})N_t^M}{\Pi_t^M(W_t^{NB})}. \tag{15}$$

where $\tau_t^{SS,F}$ is the social security tax paid by firms ("arbeidsgiveravgift") and N_t^M is the amount of hours worked in the manufacturing sector. As shown in appendix 6.2, the Nash bargaining wage increases with the value of v_0 and hence falls with the level of unemployment. In addition, the Nash bargaining wage increases with higher profitability in the manufacturing sector, caused for example by reduction in the social security tax paid by

[21] As noted by Bjørnstad and Nymoen (2015), a higher degree of coordination in wage bargaining reduces the positive association between taxes and real wages. This is because centralized or coordinated labor unions associate higher taxes with higher welfare. As a result, workers do not need to be compensated for the loss in purchasing power from higher taxes. Empirical studies on wage formation in Norway in fact rarely find any effect of labor taxes on bargained wages.

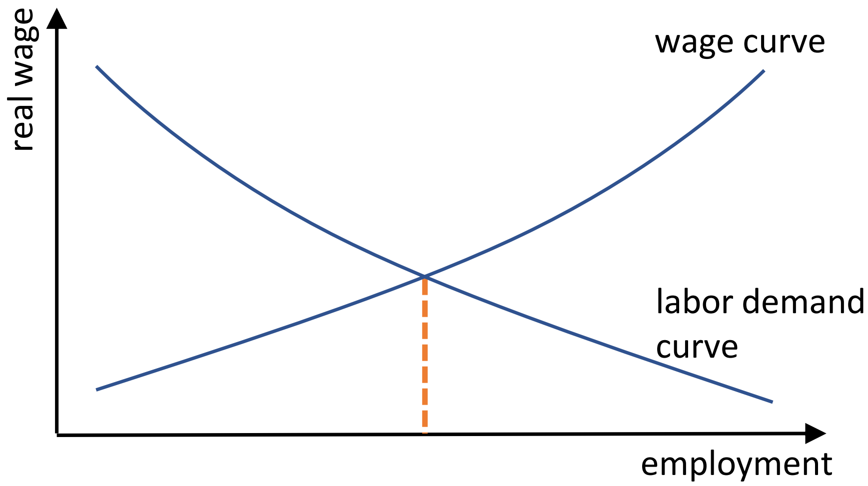
[22] The reference utility is sometimes called the threat point. We will use these two terms interchangeably.

[23] The reference utility can also be viewed as a driving force for agreement. In this interpretation a higher unemployment rate makes the union eager to reach an agreement and thus willing to accept lower wages. Conversely, low unemployment makes hiring difficult for firms and they are therefore eager to reach an agreement even if this implies higher wages.

firms or by increased demand for manufacturing goods. Conversely changes detrimental to the profitability of manufacturing-sector firms will depress the Nash bargaining wage.

The wage bargaining model thus yields a downward-sloping relationship between the real wage and the level of unemployment which corresponds to the aforementioned wage curve. At the same time, the labor demand function in equation (38) establishes a negative relationship between hours worked and the real wage, and thus between employment and the real wage. Following Nymoen and Rødseth (2003) we can assume that unemployment is a decreasing function of employment and draw the wage curve in figure 2 as a function of total employment. The intersection of the wage curve and the downward-sloping labor demand curve in equation (38) determines the level of employment in the model.

Figure 2: The wage and labor demand curve



The level of unemployment is then simply the difference between total labor supply in equation (12) and total employment.

Wage stickiness The wage determined through Nash bargaining is not implemented in the manufacturing sector immediately. Instead we follow Hall (2005) and Shimer (2004) and assume an ad-hoc form of wage stickiness, implying that wages at time t are a function of wages in the previous period $t-1$ and this period's Nash bargaining wage:

$$W_t^M = (1-\alpha^N)W_{t-1}^M + \alpha^N W_t^{NB}$$

where W_t^M is the real wage in the manufacturing sector in period t and α^N is a parameter capturing the speed of adjustment of wages towards the Nash bargaining equilibrium.[24]

Wages in the service sector The Nash bargaining solution in equation (15) determines wages in the manufacturing sector. To keep the model as simple as possible we assume that wage setting in the service sector simply follows the norm set in the manufacturing sector, in line with the frontfag model and empirical evidence documented by Gjelsvik et al. (2015):

$$W_t := S_t^S = W_t^M.$$

[24]This approach to wage stickiness has been applied to search-matching models of the type pioneered by Diamond, Mortensen and Pissarides, see for example Mortensen and Pissarides (1994), that at their core also contain a Nash bargaining process.

where W_t^S is the real wage in the service sector. Given that the wage across the manufacturing and service sector are identical we will henceforth drop the distinction between them and simply refer to the economy-wide wage level W_t.[25]

2.4 Banking sector

To simplify the Ricardian household's portfolio choice problem it is convenient to include simple banking sector in the model. In particular, we follow Sánchez (2016) and include a perfectly-competitive representative bank whose sole purpose is to collect deposits from the Ricardian household and borrow from abroad in order to finance loans to domestic firms and the government. The balance sheet (in real terms) of the perfectly-competitive representative bank can be written as

$$\underbrace{DP_t}_{\text{Deposits of opt. household}} + \underbrace{Q_t B_t^F}_{\text{Foreign debt of bank}} = \underbrace{B_t^M + B_t^S}_{\text{Loans to firms}} + \underbrace{D_t}_{\text{Loans to government}} . \tag{16}$$

where the real exchange rate Q is defined as $Q_t := e_t P_t^* / P_t$, where e_t is the nominal exchange rate and P_t^* the foreign price level. The representative bank aims to maximize the present discounted value of profits

$$E_t \sum_{j=0}^{\infty} \Delta_{t,t+j} \Bigg[\frac{R_{t-1+j}^L}{\pi_{t+j}} \left(B_{t-1+j}^M + B_{t-1+j}^S + D_{t-1+j} \right) - \frac{R_{t-1+j}}{\pi_{t+j}} DP_{t-1+j} - \frac{R_{t-1+j}^* \phi_{t-1+j}}{\pi_{t+j}^*} Q_{t+j} B_{t-1+j}^F \Bigg] \tag{17}$$

subject to the balance sheet constraint in equation (16). The rate R_t^L is the gross interest rate at which firms and the government are able to borrow from banks. The bank pays an interest rate R_t on household deposits that is set by the monetary authority. The last term in equation (17) captures the cost of foreign borrowing where the foreign gross interest rate R_t^* is subject to a debt-elastic interest rate premium ϕ_t.

The risk premium on foreign borrowing is adapted from Adolfson et al. (2008) and given by

$$\phi_t := \exp\left(\chi_A (A_t - \overline{A}) + \chi_e (E_t(\Delta e_{t+1}) \Delta e_t - (\overline{\Delta e})^2) - \chi_{GPF} (\widetilde{GPF}_t - \overline{GPF}) + Z_t^{RP} \right)$$

where $A_t = \frac{Q_t B_t^F}{\overline{Y}}$ is the domestic-currency value of private sector net foreign liabilities as a ratio to long-run GDP and $\Delta e_t = \frac{e_t}{e_{t-1}}$ is the nominal exchange rate depreciation. The risk premium on foreign borrowing increases with private sector foreign indebtedness ($\chi_A > 0$) and with expected changes in the nominal exchange rate ($\chi_e < 0$).[26] In addition, we assume that the risk premium responds indirectly to the oil price through its impact on the value of Norway's offshore sovereign wealth fund, the Government Pension Fund Global (GPFG). The oil price is assumed to affect the value of the GPFG according to the following rule

$$\widetilde{GPF}_t = \rho^{\widetilde{GPF}} \widetilde{GPF}_{t-1} + (1 - \rho^{\widetilde{GPF}}) \left(P_t^{oil} / \overline{P^{oil}} - 1 \right)$$

Hence, we capture in a reduced-form fashion that an increase in the oil price would, over time, increase our proxy of the GPFG ($\widetilde{GPF}_t$) and thus reduce the risk-premium on foreign borrowing by the private sector ($\chi_{GPF} > 0$). This is similar in spirit to NEMO (Kravik and Mimir, 2019), where the value of the GPFG affects

[25] In theory one could assume that wage setting in the service sector follows the norm set in manufacturing sector wages with a lag and additionally depends on economic conditions such as unemployment and inflation. This would require the introduction of frictions in labor movement because otherwise wage differences across sector cannot arise. To avoid having to include a detailed model of labor frictions we assume identical wages across sectors.

[26] The inclusion of the expected change in the nominal exchange rate is motivated by the observation that risk premia are strongly negatively correlated with the expected change in the exchange rate. This pattern is often referred to as the 'forward premium puzzle', see Adolfson et al. (2008) for further details. Note, that Δe captures the nominal exchange rate appreciation in the model that can potentially be different from 1.

the risk premium directly, and to KVARTS (Boug and Dyvi, 2008), where a higher oil price is assumed to reduce the risk premium.[27] Z_t^{RP} is shock to the risk premium.

The first-order conditions for domestic lending and foreign borrowing are given by

$$E_t\left[\frac{\lambda_{t+1}}{\pi_{t+1}}(R_t^L - R_t)\right] = 0 \tag{18}$$

$$E_t\left[\lambda_{t+1}\left(\frac{R_t}{\pi_{t+1}} - \frac{R_t^*\phi_t}{\pi_{t+1}^*}\frac{Q_{t+1}}{Q_t}\right)\right] = 0 \tag{19}$$

The first expression simply states that because the bank is assumed to be perfectly competitive it will set the lending rate such that the expected return from borrowing equals the interest rate the bank pays on its deposits. The second equation is an uncovered interest parity condition which relates the expected (domestic-currency equivalent) return on foreign bonds to the expected return on domestic deposits.

2.5 Firms

The production side of the economy builds on the benchmark small open-economy model by Adolfson et al. (2007). We make two changes to the standard framework. First, we distinguish between a manufacturing (denoted by superscript M) and a services (denoted by superscript S) sector that differ in their exposure to foreign competition, both from imports and from their reliance on foreign export markets.[28] This extension is motivated by the importance Norwegian policymakers place on preserving a viable non-oil tradable sector, and builds on models by Matheson (2010), Pieschacón (2012) and Bergholt et al. (2019) and is similar in spirit to policy models from Switzerland (Rudolf and Zurlinden, 2014) and Australia (Rees et al., 2016). Second, we depart from the unrealistic (but mathematically convenient) assumption that households invest and rent capital to firms that is made in almost all models of this type. Instead, we adopt the approach in Radulescu and Stimmelmayr (2010) and assume that firms finance their investments using a combination of debt and retained profits.[29]

In particular, the production side of the economy consists of two monopolistically-competitive intermediate good sectors, the manufacturing and the service sector, that use domestic labor and capital as factor inputs, finance investments via debt or retained profits and sell their output to a final goods sector. Monopolistically-competitive importing firms purchase the foreign good at the world market price and sell it to the final goods sector. Perfectly-competitive firms in the final goods sector bundle the domestic manufacturing and service goods, and the imported good, into composite manufacturing and services goods that are in turn combined to form final consumption, investment, and government consumption goods. Finally, a monopolistically-competitive exporter combines composite manufacturing and services goods into a differentiated export good that is sold on the world market at a price set in foreign currency.

2.5.1 Final goods sector

The production process of firms in the final goods sector can be separated two stages as shown in figure 3. In the first stage, domestically-produced manufacturing and services goods are combined with imports to form a composite manufacturing and services good. In the second stage, the two composite goods are combined to

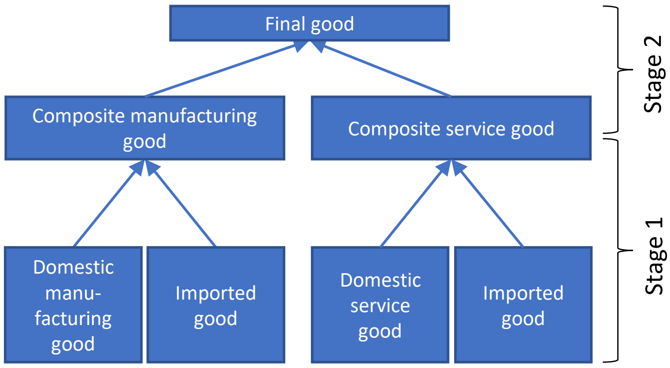
[27] For modelling purposes we distinguish between the GPFG as it relates to the risk premium on foreign borrowing ($\widetilde{GPF}_t$) and the GPFG as it relates to the government budget (GPF_t), see section 2.6.5 for more details. We make this distinction to limit the number of interlinkages between the oil price and the real exchange rate, and the government budget.

[28] We assume that both sectors have the same capital intensity. Our analysis of the data shows that capital intensity varies significantly at the industry level, but is virtually identical across the composite manufacturing and services sectors that we include in our model.

[29] As noted by Carton et al. (2017) the assumption that households invest and rent capital to firms implies that corporate taxes are a tax on households' capital returns. This approach implies a direct link between household taxation and firm investment which is at odds with empirical evidence and the literature on corporate taxation.

form final consumption, investment, export, and government consumption goods.

Figure 3: Final good sector production



First stage: composite manufacturing and services sector good For each final good $Z_t \in \{C_t, I_t, X_t, CG_t\}$, a composite manufacturing good of volume Z_t^M is produced using domestically-produced manufacturing sector goods of volume $Y_t^{Z,M}$, and imported goods of volume $IM_t^{Z,M}$ using the following production function:

$$Z_t^M = \left[(1-\alpha_{Z^M})^{1/\eta_{Z^M}} (Y_t^{Z,M})^{\frac{\eta_{Z^M}-1}{\eta_{Z^M}}} + \alpha_{Z^M}^{1/\eta_{Z^M}} (IM_t^{Z,M})^{\frac{\eta_{Z^M}-1}{\eta_{Z^M}}} \right]^{\eta_{Z^M}/(\eta_{Z^M}-1)}$$

where α_{Z^M} is the home bias parameter for the composite manufacturing good employed in the production of the final good Z_t^m and η_{Z^M} is the elasticity of substitution between the imported and the domestically-produced manufacturing sector good.

The objective of final goods firms in the first stage of production is to minimize the cost of producing the composite good. Let $P_t^m = P_t^M/P_t$ be the relative price of a domestically-produced manufacturing good, and $P_t^f = P_t^F/P_t$ the relative price of imported goods. As shown in appendix 6.3 this cost minimization problem yields the following final-good-specific demand functions for domestically-produced manufacturing and imported goods:

$$Y_t^{Z,M} = (1-\alpha_{Z^M}) (P_t^m / P_t^{z,m})^{-\eta_{Z^M}} Z_t^M \quad (20)$$

$$IM_t^{Z,M} = \alpha_{Z^M} \left(P_t^f / P_t^{z,m} \right)^{-\eta_{Z^M}} Z_t^M \quad (21)$$

where the relative price of the composite manufacturing good, $P_t^{z,m}$ is given by

$$P_t^{z,m} = \left((1-\alpha_{Z^M}) (P_t^m)^{1-\eta_{Z^M}} + \alpha_{Z^M} \left(P_t^f \right)^{1-\eta_M} \right)^{1/(1-\eta_{Z^M})} \quad (22)$$

Because final goods firms are perfectly competitive it holds that the total output of the composite manufacturing good equal the cost of production:

$$P_t^{z,m} Z_t^M = P_t^m Y_t^{Z,M} + P_t^f IM_t^{Z,M}$$

The composite service good is produced completely analogously to the composite manufacturing good. In particular, the composite service good Z_t^S is produced by combining domestically-produced service goods of volume $Y_t^{Z,S}$ with imported goods of volume $IM_t^{Z,S}$ with home bias parameter α_{Z^S} and elasticity of substitution η_{Z^S}. Cost minimization yields demand functions for domestically-produced services and imported goods that are analogous to those in equation (20) and (21). The relative price of the composite service good $P_t^{z,s}$ is given by an expression equivalent to equation (22). Total output of the composite service good is then given by:

$$P_t^{z,s} Z_t^S = P_t^s Y_t^{Z,S} + P_t^f IM_t^{Z,S}$$

Second stage: final good For each final good $Z_t \in \{C_t, I_t, CG_t\}$, final-good-specific composite manufacturing and service goods are combined to form final goods using the following production function

$$Z_t = \left[(1-\alpha_Z)^{1/\eta_Z} (Z_t^M)^{\frac{\eta_Z - 1}{\eta_Z}} + \alpha_Z^{1/\eta_Z} (Z_t^S)^{\frac{\eta_Z - 1}{\eta_Z}} \right]^{\eta_Z/(\eta_Z - 1)} \tag{23}$$

where α_Z is the final-good-specific composite service good bias parameter and η_Z the elasticity of substitution between the composite manufacturing and service good.[30] The objective of final goods firms in the second stage of production is to minimize the cost of producing a certain level of production Z_t, given the price of the composite manufacturing $P_t^{z,m}$ and service $P_t^{z,s}$ good. The solution to this cost-minimization problem, which we relegate to appendix 6.3, yields the following final-goods-specific demand functions

$$Z_t^M = (1-\alpha_Z) \left(P_t^{z,m} / P_t^z \right)^{-\eta_Z} Z_t \tag{24}$$

$$Z_t^S = \alpha_Z \left(P_t^{z,s} / P_t^z \right)^{-\eta_Z} Z_t \tag{25}$$

The relative price of final good Z is then given by

$$P_t^z = \left((1-\alpha_Z) \left(P_t^{z,m} \right)^{1-\eta_Z} + \alpha_Z \left(P_t^{z,s} \right)^{1-\eta_Z} \right)^{1/(1-\eta_Z)}$$

The market clearing conditions for each final good Z_t are given by

$$\begin{aligned} C_t &= P_t^{c,m} C_t^M + P_t^{c,s} C_t^S \\ P_t^i I_t &= P_t^{i,m} I_t^M + P_t^{i,s} I_t^S \\ P_t^{cg} CG_t &= P_t^{cg,m} CG_t^M + P_t^{cg,s} CG_t^S \end{aligned}$$

where the relative price of one unit of the final consumption good (the numeraire good in the model) is 1.

2.5.2 Final export good sector

The final good export sector differs from the other final good sectors in that there is a continuum of firms $i \in [0,1]$ that each produce a differentiated export good that are imperfect substitutes, thus allowing them to set prices. Consistent with the significant amount of evidence of deviations from the law of one price even for traded goods (Betts and Devereux, 2000), we assume that exporters set their prices in the local currency of sale, a practice sometimes called pricing-to-market.

Export firm i produces output of volume $X_t(i)$ and sells it at the relative price $P_t^x(i) = \frac{P_t^X(i)}{P_t^*}$ where $P_t^X(i)$ is the nominal price of a unit of exports in foreign currency and P_t^* is the foreign price level which given the small open economy assumption is exogenous. A perfectly-competitive (foreign) retailer combines the differentiated export goods into an aggregate export good X_t using the following bundling function

$$X_t = \left(\int_0^1 X_t(i)^{\frac{\epsilon_X - 1}{\epsilon_X}} di \right)^{\frac{\epsilon_X}{\epsilon_X - 1}}$$

[30] Consumption taxes are levied on the composite consumption good C_t. We therefore assume that the domestically-produced and the imported component of the consumption good are taxed at the same rate.

where ϵ_X is the elasticity of substitution across the differentiated export goods.[31] Retailers aim to maximize output of the aggregate export good X_t for a given level of inputs $\int_0^1 P_t^x(i) X_t(i) di$, which yields a set of demand functions given by

$$X_t(i) = \left(\frac{P_t^x(i)}{P_t^x} \right)^{-\epsilon_X} X_t$$

Hence, each individual exporter i takes into account that the demand for their goods $X(i)_t$ depends on the price they set $P_t^x(i)$ relative to the aggregate price $P_t^x = (\int_0^1 P_t^x(i)^{1-\epsilon_X} di)^{\frac{1}{1-\epsilon_X}}$ for exports.

Foreign trading partners' demand for the final aggregate export good is given by

$$X_t = (P_t^x)^{-\eta_x} Y_t^* \tag{26}$$

where Y_t^* denotes output among foreign trading partners which will be discussed in 2.7. η_x is the elasticity of substitution between domestic and imported goods in the foreign economy, which captures how sensitive Norwegian exports are to changes in the aggregate export price. This relationship is taken as given by Norwegian exporters who individually are assumed to be too small to affect the aggregate export price.

Cost minimization The production function of final good exporter i is given by

$$X_t(i) = \left[(1-\alpha_X)^{1/\eta_X} (X_t^M(i))^{\frac{\eta_X - 1}{\eta_X}} + \alpha_X^{1/\eta_X} (X_t^S(i))^{\frac{\eta_X - 1}{\eta_X}} \right]^{\eta_X/(\eta_X - 1)}$$

where α_X is the service good bias parameter for exports and η_X is the elasticity of substitution between the composite manufacturing $X_t^M(i)$ and service $X_t^S(i)$ good for the final export good. Exporter i seeks to minimize its costs of producing a certain desired level of production $X_t(i)$, given the price of the composite manufacturing $P_t^{x,m}$ and service $P_t^{x,s}$ good derived earlier. The derivation of this problem closely follows appendix 6.3, with the exception that the Lagrange multiplier can now be interpreted as the marginal cost of each individual exporter $MC_t^X(i)$. The solution yields the following demand functions for the composite manufacturing and service good by the final good export sector

$$\begin{aligned} X_t^M(i) &= (1-\alpha_X) \left(P_t^{x,m} / MC_t^X(i) \right)^{-\eta_X} X_t(i) \\ X_t^S(i) &= \alpha_X \left(P_t^{x,s} / MC_t^X(i) \right)^{-\eta_X} X_t(i) \end{aligned}$$

where marginal costs can be shown to be the same across firms $MC_t^X(i) = MC_t^X$ and given by

$$MC_t^X = \left((1-\alpha_X) (P_t^{x,m})^{1-\eta_X} + \alpha_X (P_t^{x,s})^{1-\eta_X} \right)^{1/(1-\eta_X)} \tag{27}$$

Price setting Firms in the final goods export sector set prices to maximize profits net of corporate taxes $\tau_t^{OI,F}$

$$\Pi_t^X = (1-\tau_t^{OI,F})[(P_t^x(i) Q_t - MC_t^X) X_t(i) - AC_t^X(i)] \tag{28}$$

Profits each period are therefore a function of the sales price in domestic currency $P_t^x(i) Q_t$ and the cost of production MC_t^X. Following Kravik and Mimir (2019), adjustment costs are given by

[31] Retailers are commonly-used modelling devices in DSGE models that serve the purpose of combining the input of competing firms within one sector. Our model features a export retailer as well as a retailer in the manufacturing and the service sector and the import sector, which will be introduced later. Due to the limited role these retailers play they have been omitted from the graphical overview in figure 1 and the model overview at the beginning of this section.

$$AC_t^X(i) = \frac{\chi_x}{2}\left(\frac{\frac{P_t^x(i)}{P_{t-1}^x(i)}\pi_t^*}{\left(\frac{P_{t-1}^x}{P_{t-2}^x}\pi_{t-1}^*\right)^{\chi_a}(\bar{\pi}^*)^{1-\chi_a}} - 1\right)^2 X_t Q_t P_t^x \tag{29}$$

where $AC_t^X(i)$ denotes adjustment costs in real domestic currency terms for exporter i, χ_x is a parameter determining the magnitude of adjustment costs, and χ_a is a parameter determining the degree of price indexation.[32]

The solution to the price-setting problem, which involves maximizing the net present value of the expected future value of profits each period in equation (28) subject to the demand function given by equation (2.5.2), is provided in appendix 6.4. The solution reveals that all exporting firms set identical prices such that $P_t^x(i) = P_t^x$ and that export prices in steady state are set at a mark-up $\frac{\epsilon_X}{\epsilon_X - 1}$ over marginal costs.[33]

2.5.3 Intermediate good manufacturing and services sector

The intermediate good manufacturing and services sectors each consist of a continuum of firms $i \in [0, 1]$ that produce a differentiated manufacturing and services good which are assumed to be imperfect substitutes, and set prices as a markup over marginal costs. Firms choose the optimal level of hours, investment, borrowing, and set prices in order to maximize firm value given by the present discounted value of future after-tax dividends. We solve the maximization problem for the manufacturing sector. The solution for the service sector is completely symmetric and will not be derived explicitly.

Production The production function of firm i in the manufacturing sector is given by

$$Y_t^M(i) = Z_t^{Y^M}(K_t^G)^{\kappa^M}(K_t^M(i))^{\alpha^M}(N_t^M(i))^{1-\alpha^M} - FC^M \tag{30}$$

where $Y_t^M(i)$ denotes output of firm i in the manufacturing sector, $K_t^M(i)$ and $N_t^M(i)$ are the amount of capital and labor inputs used in the production process, α^M is the output elasticity of capital, and FC^M are fixed costs. Following Sims and Wolff (2018) and Baxter and King (1993) we assume that public capital K_t^G can augment productivity of private firms. For this purpose we multiply $Z_t^{Y^M}$, which captures the total factor productivity shock, with $(K_t^G)^{\kappa^M}$ where κ^M measures the effectiveness of public capital in increasing productivity in the manufacturing sector.[34]

Cost minimization Analogous to the export sector, perfectly-competitive retailers buy the output of intermediate goods firms $Y_t^M(i)$ at a relative price $P_t^m = \frac{P_t^M(i)}{P_t}$ and bundle them into a domestic manufacturing good Y_t^M using the following bundling function

$$Y_t^M = \left(\int_0^1 Y_t^M(i)^{\frac{\epsilon_M - 1}{\epsilon_M}} di\right)^{\frac{\epsilon_M}{\epsilon_M - 1}}$$

where ϵ_M is the elasticity of substitution across goods produced by different manufacturing sector firms. Retailers aim to maximize output of the aggregate manufacturing good Y_t^M for a given level of inputs $\int_0^1 P_t^m(i)Y_t^M(i)di$, which yields a set of demand functions given by

$$Y_t^M(i) = \left(\frac{P_t^m(i)}{P_t^m}\right)^{-\epsilon_M} Y_t^M$$

[32] Note that since $\frac{P_t^x(i)}{P_{t-1}^x(i)}\pi_t^* = \frac{P_t^X(i)}{P_{t-1}^X(i)}$ adjustment costs are a function of the change in nominal export prices.

[33] Because exporters set identical prices they also have the same output, the same profits, and the same demand for composite manufacturing and service goods, implying that we can drop the i subscript from now on.

[34] The parameter κ^M can be freely chosen by the model operator, implying that public investment shocks (see section 2.6.4) can also be assumed to have no effect on total factor productivity.

Hence, each individual firm in the manufacturing sector takes into account that the demand for their good $Y_t^M(i)$ depends on the price they set $P_t^M(i)$ relative to the aggregate price $P_t^m = (\int_0^1 P_t^m(i)^{1-\epsilon_M} di)^{\frac{1}{1-\epsilon_M}}$ for manufacturing goods. The retailers sell the domestic manufacturing good to the final good sector, which combines it with imports and the composite service good to generate the final goods as discussed in the previous section.

Price adjustment costs Intermediate sector firms face, analogously to the export sector, adjustment costs when changing prices. These are a given by

$$AC_t^M(i) = \frac{\chi_M}{2}\left(\frac{\frac{P_t^m(i)}{P_{t-1}^m(i)}\pi_t}{\left(\frac{P_{t-1}^m}{P_{t-2}^m}\pi_{t-1}\right)^{\chi_a}\overline{\pi}^{1-\chi_a}} - 1\right)^2 Y_t^M P_t^m$$

where $AC_t^M(i)$ denotes real adjustment cost for manufacturing firm i, χ_M is a parameter determining the magnitude of adjustment costs in the manufacturing sector, and χ_a is a parameter determining the degree of price indexation.[35]

Capital accumulation The firm's capital stock evolves according to the following capital accumulation equation

$$K_{t+1}^M = I_t^M + (1-\delta)K_t^M \tag{31}$$

where I_t^M denotes investments in the manufacturing sector and δ is the capital depreciation rate.[36] The firm incurs costs to adjusting the level of investment

$$\gamma_t^K := \left(\frac{\chi_K}{2}\left(\frac{I_t^M}{I_{t-1}^M} - 1\right)^2\right) I_t^M$$

where χ_K is a parameter determining the magnitude of investment adjustment costs.

Borrowing Manufacturing firms borrow money to finance their operations by issuing bonds B_t^M. Nominal firm debt accumulates according to

$$P_t B_t^M \quad = \quad P_t BN_t^M + P_{t-1} B_{t-1}^M \tag{32}$$

where BN_t^M denotes the real value of new domestic borrowing. We define the debt-to-capital ratio as

$$b_t^M \quad := \quad \frac{B_t^M}{P_t^i K_{t+1}^M}$$

where P_t^i is the relative price of investment.[37]

The cost of borrowing for manufacturing firms is given by $R_{t-1}^L \phi_{t-1}^m$-1, where ϕ_t^m captures a risk premium that increases with the amount of borrowing, as captured by the firm's debt-to-capital ratio. In particular, we assume that

[35] Analogously to the final good export sector, $\frac{P_t^m(i)}{P_{t-1}^m(i)}\pi_t$ is equivalent to $\frac{P_t^M(i)}{P_{t-1}^M(i)}$, implying that adjustment cost operate on the nominal price of the manufacturing good.

[36] We can drop the i subscript as the problem is symmetric for each individual firm in the manufacturing sector.

[37] Note the difference in time subscripts which is because B_t^M measures the stock of bonds at the end of period t while K_t^M measures the stock of capital at the beginning of period t.

$$\phi_t^m = \exp^{\chi_B\left(b_t^M - \beta^M\right)} \tag{33}$$

where χ_B captures the responsiveness of the risk premium to the debt-to-capital ratio and β^M is a parameter calibrated to ensure that the model matches the empirical debt-to-capital ratio in Norwegian firms, see appendix 6.9 for further details. The firm payments associated with the risk premium, i.e. the debt servicing costs exceeding the rate of lending charged by the bank, are assumed to be redistributed in a lump-sum fashion to the Ricardian household.[38]

Additionally, firms face costs when adjusting the level of new borrowing.[39] Preserving the symmetry with investment adjustment costs we assume borrowing adjustment costs to be given by

$$\gamma_t^{BN} := \left(\frac{\chi_{BN}}{2}\left(\frac{BN_t^M}{BN_{t-1}^M} - 1\right)^2\right) BN_t^M.$$

Net investments We define net investments IN_t^M as the amount of investments in excess of capital depreciation

$$IN_t^M := I_t^M - \delta K_t^M$$

Net investments are then financed either by retained profits $\Pi_t^{M,R}$ or new borrowing BN_t^M

$$P_t^i IN_t^M = \Pi_t^{M,R} + BN_t^M \tag{34}$$

Note, that this setup also gives rise to cash-hoarding behaviour of firms along the lines of Chen et al. (2017) as total retained profits can be used either for investment or for repaying existing firm debt, the latter being a form of corporate saving.[40]

Profits and Dividends Total before-tax profits of a firm in the manufacturing sector are given by

$$\begin{aligned}\Pi_t^M(i) = \quad & \underbrace{P_t^m(i) Y_t^M(i)}_{\text{sales}} - \underbrace{(1+\tau_t^{SS,F}) W_t N_t^M(i)}_{\text{labor costs}} - \underbrace{\delta P_t^i K_t^M(i)}_{\text{depreciation costs}} \\ & - \underbrace{(R_{t-1}^L \phi_{t-1}^m - 1)\frac{B_{t-1}^M(i)}{\pi_t}}_{\text{interest on dom. borrowing}} - \underbrace{(AC_t^M(i) + \gamma_t^K(i) + \gamma_t^{BN}(i))}_{\text{Adj. costs}}\end{aligned} \tag{35}$$

where $P_t^m(i)$ is the relative price of the firm's output and $\tau_t^{SS,F}$ is the social security tax paid by firms.[41] Note that equation (35) represents profits after replacement of depreciated capital and interest payments which simplifies the definition of the tax base for profits as depreciation of capital and interest payments on borrowing are deductable in the Norwegian tax code. In accounting this is typically referred to as earnings before income taxes (EBT).[42] The tax base for the corporate profit tax is then given by

$$\Pi_t^{M,TB} = \Pi_t^M - TD^{OI,F}.$$

[38] This represents a short-cut to explicitly modeling the risk premium as a profit to banks that is then redistributed to the owner of the bank, the Ricardian household. Note, that the total value of risk premiums that both, manufacturing and service sector firms pay are given by $R_{t-1}^L(\phi_{t-1}^m - 1)\frac{B_{t-1}^M}{\pi_t} + R_{t-1}^L(\phi_{t-1}^s - 1)\frac{B_{t-1}^S}{\pi_t}$. This monetary stream is redistributed to the Ricardian household in each period in the numerical implementation of the model.

[39] In this we follow Alfaro et al. (2018) arguing that it is costly in terms of managerial time to change existing borrowing arrangements.

[40] This becomes evident when rearranging equation (34) to obtain $\Pi_t^{M,R} = P_t^i IN_t^M + (-BN_t^M)$ where the last term captures debt repayment. Hence, any rise in corporate profits can potentially increase investments but also non-investment saving of firms.

[41] We reintroduce the i-dependency to make clear the variables under control of individual firms.

[42] We implicitly assume that the depreciation allowance corresponds to the true rate of depreciation of the firm's physical capital and thereby avoid distortionary effects of the profit tax rate through the depreciation shield channel, see Sandmo (1974).

The term $TD^{OI,F}$ captures an allowance on corporate profits and is calibrated such that the tax base profits in steady-state are in line with data. Implicit in the definiton of the tax base and in line with the Norwegian tax code is the fact, that costs of borrowing are considered a deductible expense for tax purposes while new investments financed by equity are not. Total profits are then either retained in order to finance net investments, used to pay dividends to shareholders, or used to pay profit taxes to the government. Hence, it holds that

$$\Pi_t^M(i) = \Pi_t^{M,R}(i) + DIV_t^M(i) + \Pi_t^{M,TB}(i)\tau_t^{OI,F}. \tag{36}$$

Firm's stock price As noted in equation (8), which we repeat below for convenience, the firm's stock price is equal to the present discounted value of future dividends

$$P_t^{e,M}(i) = \sum_{j=1}^{\infty} \frac{1}{R_{t+j}^e} DIV_{t+j}^M(i)$$

where the firm's discount factor (from time $t = 1$) is equal to $R_{t+j}^e = \prod_{l=1}^j \frac{1-\Delta_{t+l}/\pi_{t+l}\tau_{t+l}^D(1+RRA_{t+l})}{\Delta_{t+l}(1-\tau_{t+l}^D)}$. It will prove useful to write the households period-to-period discount factor for dividends as

$$\Theta_{t+j+1} := \frac{R_{t+j+1}^e}{R_{t+j}^e} = \frac{1-\Delta_{t+j+1}/\pi_{t+j+1}\tau_{t+j+1}^D(1+RRA_{t+j+1})}{\Delta_{t+j+1}(1-\tau_{t+j+1}^D)}. \tag{37}$$

Firm's maximization problem Firm i's decision variables are the amount of labor it wants to employ $N_t^M(i)$ given the wage rate in the economy, the amount of investment $I_t^M(i)$ it wants to undertake, the amount of new borrowing $BN_t^M(i)$ it needs to carry out that investment, and the price it wants to charge for the good it produces $P_t^m(i)$. The firm chooses the optimal value of these variables in order to maximize its share price, taking into account constraints related to how physical capital (see equation (31)) and firm debt (see equation (32)) accumulates, and the need to satisfy the demand that materializes at the prevailing wage and price using the production technology in equation (30).

The first-order condition on ***labor*** (further details can be found in appendix 6.5) is given by

$$(1-\tau_t^{OI,F})(1+\tau_t^{SS,F})W_t = (1-\alpha^M)\lambda_t^{Y,M}\frac{Y_t^M(i)+FC^M}{N_t^M} \tag{38}$$

Hence, firms choose the amount of labor they want to employ in such a way that the after-tax wage equals the marginal product of labor.

The first-order condition on ***investment*** is a complicated and lengthy expression that we relegate to the appendix. It states that firms choose the amount of investment they want to undertake in such a way that the marginal product of capital is equal to the cost of investment, consisting of the price of investment and investment adjustment costs.

The first-order condition on ***new borrowing*** is, absent adjustment costs on new borrowing, given by $\lambda_t^{B^M} = -1$, where $\lambda_t^{B^M}$ is the Lagrange multiplier on new borrowing. Hence, each additional unit of new borrowing decreases the value of the firm by one unit. The expression with adjustment costs is more complex (and derived in the appendix, but follows the same basic intuition. New borrowing, however, also allows the firm to invest, which has positive effects on the value of the firm. This is captured by the envelope condition on the level of debt B_t^M, which is given by

$$(\Theta_{t+1}\pi_{t+1} - 1) = (1-\tau_{t+1}^{OI,F})(R_t^L\phi_t^m(1+\chi_B b_t^M) - 1) \tag{39}$$

The right-hand side of equation (39) captures the marginal cost of borrowing. It depends on the interest rate charged by banks on firm loans R_t^L, the risk premium on firm borrowing ϕ_t^m, and the marginal increase in the risk premium $(1 + \chi_B b_t^M)$ caused by an increase in the debt-to-capital ratio, see equation (33). Furthermore, the higher the ordinary income tax rate on profits, the less expensive becomes debt-financing relative to equity-financing as debt is exempt from the firm's ordinary income tax base. The left-hand side of equation (39) captures the marginal cost of equity-financing, which depends positively on Θ_{t+1} and hence on how profits and dividends are taxed, see equation (37). In particular, Θ_{t+1} declines with the rate-of-return allowance RRA_t. Hence, a higher rate-of-return allowance will reduce the marginal cost of equity-financing.[43]

The first-order condition on ***prices*** implies that all firms set the same price $P_t^m(i) = P_t^m$ which in steady state is given by

$$(1 - \tau^{OI,F})P^m = \lambda^{Y,M} \frac{\epsilon_M}{\epsilon_M - 1} \tag{40}$$

Hence, the after-tax price of the manufacturing good in steady-state is set as a mark-up over the value of one unit of production.[44]

2.5.4 Imported goods sector

Individual importing firms sell their output $IM_t(i)$ at a relative price $P_t^f(i)$ to perfectly-competitive import retailers who produce a homogeneous imported good IM_t which is sold to the final good sector. Import retailers produce the homogeneous imported good using the following bundling function

$$IM_t = \left(\int_0^1 IM_t(i)^{\frac{\epsilon_f - 1}{\epsilon_f}} di \right)^{\frac{\epsilon_f}{\epsilon_f - 1}}$$

where ϵ_f is the elasticity of substitution across imported goods sold by individual importers. Output maximization, analogous to the retailers in the export and intermediate good sector, by import retailers then implies

$$IM_t(i) = \left(\frac{P_t^f(i)}{P_t^f} \right)^{-\epsilon_f} IM_t \tag{41}$$

Hence, the demand faced by an individual importing firm $IM_t(i)$ depends on the price it sets $P_t^f(i)$ relative to the aggregate price index $P_t^f = \int_0^1 P_t^f(i)^{1-\epsilon_f} di^{\frac{1}{1-\epsilon_f}}$ for imported goods.

Individual importing firms set prices in order to maximize after-tax profits

$$(1 - \tau_t^{OI,F})\Pi_{F,t}(i) = (1 - \tau_t^{OI,F}) \left[(P_t^f(i) - Q_t) IM_t(i) - AC_t^F(i) \right] \tag{42}$$

where $\tau_t^{OI,F}$ is the corporate tax rate and the "cost of production" equals the real exchange rate Q_t since this is

[43] In appendix 6.6, we show that if the ordinary income tax rate on households $\tau_t^{OI,H}$ and on firm profits $\tau_t^{OI,F}$ are equal, transaction costs are zero and the rate-of-return allowance RRA_t is set equal to the after-tax return on deposits, there is no tax-induced distortion towards debt financing for firms. Instead, firms find it optimal to use no debt at all and rely entirely on equity to finance new investments. The intuition behind this result is that while the RRA_t (if set correctly) eliminates the tax-induced bias in favor of debt financing, the risk premium on firm debt ensures that debt financing will always be more costly than equity financing. There are two ways we overcome this in our model. First, while the statutory rates are identical, the effective tax rate on firm profits is higher than the effective ordinary income tax rate on households (due to financial sector profits which are taxed at a higher rate than in other sectors), implying that despite of the RRA_t there is a tax-induced bias in favor of debt financing sufficient to ensure a non-zero level of firm debt in steady state. Second, financial fees associated with trading firm stocks (shown in equation 5) imply an equity premium which imposes further costs on equity-financing. In the real world, foreign equity owners (who do not benefit from the RRA_t) would additionally ensure that there remains a bias in favor of debt financing even in sectors where the tax rate on profits and household ordinary income are identical.

[44] In our framework firms operate as stock price maximizer rather than cost minimizer as usually the case in standard DSGE models. This gives rise to a problem whereby the value of one unit of production enters the maximization problem as opposed to the more commonly used measure of marginal costs arising in cost minimization. The two measures are, however, equivalent. As evident from equation (40), the term $\lambda_t^{Y,M}$ can be interpreted as marginal cost in the manufacturing sector such that the after-tax price is set as a mark-up, a function of the elasticity ϵ_M, over marginal cost.

the price at which the importer can purchase one unit of foreign output. Price adjustment costs are analogous to those in the domestic intermediate sectors and the export sector

$$AC_t^F(i) = \frac{\chi_f}{2}\left(\frac{\frac{P_t^f(i)}{P_{t-1}^f(i)}\pi_t}{\left(\frac{P_{t-1}^f}{P_{t-2}^f}\pi_{t-1}\right)^{\chi_a}\overline{\pi}^{1-\chi_a}} - 1\right)^2 IM_t P_t^f$$

The solution to the price-setting problem, which involves maximizing the net present value of profits given by equation(42) subject to the demand function given by equation (41), is given in appendix 6.7. The result implies that all import firms set the same price $P_t^f(i) = P_t^f$, and that in steady state the price is set as a markup over the real exchange rate $P_t^f = Q_t \frac{\epsilon_f}{\epsilon_f - 1}$.

2.6 Monetary and fiscal policy

Monetary policy in our model is relatively standard. However, our description of fiscal policy is relatively disaggregated and includes a number of Norway-specific institutional details. Examples of DSGE models with a comparable level of fiscal detail include Gadatsch et al. (2016) and Stähler and Thomas (2012).

2.6.1 Central bank

The central bank sets the nominal interest rate according to a Taylor rule, which we take from the 2019 version of NEMO, see Kravik and Mimir (2019).

$$R_t = \overline{R}_t^{\text{ma}}\left(\frac{R_{t-1}}{\overline{R}_t^{\text{ma}}}\right)^{\psi_r}\left(\left(\frac{\pi_t^{ann}}{\overline{\pi^{ann}}_t^{\text{ma}}}\right)^{\psi_p}\left(\frac{\pi_{t+1}^{ann}}{\overline{\pi^{ann}}_t^{\text{ma}}}\right)^{\psi_{p1}}\left(\frac{\pi_{t+1}^{W,N}}{\overline{\pi^{W,N}}_t^{\text{ma}}}\right)^{\psi_w}\left(\frac{Y_t}{\overline{Y}_t^{\text{ma}}}\right)^{\psi_y}\left(\frac{Q_t}{\overline{Q}_t^{\text{ma}}}\right)^{\psi_q}\right)^{1-\psi_r}\exp(Z_t^R) \quad (43)$$

where π_t^{ann} is annual inflation, $\pi^{W,N}$ nominal wage inflation and $\overline{X}_t^{\text{ma}} \in \{\overline{R}_t^{\text{ma}}, \overline{\pi^{ann}}_t^{\text{ma}}, \overline{\pi^{W,N}}_t^{\text{ma}}, \overline{Y}_t^{\text{ma}}, \overline{Q}_t^{\text{ma}}\}$ denotes the (potentially time-varying) "target" value of X_t, which we discuss further below. The parameters $\psi_r, \psi_p, \psi_{p1}, \psi_w, \psi_y$ and ψ_q capture the weight placed by the central bank on smoothing changes in the interest rate, preventing deviations of annual inflation, current and one quarter ahead, and nominal wage inflation from target as well as keeping output at potential and the real exchange rate at its steady-state value. The term Z_t^R captures a shock to the nominal interest rate.

Following permanent shocks or structural policy changes it is possible that the steady-state interest rate and level of potential output changes.[45] To capture the fact that the central bank would gradually recognize that the economy has moved to a new steady-state and adjust their policy targets, we follow Laxton et al. (2010) and implement a moving average process

$$\overline{X}_t^{\text{ma}} = \left(\overline{X}_T\left(\overline{X}_{t-1}^{\text{ma}}\right)^{\rho^X}\right)^{\frac{1}{\rho^X+1}}$$

for the variables $X_t \in \{R_t, \pi_t^{ann}, \pi_t^{W,N}, Y_t, Q_t\}$. The process ensures that following such a shock or change in policy, the central bank's "target" values for the interest rate and output will move gradually towards the new end steady state, with the speed of adjustment determined by the smoothness parameter ρ^X.

[45]The steady-state level of inflation in our model would only change if the inflation target changed, as happened in 2019 when the inflation target was reduced from 2.5 to 2 percent.

2.6.2 Government budget

The government finances its expenditures, which consist of purchases of goods and services from the public sector, government investments, unemployment benefits, transfers to households, the government wage bill, and debt service payments on the public debt, by levying a range of taxes and through withdrawals from the Government Pension Fund Global (GPFG). The tax instruments available to the government are summarized in table 1.

Table 1: Overview on tax instruments

Variable	Description	Taxpayer
τ_t^C	Value-added tax on consumption	Households
f_t^C	Nominal consumption fee	Households
$\tau_t^{OI,H}$	Household ordinary income tax	Households
$\alpha_t^{OI,H}$	Scale-up factor for dividend taxation	Households
RRA_t	Allowance on return on shares	Households
$\tau_t^{OI,F}$	Firm ordinary income tax	Firms
τ_t^{LS}	labor surtax	Households
$\tau_t^{SS,H}$	Household social security contribution	Households
$\tau_t^{SS,F}$	Firm social security contribution	Firms
T_t^L	Lump-sum tax	Households

Total government revenue is thus given by

$$\begin{aligned} T_t = \; & \underbrace{T_t^L}_{\text{Lump-sum tax}} + \underbrace{C_t(\tau_t^C + f_t^C/P_t)}_{\text{Consumption taxes and fees}} + \underbrace{(W_t N_t^P + W_t^G N_t^G)\tau_t^{SS,F}}_{\text{Social security contributions of employers}} \\ & + \underbrace{(W_t N_t^P + W_t^G N_t^G + UB_t(L_t - N_t) + TR_t + \frac{DP_{t-1}}{\pi_t}(R_{t-1} - 1) - TD^{OI,H})\tau_t^{OI,H}}_{\text{Ordinary income tax on personal income}} \\ & + \underbrace{(W_t N_t^P + W_t^G N_t^G + UB_t(L_t - N_t) + TR_t - TD^{LS})(\tau_t^{LS} + \tau_t^{SS,H})}_{\text{Additional taxes on Labor income and transfers}} \\ & + \underbrace{(\Pi^{M,TB} + \Pi^{S,TB} + \Pi_t^{X,TB})\tau_t^{OI,F}}_{\text{Corporate income taxation}} + \underbrace{(DIV_t + AV_t - RRA_t P_t^e)\,\alpha_t^{OI,H}\tau_t^{OI,H}}_{\text{Dividend and capital gains tax}} \end{aligned} \tag{44}$$

where we exploit the fact that number of stocks are normalized to one, and sum up total dividends $DIV_t = DIV_t^M + DIV_t^S$, capital gains $AV_t = AV_t^M + AV_t^S$, and stock values $P_t^e = P_t^{e,M} + P_t^{e,S}$ across sectors.

Total government primary expenditures are given by

$$\begin{aligned} G_t = \; & \underbrace{P_t^{cg} C_t^G}_{\text{Government purchases}} + \underbrace{P_t^i I_t^G}_{\text{Government investment}} + \underbrace{UB_t(L_t - N_t)}_{\text{Unemployment benefits}} \\ & + \underbrace{TR_t + AVT_t}_{\text{Lump-sum transfers}} + \underbrace{W_t^G N_t^G(1 + \tau_t^{SS,F})}_{\text{Government wage bill}} \end{aligned} \tag{45}$$

The government's real value of debt at time t is given by D_t. Recalling that R_{t-1}^L is the nominal gross lending rate, the real value of debt interest payments DI_t is then given by

$$DI_t = \frac{R_{t-1}^L - 1}{\pi_t} D_{t-1}$$

The government surplus can me measured in three ways, depending on whether debt interest payments and fund withdrawals are included

$$
\begin{aligned}
\underbrace{PS_t}_{\text{Primary surplus}} &= T_t - G_t, \\
\underbrace{GS_t}_{\text{Total surplus}} &= T_t - G_t - DI_t, \\
\underbrace{GS_t^{adj}}_{\text{Total petroleum-adjusted surplus}} &= OILR_t + T_t - G_t - DI_t,
\end{aligned}
$$

where $OILR_t$ denotes withdrawals from the Government Pension Fund Global (GPFG), that will be discussed in section 2.6.5.

The government budget constraint is then given by

$$
\underbrace{D_{t-1}/\pi_t - D_t}_{\text{Net change in government debt}} = GS_t^{adj} = OILR_t + T_t - G_t - DI_t \tag{46}
$$

Norway does not borrow money to finance government expenditures. In most simulations we therefore enforce a zero total petroleum-adjusted surplus $GS_t^{adj} = 0$. In this case equation (46) simplifies to

$$
\underbrace{T_t}_{\text{Revenue}} + \underbrace{OILR_t}_{\text{Withdrawals from GPFG}} = \underbrace{G_t}_{\text{Government spending}} + \underbrace{DI_t}_{\text{Debt interest payments}} \tag{47}
$$

During simulations the user selects one or more "fiscal instruments" such as withdrawals from the GPFG, tax rates or categories of government primary expenditures, that adjust in such a way that the balanced budget equation in (47) always holds.

2.6.3 Government revenue and current spending

Unless they are "fiscal instruments" used to balance the budget in equation (47), the revenue and current (non-investment) spending components of the government budget are modelled as simple autoregressive shock processes.

Tax rates are assumed to follow the following additive process

$$
X_t = \overline{X} + \rho^X (X_{t-1} - \overline{X}) + Z_t^X \tag{48}
$$

where $X_t \in \{\tau_t^C, \tau_t^{OI,H}, \tau_t^{OI,F}, \tau_t^{LS}, \tau_t^{SS,H}, \tau_t^{SS,F}\}$ and $\overline{X}$ denotes the steady state of X_t. Spending components (except public investment which is discussed in section 2.6.4) and non-tax-rate revenue instruments are assumed to follow the following multiplicative process

$$
X_t = \overline{X} \left(\frac{X_{t-1}}{\overline{X}} \right)^{\rho_X} \exp(Z_t^X) \tag{49}
$$

where $X_t \in \{C_t^G, T_t^L, OILR_t, TR_t^l, TR_t^r, UB_t, N_t^G, \alpha_t^{OI,H}\}$. Hence, instrument X_t remains constant at its steady-state level $\overline{X}$ in the absence of any shock to that instrument, i.e. $Z_t^X = 0$. For tax rates, increasing Z_t^X to 0.01 would raise the relevant rate above its steady-state level by one percentage point, while for current spending components and non-tax-rate revenue instruments raising Z_t^X to 0.01 would increase spending component X_t by one percent. Because of the autoregressive nature of equation (48) and (49), shocks to $Z_t^X = 0$ will only gradually translate into higher government revenue spending, with the speed of adjustment determined by the parameter ρ^X. A special case is when $\rho^X = 0$ in which case shocks to Z_t^X are immediately transmitted to higher revenue or higher spending.[46] Shocks to Z_t^X may be temporary, as would the case with a temporary increase in government spending, or permanent, as would be the case with a structural change to the tax system. Fiscal policy shocks can in addition either be announced ahead of time, for example due to lags in the budget process, or fully unanticipated in which case they take effect the period they are announced.[47]

2.6.4 Public investment and capital

We model the public capital stock using the time-to-build specification in Leeper et al. (2010) and Coenen et al. (2013). Hence we assume that authorized public investment programs take time to complete before they become available as public capital to domestic firms.

For expositional purposes we first consider a simplified example in which a single public investment project is authorized in period $t = 1$, requiring a total of 3 periods to be completed. We also abstract from public capital depreciation. During the 3 periods it takes to complete the public investment project the public capital does not change, i.e. $K^G_{t=1} = K^G_{t=2} = K^G_{t=3}$. Only in period 4, once the public investment project is completed, does the augmented public capital stock become available to firms and affect the economy

$$K^G_{t=4} = K^G_{t=3} + A^{I^G}_{t=1}$$

where $A^{I^G}_{t=1}$ is the authorized amount of public investment in the first period. After period four, the public capital stock remains at its higher value. We assume that the government pays for the public investment project as it is being completed. The shares of the public investment project completed in periods 1-3 are given by ϕ_1, ϕ_2 and ϕ_3. Hence, public investment in the first period amounts to $I^G_{t=1} = \phi_1 A^{I^G}_{t=1}$ and in the second period to $I^G_{t=2} = \phi_2 A^{I^G}_{t=1}$, with third period investment given analogously. Of course, the shares have to add up to one such that the entire authorized investment is completed before the augmented capital stock is to be made available to firms.

In reality, public capital depreciates and new public investments are authorized every period. Assuming that it takes more than 1 period to complete a project, this means that multiple public investment projects will tend to overlap. In the following exposition we assume that it takes $N \geq 1$ periods for a given authorized public investment project to become public capital. The accumulation of the public capital stock is then given by

$$K^G_{t+1} = (1 - \delta_{KG}) K^G_t + A^{I^G}_{t-N+1}$$

where δ_{KG} is the depreciation rate of public capital and $A^{I^G}_{t-N+1}$ is the authorized amount of public investment

[46] Note that in simulations where the user wishes to use government borrowing to (temporarily) finance higher deficits, at least one fiscal instrument needs to include a debt feedback term to ensure that government debt does not explode. In this case the process for tax rates in equation (48) would take the form

$$X_t = \overline{X} + \rho^X (X_{t-1} - \overline{X}) + (1 - \rho^X)\phi^X \left(\frac{D_{t-1}}{Y_{t-1}} - \frac{\overline{D}}{\overline{Y}} \right) + Z_t^X$$

while the process for current spending components and non-tax-rate revenue in equation (49) would follow

$$X_t = \overline{X} \left(\frac{X_{t-1}}{\overline{X}} \right)^{\rho_X} \left(\frac{D_{t-1}/Y_{t-1}}{\overline{D}/\overline{Y}} \right)^{(1-\rho^X)\phi^X} \exp(Z_t^X)$$

where $\phi^X > 0$ governs the responsiveness of the fiscal instrument X_t to deviations in the government debt-to-GDP ratio from its steady state value.

[47] Nominal consumption fees f_t^C are adjusted by inflation every year, and thus have exactly the same effect in our model as the value-added tax on consumption τ_t^C. We therefore do not allow the user to separately shock f_t^C. During simulations the RRA_t is set to the level which avoids double taxation of the risk-free return on equity. As shown in appendix 6.6 this implies that the RRA_t depends on the prevailing interest rate and the household's ordinary income tax rate

$$RRA_t = (R_t - 1)(1 - \tau_t^{OI,H})$$

It is currently not possible to independently shock the RRA_t.

$N-1$ periods ago. The cost of the authorized public investment project is spread over the time it takes to complete the project. As in the example above, we assume that the spending shares for each period n from authorization to completion of the project are given by ϕ_n. Hence, ϕ_n indicates what share of the total authorized investment is constructed in the nth period since the investment was authorized. Public investment volume each period I_t^G is then given by

$$I_t^G = \sum_{n=0}^{N-1} \phi_n A_{t-n}^{I^G}. \tag{50}$$

Equation (50) captures the amount of public investment in period t on all ongoing public investment projects dating back to $N-1$ periods ago. Since public investments have to be fully funded over the implementation period, $\sum_{n=0}^{N-1} \phi_n = 1$ holds.

The amount of authorized public investments follows the autoregressive process

$$A_t^{I^G} = \overline{A^{I^G}} \left(\frac{A_{t-1}^{I^G}}{\overline{A^{I^G}}} \right)^{\rho_A} \exp(Z_t^{A^{IG}})$$

where $\overline{A^{IG}}$ is the steady-state level of authorized investment, $Z_t^{A^{IG}}$ is a shock to authorized public investment, and ρ_A is an autoregressive parameter that determines the speed at which a shock $Z_t^{A^{IG}}$ translates into higher authorized public investment.

2.6.5 Government pension fund global

The model includes a simplistic model of the Government pension fund global (GPFG). The first simplification relates to the fact that we do not model the oil production sector, and thus abstract from any inflows into the GPFG. The second simplification relates to the fact that we abstract from exchange rate movements that would alter the domestic currency value of the GPFG.[48] The third simplification relates to the fact that we assume a constant real rate of return on the fund. These simplifications, which may be relaxed in future versions of the model, allow us to focus exclusively on the trade-offs associated with increasing or decreasing the pace of withdrawals from the GPFG.

The real value of the GPFG in foreign currency GPF_t is assumed to evolve according to the following process

$$GPF_t = (1 + \overline{r^F}) GPF_{t-1} - \frac{OILR_t}{\overline{Q}} \tag{51}$$

where $\overline{r^F}$ is the constant real rate of return of the fund, $\overline{Q}$ is the steady-state exchange rate, and $OILR_t$ denotes the domestic-currency value of withdrawals from the GPFG. Hence, $\frac{OILR_t}{\overline{Q}}$ captures the value of oil fund withdrawals in foreign currency.

During simulations it is possible to use oil fund withdrawals $OILR_t$ as a financing instrument. This can be done in two ways. In the first case, equation (51) is not active and changes in the amount withdrawn from the fund is assumed to have no effect on the value of the GPFG. This option, which implies there are no direct costs associated with increasing the use of oil fund withdrawals to finance government expenditures, is unrealistic but may be useful for comparison purposes.[49]

[48] Keeping the exchange rate applied to the value of the GPFG fixed helps prevent potentially large wealth effects associated with changes in the expected future tax burden stemming from movements in the domestic currency value of the fund.

[49] Even in this case there will be general equilibrium costs associated with increasing oil fund withdrawals, notably an appreciation of the real exchange rate.

In the second case, equation (51) is active and changes in $OILR_t$ will affect the value of the GPFG. In order to avoid an imploding (or exploding) value of the fund, the take-out rate $TOR_t := \frac{OILR_t}{Q \cdot GPF_t}$ has to return to the real rate of return of the GPFG in the long run.

$$\overline{TOR} = \overline{r^F}$$

This can be achieved in several ways. For example, a temporary increase in oil fund withdrawals followed by a temporary decrease sufficient to restore the GPFG to its original value would ensure that the take-out rate returns to its sustainable level. Alternatively, a temporary increase in oil fund withdrawals could be followed by a permanently lower level of oil fund withdrawals to take account of the now lower level of sustainable capital income generated by the fund. The exact conditions under which the take-out rate returns to its sustainable level can be chosen by the user during simulations.

2.7 Foreign Sector

Following Norges Bank's NEMO, see Kravik and Mimir (2019), we model the foreign sector using an exogenous block that links foreign inflation π_t^*, foreign output by trading Y_t^* and non-trading $Y_t^{*,NPT}$ partners, the foreign interest rate R_t^* and the oil price P_t^{oil}. In contrast to NEMO, which includes a microfounded oil production sector, we model the demand for domestically-produced investment goods from the off-shore oil sector I_t^{OIL} in a reduced-form fashion depending on the oil price.

The output of trading partners Y_t^* is given by the following system of equations

$$\begin{aligned} Y_t^* &= \overline{Y}^* \left(\frac{Y_{t-1}^*}{\overline{Y}^*}\right)^{\rho_{Y^*}} \left(\frac{Y_{f,t}^*}{\overline{Y}_f^*}\right)^{1-\rho_{Y^*}} \left(\frac{P_t^{oil}}{\overline{P}^{oil}}\right)^{-\psi_{Y^*,oil}} \left(\frac{Y_t^{*,NTP}}{\overline{Y}^{*,NTP}}\right)^{\psi_{Y^*,NTP}} \exp(Z_t^{Y^*}) \\ Y_{f,t}^* &= \overline{Y}_f^* \left(\frac{Y_{f,t+1}^*}{\overline{Y}_f^*}\right)^{\rho_{Yf^*}} \left(\frac{R_t^*}{\pi_{t+1}^*} / \frac{\overline{R}^*}{\overline{\pi}^*}\right)^{-\psi_{Y_f,R^*}} \end{aligned}$$

Hence, we model the output of foreign trading partners as partly backward-looking, as having dynamic IS-curve features by being linked to the real interest rate through $Y_{f,t}^*$, as responding negatively to the oil price due to trading partners being net oil importers and finally, as responding positively to the output gap among non-trading partners, $Y_t^{*,NTP}$, who are assumed to trade with Norway's trading partners but not directly with Norway. The term $Z_t^{Y^*}$ denotes a shock to the output of trading partners.

The output of non-trading partners $Y_t^{*,NPT}$ is given by

$$Y_t^{*,NTP} = \overline{Y}^{*,NTP} \left(\frac{Y_{t-1}^{*,NTP}}{\overline{Y}^{*,NTP}}\right)^{\rho_{Y^*,NTP}} \left(\frac{P_t^{oil}}{\overline{P}^{oil}}\right)^{-\psi_{Y^*,NTP,oil}} \left(\frac{Y_t^*}{\overline{Y}^*}\right)^{\psi_{Y^*}} \exp(Z_t^{Y^{NTP}})$$

Hence, the output of non-trading partners is partly backward-looking and responds negatively to the oil price and positively to demand from foreign trading partners. Following Kravik and Mimir (2019), the shock $Z_t^{Y^{NTP}}$ can be interpreted as a global demand shock.

Overall global output is then given by a weighted sum of the output of trading partners and non-trading partners:

$$\frac{Y_t^{*,glob}}{\overline{Y}^{*,glob}} = \alpha^{glob} \frac{Y_t^*}{\overline{Y}^*} + (1 - \alpha^{glob}) \frac{Y_t^{*,NTP}}{\overline{Y}^{*,NTP}}$$

where α^{glob} captures the steady-state share of trading partners' output in total global output.

Inflation in Norway's trading partners is given by the following system of equations

$$\begin{aligned}
\pi_t^* &= \pi^* \left(\frac{\pi_{t-1}^*}{\pi^*}\right)^{\rho_{\pi^*}} \left(\frac{\pi_{f,t}^*}{\pi_f^*}\right)^{1-\rho_{\pi^*}} \left(\frac{P_t^{oil}}{\overline{P}^{oil}}\right)^{\psi_{\pi^*,oil}} \\
\pi_{f,t}^* &= \pi_f^* \left(\frac{\pi_{f,t+1}^*}{\pi_f^*}\right)^{\rho_{\pi_f^*}} \left(\frac{Y_t^*}{\overline{Y}^*}\right)^{\psi_{\pi_f Y^*}} \exp(Z_t^{\pi^*})
\end{aligned}$$

Hence, inflation in foreign trading partners is partly backward looking, captures the positive effect of oil prices on marginal costs and hence on inflation, and incorporates the standard forward-looking Phillips curve dynamics through π_f^*. The shock $Z_t^{\pi^*}$ to the foreign inflation rate can be interpreted as a foreign markup shock.

Foreign trading partners' monetary policy is given by a standard Taylor rule where the interest rate responds to the contemporaneous inflation and output

$$R_t^* = \overline{R}^* \left(\frac{R_{t-1}^*}{\overline{R}^*}\right)^{\rho_{r^*}} \left(\left(\frac{\pi_t^*}{\overline{\pi}^*}\right)^{\psi_\pi^*} \left(\frac{Y_t^*}{\overline{Y}^*}\right)^{\psi_y^*}\right)^{1-\rho_{r^*}} \exp(Z_t^{R^*})$$

The parameters ψ_π^* and ψ_y^* capture the weights placed by the foreign trading partner central bank on preventing deviations of inflation from target and keeping output at potential, while ρ_{r^*} captures the weight placed on interest rate smoothing. The shock $Z_t^{R^*}$ can be interpreted as a shock to the nominal interest rate in foreign trading partners.

The international oil price is forward-looking and responds to movements in global demand

$$P_t^{oil} = \overline{P}^{oil} \left(\frac{P_{t+1}^{oil}}{\overline{P}^{oil}}\right)^{\rho_{oil}} \left(\frac{Y_t^{*,glob}}{\overline{Y}^{*,glob}}\right)^{\psi_{oil,Y^{*,glob}}} \exp(Z_t^{P^{OIL}})$$

where $Z_t^{P^{OIL}}$ can be interpreted as an oil price shock.

Demand for domestically-produced investment goods by the offshore oil production sector depends positively on the oil price and is given by a following reduced-form autoregressive process

$$I_t^{OIL} = \overline{I^{OIL}} \left(\frac{I_{t-1}^{OIL}}{\overline{I^{OIL}}}\right)^{\rho_{ioil}} \left(\frac{P_t^{oil}}{\overline{P}^{oil}}\right)^{\psi_{ioil}} \exp(Z_t^{I^{OIL}})$$

where $Z_t^{I^{OIL}}$ captures a shock to oil sector investment demand.

2.8 Aggregation and market clearing

To complete the technical description of the model we introduce several variables that describe the behaviour of firms at the aggregate level and define mainland GDP. To close the model we discuss the balance of payments of the mainland economy and derive the aggregate market clearing condition.

2.8.1 Total investment demand

Total investment demand in the economy is given by the sum of investments in the manufacturing and service sector, demand for domestically-produced investment goods by the offshore oil sector, and public investment

$$I_t = I_t^M + I_t^S + I_t^{OIL} + I_t^G$$

For calibration purposes, we define mainland investment as $I_t^{ML} := I_t^M + I_t^S + I_t^G$ and mainland private-sector investment as $I_t^P := I_t^M + I_t^S$.

2.8.2 Production in the manufacturing, service and import sector

Total production in the manufacturing, service, and import sector is given by the sum of inputs required to produce the four final goods $Z_t \in \{C_t, I_t, X_t, CG_t\}$ in the economy

$$\begin{aligned} Y_t^M &= Y_t^{C,M} + Y_t^{I,M} + Y_t^{CG,M} + Y_t^{X,M} \\ Y_t^S &= Y_t^{C,S} + Y_t^{I,S} + Y_t^{CG,S} + Y_t^{X,S} \\ IM_t &= IM_t^{C,M} + IM_t^{I,M} + IM_t^{CG,M} + IM_t^{X,M} + IM_t^{C,S} + IM_t^{I,S} + IM_t^{CG,S} + IM_t^{X,S} \end{aligned} \tag{52}$$

Hence, total output in the manufacturing, service, and import sector consists of the corresponding first-stage inputs into the production of the four final goods. Since, as shown in figure 3, imported goods are bundled both with the composite manufacturing good and the composite service good in the production of the four final goods, the expression for total production in the import sector in equation (52) consists of a total of eight terms.[50]

2.8.3 Domestic output

Before introducing the total volume of domestic production, it is useful to define domestically-sold production in the service and manufacturing sector:

$$\begin{aligned} Y_t^{D,M} &= Y_t^M - Y_t^{X,M} \\ Y_t^{D,S} &= Y_t^S - Y_t^{X,S} \end{aligned}$$

The total value of domestic output (in CPI units) is given by

$$P_t^y Y_t^D = \underbrace{P_t^m Y_t^{D,M} + P_t^s Y_t^{D,S}}_{\text{Value of domestically-sold output}} + \underbrace{Q_t P_t^x X_t - P_t^f (IM_t^{X,M} + IM_t^{X,S})}_{\text{Value added in the export sector}} \tag{53}$$

where P_t^y is the relative price of domestic output and Y_t^D denotes the volume of domestic output. Note that we need to split domestic production into a domestically-sold part and an exported part as the latter will be sold at a price set by exporters in the local currency of sale, see section 2.5.2 for further details. In addition we need to subtract the value of imports that are used to produce the exported good in order to arrive at value-added in the export sector.

The total value of domestic output can be rewritten as

$$P_t^y Y_t^D = P_t^m Y_t^M + P_t^s Y_t^S + VA_t^X X_t$$

where $VA_t^X = Q_t P_t^x - MC_t^X$ is the value added per unit in the export sector. Marginal costs in the final export sector MC_t^X are given in equation (27). Profits in the export sector are then given by $\Pi_t^{X,r} = (1 - \tau_t^{OI,F})(VA_t^x X_t - AC_t^X)$. Adjustment costs in the final export sector AC_t^X are defined in equation (29).

We use the Törnqvist-Index to construct the relative price of domestic output P_t^y, which in turn allows us

[50] We can simply add the first-stage inputs from each sector as the sectors produce only one homogeneous good, or to be more precise, the retailer aggregating up firm-specific goods produces one homogeneous manufacturing, service, and imported good. Inputs from the same intermediate goods sector (manufacturing, service or import sector) into different final good sectors are thus perfect substitutes.

to obtain a measure of domestic output volume Y_t^D, see appendix 6.8 for further details. GDP is then defined as the sum of domestic output, the government wage bill, public capital depreciation and inventory changes

$$Y_t = Y_t^D + \frac{(1+\overline{\tau^{SS,F}})\overline{W^G}}{\overline{P^y}} N_t^G + \frac{\overline{P^i}\delta_{KG}}{\overline{P^y}} K_t^G + INV_t \tag{54}$$

The public wage bill and public capital depreciation are divided by the relative price of domestic output to translate their values, which are given in CPI-terms, into units of the domestic good. The terms preceding N_t^G and K_t^G in equation (54) are held constant at their steady-state value following the national accounts convention that government employment and capital depreciation are to be valued at base prices. As a consequence, only volume changes (i.e. changes in public employment or the public capital stock) affect the government wage bill and public capital depreciation component in the GDP definition. Inventory changes INV_t are given by an exogenous process.

GDP in CPI units Y_t^{CPI} is given by the sum of the components of Y_t expressed in CPI units

$$\begin{aligned} Y_t^{CPI} &= P_t^Y Y_t \\ &= P_t^y Y_t^D + (1+\overline{\tau^{SS,F}})\overline{W^G} N_t^G + \overline{P^i}\delta_{KG} K_t^G + P_t^y INV_t \end{aligned}$$

2.8.4 Balance of payments

Before deriving the balance of payments we introduce "residual" imports IM_t^{Res} that are necessary for the model to match the national accounts. IM_t^{Res} are imports that are not captured by inputs to production in the manufacturing and service sector. These stem from imports by the offshore oil industry that are embedded in the domestically-produced investment good purchased by the oil industry, which our model is currently not able to capture. To avoid having to introduce a theoretical model of the offshore oil industry we simply assume that "residual" imports move in line with imports.

$$IM_t^{Res} = \overline{IM^{Res}} \frac{IM_t}{\overline{IM}}$$

where $\overline{IM^{Res}}$ is the steady-state level of "residual" imports necessary to match the national accounts data.

We can then define net exports NX_t as the difference between exports and overall imports measured in CPI units

$$NX_t = Q_t P_t^x X_t - P_t^f (IM_t + IM_t^{Res})$$

where $Q_t P_t^x$ is the relative domestic-currency price of exports and P_t^f is he relative price of imports.

We now can write down the balance of payments for the economy in our model

$$NX_t + OILR_t + P_t^i I_t^{OIL} = \frac{e_t P_t^*}{P_t}(-B_t^F) - \frac{e_t P_{t-1}^*}{P_t}(-B_{t-1}^F) R_{t-1}^* \phi_{t-1}(A_{t-1}) \tag{55}$$

The left hand side of equation (55) denotes payments to the domestic economy, consisting of (potentially negative) net exports, withdrawals from the GPFG, and the sale of domestically-produced investment goods to the offshore oil sector. The latter is included because we have chosen to only model the mainland economy, and the sale of domestically-produced investment goods to the offshore oil sector thus represents a transaction between a resident (of the the mainland economy) and a non-resident.[51] The right hand side of equation (55)

[51] Our version of the balance of payments stands in contrast to official statistics on the balance of payments of the overall Norwegian

captures the net change in in foreign assets (excluding the GPFG) including interest interest income.[52]

2.8.5 Aggregate market clearing

We obtain the aggregate market clearing condition by inserting the balance of payments in equation (55), the government budget constraint in equation (46), the budget constraint for liquidity-constrained households in equation (9), the profit functions of intermediate goods firms in the manufacturing and service sector in (35), and the bank balance sheet in equation (16) into the budget constraint of Ricardian households in equation (5)

$$P_t^y Y_t^D = C_t + NX_t + P_t^i I_t + P_t^{cg} C_t^G + AC_t + (1-\omega)\gamma_t^W. \tag{56}$$

where $AC_t = AC_t^M + AC_t^S + AC_t^X + (1-\omega)\gamma_t^W$ are total adjustment costs in the economy.[53]. The aggregate market clearing condition in equation (56) differs from the definition of output in (53) in that the latter expresses total output as the sum of domestic production, i.e. from the supply side of the economy, whereas equation (56) expresses GDP as the sum of total demand. Together equations (53) and (56) shows that supply equals demand in our model economy.

2.9 Shocks

The shocks in the model are denoted by Z_t^X, where X denotes the model variable that is most directly affected by the shock. All shocks are assumed to be AR(1) processes, where the λ^X parameters capture the auto-correlation of the shock processes with its first lag while the E^X's are normally-distributed exogenous innovations to the shock process. The σ^X parameters capture the standard deviations of the respective exogenous innovations. In the following we provide a list of all shocks occuring in the model.

Manufacturing sector technology shock

$$Z_t^{Y^M} = \lambda^{Y^M} Z_{t-1}^{Y^M} + \sigma^{Y^M} E_t^{Y^M}$$

Service sector technology shock

$$Z_t^{Y^S} = \lambda^{Y^S} Z_{t-1}^{Y^S} + \sigma^{Y^S} E_t^{Y^S}$$

Consumption preferences shock

$$Z_t^U = \lambda^U Z_{t-1}^U + \sigma^U E_t^U$$

Risk premium shock

$$Z_t^{RP} = \lambda^{RP} Z_{t-1}^{RP} + \sigma^{RP} E_t^{RP}$$

Monetary policy shock

$$Z_t^R = \lambda^R Z_{t-1}^R + \sigma^R E_t^R$$

Trading partners' output shock

$$Z_t^{Y^*} = \lambda^{Y^*} Z_{t-1}^{Y^*} + \sigma^{Y^*} E_t^{Y^*}$$

Non-trading partners' output shock

$$Z_t^{Y^{NTP}} = \lambda^{Y^{NTP}} Z_{t-1}^{Y^{NTP}} + \sigma^{Y^{NTP}} E_t^{Y^{NTP}}$$

economy which treats the offshore oil sector as a resident entity. In that case the sale of domestically-produced investment goods to the offshore oil sector would be considered a transaction between two resident entities, and would not enter the balance of payments. On the other hand, the balance of payments for the overall economy would additionally include transactions between the offshore oil sector and the rest of the world, notably oil exports and transfers from the offshore oil sector to the GPFG.

[52]Note that B_t^F is defined as the value of foreign liabilities. Hence, $-B_t^F$ can be interpreted as the value of foreign assets.

[53]Further details on the derivation of the aggregate market clearing condition can be found in the appendix 6.10

Foreign inflation shock

$$Z_t^{\pi^*} = \lambda^{\pi^*} Z_{t-1}^{\pi^*} + \sigma^{\pi^*} E_t^{\pi^*}$$

Foreign monetary policy shock

$$Z_t^{R^*} = \lambda^{R^*} Z_{t-1}^{R^*} + \sigma^{R^*} E_t^{R^*}$$

Government purchases shock

$$Z_t^{C^G} = \lambda^{C^G} Z_{t-1}^{C^G} + \sigma^{C^G} E_t^{C^G}$$

Lump-sum tax shock

$$Z_t^{\tau^L} = \lambda^{\tau^L} Z_{t-1}^{\tau^L} + \sigma^{\tau^L} E_t^{\tau^L}$$

Consumption tax shock

$$Z_t^{\tau^C} = \lambda^{\tau^C} Z_{t-1}^{\tau^C} + \sigma^{\tau^C} E_t^{\tau^C}$$

Household ordinary income tax shock

$$Z_t^{\tau^{OIH}} = \lambda^{\tau^{OIH}} Z_{t-1}^{\tau^{OIH}} + \sigma^{\tau^{OIH}} E_t^{\tau^{OIH}}$$

Firm ordinary income tax shock

$$Z_t^{\tau^{OIF}} = \lambda^{\tau^{OIF}} Z_{t-1}^{\tau^{OIF}} + \sigma^{\tau^{OIF}} E_t^{\tau^{OIF}}$$

labor surtax shock

$$Z_t^{\tau^{LS}} = \lambda^{\tau^{LS}} Z_{t-1}^{\tau^{LS}} + \sigma^{\tau^{LS}} E_t^{\tau^{LS}}$$

Household social security contributions shock

$$Z_t^{\tau^{SSH}} = \lambda^{\tau^{SSH}} Z_{t-1}^{\tau^{SSH}} + \sigma^{\tau^{SSH}} E_t^{\tau^{SSH}}$$

Firm social security contributions shock

$$Z_t^{\tau^{SSF}} = \lambda^{\tau^{SSF}} Z_{t-1}^{\tau^{SSF}} + \sigma^{\tau^{SSF}} E_t^{\tau^{SSF}}$$

Oil fund withdrawals shock

$$Z_t^{T^{BF}} = \lambda^{T^{BF}} Z_{t-1}^{T^{BF}} + \sigma^{T^{BF}} E_t^{T^{BF}}$$

Government employment shock

$$Z_t^{NG} = \lambda^{NG} Z_{t-1}^{NG} + \sigma^{NG} E_t^{NG}$$

Government authorized investment shock

$$Z_t^{A^{IG}} = \lambda^{A^{IG}} Z_{t-1}^{A^{IG}} + \sigma^{A^{IG}} E_t^{A^{IG}}$$

Oil sector investment shock

$$Z_t^{I^{OIL}} = \lambda^{I^{OIL}} Z_{t-1}^{I^{OIL}} + \sigma^{I^{OIL}} E_t^{I^{OIL}}$$

Transfers to liquidity-constrained households shock

$$Z_t^{TR^L} = \lambda^{TR^L} Z_{t-1}^{TR^L} + \sigma^{TR^L} E_t^{TR^L}$$

Transfers to Ricardian households shock

$$Z_t^{TR^R} = \lambda^{TR^R} Z_{t-1}^{TR^R} + \sigma^{TR^R} E_t^{TR^R}$$

Oil price shock

$$Z_t^{P^{OIL}} = \lambda^{P^{OIL}} Z_{t-1}^{P^{OIL}} + \sigma^{P^{OIL}} E_t^{P^{OIL}}$$

Labor force participation shock

$$Z_t^L = \lambda^L Z_{t-1}^L + \sigma^L E_t^L$$

Nash reference utility shock

$$Z_t^V = \lambda^V Z_{t-1}^V + \sigma^V E_t^V$$

3 Calibration

The current version of the model is calibrated to the Norwegian mainland economy following a two-step strategy. In a first step the parameters that determine the steady state of the model are chosen such that the model replicates a number of long-run moments in the data, or (where this is not possible) are set equal to comparable parameter values used in the most recently estimated version of NEMO (Kravik and Mimir, 2019) or the academic literature.[54] In a second step parameters that only affect the dynamic properties of the model are chosen to minimize the distance between the model-implied impulse responses to a number of shocks and impulse responses to the same shocks from the most recent version of NEMO (Kravik and Mimir, 2019).[55] In doing so we follow a variant of the limited-information strategy used in Christiano et al. (2005).

3.1 Steady-state calibration

The value of the steady-state parameters in the model are reported in table 2.

We first discuss the steady-state parameters that are chosen such that the deterministic steady-state of the model replicates long-run targets in the data.[56] Some of the more than 40 empirical targets we seek to replicate (for an overview see table 3) can be matched by setting the steady-state value of the related variable directly. This is the case, for example, with the steady-state inflation rate. Others are matched by finding an appropriate value for the parameter that determines the value of the target in the model. This is the case, for example, with the import content of private consumption. The technical details to this approach are provided in appendix 6.9. In what follows we provide a brief summary.

The steady-state gross inflation rate in Norway π is set to two percent annually, consistent with Norges Banks new inflation target.[57] The steady-state rate of inflation in Norway's trading partners π^* is also set equal to 2 percent as in the most recent version of NEMO (Kravik and Mimir, 2019). The discount factor β is set to 0.9973 in order to yield a steady-state nominal interest rate of 3.94 percent per annum as in the most recent version of NEMO. The UIP condition in equation (19) then implies a steady-state nominal interest rate abroad of the same value as in Norway.

We set the service sector bias of final consumption goods α_C and private investment goods α_I goods to 0.79 to match the values in the input-output tables underlying the national accounts.[58] The service sector bias of government purchases α_{CG} and export goods α_X is set to 0.92 and 0.5 using the same approach. National account input-output table also allow us to determine the import content of the composite manufacturing good

[54] We refer to parameters that affect the steady state of the model as steady-state parameters as opposed to dynamic parameters that only govern the dynamic response of the model to shocks.

[55] Our approach differs from the traditional impulse response matching literature in that we minimize the distance to an existing structural model rather than a reduced-form vector autoregression (VAR).

[56] The empirical targets used to calibrate the steady state are based on the 2010-17 mean of the relevant empirical moments that we take from Statistics Norway databases. For example, we calculate the mean consumption-to-GDP ratio over this time period and calibrate our steady-state consumption share to that value. Note, however, that we set steady-state tax rates equal to their most current effective rate, i.e. the rate from 2017.

[57] Note, that in the impulse response matching exercise that we perform later we set the inflation rate to 2.5 percent which is the inflation target assumed in the impulse responses from NEMO that we are targeting.

[58] These data are based on a version of the national accounts that correspond to the aggregation level in the model. A more detailed description of how these data are constructed and the corresponding input-output tables will be published as a separate document.

Table 2: Steady-state parameters

Parameter	Description	Value
σ	Intertemporal elasticity of substitution	1.01
η_C^M, η_C^S	Elasticity of substitution across imports and domestic goods for consumption	0.5
η_I^M, η_I^S	Elasticity of substitution across imports and domestic goods for private investment	0.5
η_{CG}^M, η_{CG}^S	Elasticity of substitution across imports and domestic goods for government purchases	0.5
η_X^M, η_X^S	Elasticity of substitution across imports and domestic goods for exports	0.5
η_C	Elasticity of substitution across sectors for consumption	1.01
η_I	Elasticity of substitution across sectors for investment	1.01
η_{CG}	Elasticity of substitution across sectors for government purchases	1.01
η_X	Elasticity of substitution across sectors for exports	1.01
η_x	Foreign elasticity of substitution across imports and domestic goods	1.5
ϵ_M	Elasticity of substitution across differentiated intermediate manufacturing sector goods	6
ϵ_S	Elasticity of substitution across differentiated intermediate service sector goods	6
ϵ_f	Elasticity of substitution across differentiated imported goods	6
ϵ_X	Elasticity of substitution across differentiated export goods	6
ω	Share of liquidity-constrained households	0.3
β	Discount factor	0.9973
δ	Private capital depreciation	0.0165
δ_{KG}	Public capital depreciation	0.0201
α_C^M, α_C^S	Import content of composite consumption good	0.71, 0.20
α_I^M, α_I^S	Import content of composite private investment good	0.85, 0.11
$\alpha_{CG}^M, \alpha_{CG}^S$	Import content of composite government purchases good	1.00, 0.05
α_X^M, α_X^S	Import content of composite export good	0.22, 0.15
α_C	Service sector bias of final consumption good	0.79
α_I	Service sector bias of final private investment good	0.79
α_{CG}	Service sector bias of final government purchases good	0.92
α_X	Service sector bias of final export good	0.5
FC^M, FC^S	Fixed costs in production function	0.0929, 0.159
α^S, α^S	Capital elasticity in production function	0.41
$TD^{OI,H}$	Tax deduction, ordinary income tax households	1.6139
$TD^{OI,F,M}$	Tax deduction, ordinary income tax manufacturing sector firms	0.0545
$TD^{OI,F,S}$	Tax deduction, ordinary income tax service sector firms	0.3165
$TD^L S$	Tax deduction parameter, labor surtax and social security contribution	0.0329

used in the production of the final consumption good α_C^M, which we set to to 0.71. The import content for the composite manufacturing good used to produce the final investment good α_I^M, the final government consumption good α_{CG}^M, and the final export good α_X^M are set to 0.85, 1.00 and 0.22, respectively. The corresponding parameters in the service sector (α_C^S, α_I^S, α_{CG}^S, α_X^S) are set to 0.20, 0.11, 0.05 and 0.15. Taken together these parameters yield GDP shares of the four final goods C_t, I_t, CG_t, and X_t that are in line with the national accounts, see table 3.

The depreciation rate of public capital δ_{KG} is set to 0.0201 (approximately 8.3 percent per annum) to match the empirical government investment to GDP ratio. Since in our model the government investment to GDP ratio must equal depreciated public capital in the steady state, we can not match both empirical moments simultaneously. That is why we overestimate public capital depreciation as a share of GDP. The government wage bill as a share of GDP is calibrated to its empirical counterpart by setting the wage mark-up WG^M to 0.83. As noted in section 2.8.4 the combined import-content of the four final goods in the model does not match the aggregate import share in the national accounts. We overcome this discrepancy by setting steady-state residual imports IM^{Res} to the value necessary to exactly offset this gap in steady state. This allows us to match total imports in the economy according to the national accounts. The economic size of Norway's trading partners Y^* is set to be consistent with already-calibrated export-to-GDP ratio. Note that due to the adjustment to imports and the failure to match government capital depreciation discussed above, the change in inventories (which we use as a residual in the national accounts identity) does not match its empirical counterpart.

To match the empirical private sector capital to output ratio, we set α_S and α_M to 0.41. We set the depreciation rate of private capital δ to 0.0165 (approximately 6.8 percent per annum) to be consistent with the calibrated values of private investment and capital to GDP ratios. Net foreign debt of banks and government debt can be calibrated directly by setting the steady-state of these variables as a share of GDP to match the corresponding value in the data.

Components of the government budget that follow AR(1) processes can in most instances be calibrated directly by setting their steady-state to their corresponding value in the data. This is the case, for example, with unemployment benefits, government transfers, and the tax rates in the model.[59] We set the tax deduction parameters $TD^{OI,H} = 1.6139, TD^{OI,F,M} = 0.0541, TD^{OI,F,S} = 0.3165$ and $TD^{LS} = 0.0329$ such that the tax base to GDP ratio is in line with the data. Our model does a relatively good job at matching the tax base for the social security rate for firms despite not modeling any corresponding deduction that would allow us to match it directly.[60] In order to replicate the size of the labor income share in domestic production, we set fixed costs in the manufacturing FC^M and service FC^S sector to 0.0424 and 0.2478. We are not able to calibrate the amount of oil fund withdrawals $OILR$ directly. This is because $OILR$ is used as balancing item to make sure the balance of payments holds. As shown in table 3 our model nevertheless does a good job at matching the amount of oil fund withdrawals as a share of GDP in the data. Lump-sum taxes, which do not have any empirical counterpart, are used as a balancing item in the government budget and therefore not calibrated.

We normalize (without loss of generality) hours worked per worker per period $\overline{NpW}$ to one in steady state. This has the convenient consequence that total hours worked N equals the employment rate E in steady-state and can be interpreted as such. The private (N^P) and public (N^G) sector employment to population ratios are set to 0.48 and 0.20 to match their empirical counterparts, yielding a total employment rate of 0.68. Steady-state participation rates for the seven sub-populations are taken from KVARTS/MODAG and yield an aggregate steady-state participation rate of 71 percent, implying an equilibrium unemployment rate of 3.9 percent.

The reamining steady-state parameters are set equal to comparable parameter values used in other models and the academic literature more broadly. The intertemporal elasticity of substitution σ is set to 1.01 to approximate the logarithmic within-period utility function for consumption used in NEMO and much of the academic literature. Furthermore, we adopt from NEMO the value 2.5 for the elasticity of substitution across differentiated labor inputs (ϵ_W), which governs the steady-state wage mark-up. In the absence of any estimate from NEMO we set the share of liquidity-constrained households ω to 0.3. This is close to the value of 0.35 used in Konjunkturinstitutet's DSGE model (SELMA) of the Swedish economy (Akkaya et al., 2019) and within the range of estimates found by Campbell and Mankiw (1991).

The elasticity of substitution between domestically-produced and imported goods in the domestic economy is set to 0.5 in both the manufacturing (η_{Z^M}) and service (η_{Z^S}) sector for each of the four final goods $Z \in \{C, I, X, CG\}$. This is identical to the value used in NEMO and within the 0.25-0.75 range of values for the elasticities of substitution across different types of intermediate goods used in Statistics Norway's multisectoral SNOW model (Rosnes et al., 2019). The corresponding elasticity for the foreign economy η_x is set at 1.5. This is above the value of 0.5 used in NEMO but more in line with the rest of the literature including Konjunkturinstitutet's SELMA model (Akkaya et al., 2019) and the RAMSES model at the Swedish Riksbank (Adolfson et al., 2013). Setting η_x to the value in NEMO reduces the extent to which foreigners can substitute

[59] Further details on our methodology for calculating effective tax rate can be found in appendix 6.11.

[60] No such deduction exists in the Norwegian tax code such that a good match between the model tax base and the data is to be expected.

between imports from Norway and domestically-produced goods. This makes Norwegian export prices (and thus the real exchange rate) significantly more volatile, resulting in outcomes for inflation and other domestic variables that are inconsistent with our economic intuition.

The elasticity of substitution across sectors η_Z is set close to 1 for each of the four final goods $Z \in \{C, I, X, CG\}$. This is in line with the value used by Bergholt et al. (2019) in their model of the Norwegian economy and with much of the academic literature. The elasticity of substitution between differentiated intermediate home goods can be related to the degree of competition in the domestic economy given that $\epsilon/(\epsilon - 1)$ can be interpreted as a price markup. In line with NEMO we set the elasticity of substitution to 6 for domestically-produced manufacturing (ϵ_M) and service sector (ϵ_S) goods, imported goods (ϵ_f), and exported goods (ϵ_X), which implies a markup of 20 percent.

3.2 Dynamic parameters - TO BE UPDATED

Most of the dynamic parameters in the domestic economy block of the model are calibrated by matching model-implied impulse responses to the most recently-estimated version of NEMO (Kravik and Mimir, 2019). A small number of domestic economy dynamic parameters are calibrated directly, either because they can not be identified using the impulse responses in NEMO (e.g. the transition speed to new targets in the monetary policy reaction function) or need to fixed to ensure reasonable model dynamics following permanent shocks. As there is an exact correspondence between the foreign economy block in our model and NEMO we take the parameters of the foreign economy block directly from NEMO. Table 4 provides an overview over all dynamic parameters and the approach used to determine those parameters.

The impulse response matching procedure involves choosing 16 dynamic parameters in order to minimize the distance between the response of 10 macroeconomic variables to 5 macroeconomic shocks in our model and the most recently-estimated version of NEMO (Kravik and Mimir, 2019). The five shocks included in the impulse matching procedure are a monetary policy shock, a stationary technology shock, an external risk premium shock, a foreign demand shock, and an oil price shock. The 10 macroeconomic variables we match are mainland GDP, private consumption, private investment, oil sector investments, exports, imports, hours worked, real wages, CPI inflation, and the real exchange rate. Overall our model does a reasonable job at matching the impulse responses from NEMO. This is particularly true for the monetary policy shock, the domestic technology shock, and the shock to the external risk premium.[61] We relegate a detailed discussion of the differences in impulse responses between our model and NEMO to appendix 6.12, and in the remainder of this section focus instead on the resulting parameter estimates.

The upper bound of 0.95 imposed during the matching procedure for the habit persistence parameter for consumption (h) is binding, implying a significant degree of inertia in private consumption, which is comparable to that in NEMO where the estimate is 0.94.[62] The estimate of the habit persistence parameter for leisure (h_N) is 0.75 which is significantly higher than the value of 0.59 used in NEMO. A relatively high habit persistence parameter for leisure discourages sharp movements in hours worked and increases the real wage necessary to induce households to meet an increase in labor demand.

Given that NEMO only includes one non-oil production sector, the impulse responses from that model are

[61] We refrain from any further discussion of the technology shock in NEMO as this shock has not been included in any official publication by Norges Bank.

[62] We impose upper and lower bounds on parameters during the matching procedure to (i) restrict parameters to values that are consistent with economic theory (e.g. a lower bound of zero for habit persistence), (ii) avoid parameter estimates that deviate too much from what is typically found in the literature (e.g. an upper bound on price and wage adjustment cost parameters), or (iii) avoid estimates that result in counterintuitive results during simulations of permanent changes in fiscal policy using the non-linear model (e.g. a lower and upper bound on risk premium parameters)

Table 3: Steady-state calibration

Description	Model	Data	Target
Monetary variables (annualized rate)			
Inflation rate Norway	1.02	1.02	Yes
Nominal interest rate Norway	1.039	1.039	Yes
Inflation rate trad. part.	1.02	1.02	Yes
Nominal interest rate trad. part.	1.039	1.039	Yes
GDP components (ratio to mainland GDP)			
Consumption	0.517	0.517	Yes
Government purchases of goods and services	0.067	0.067	Yes
Government wage bill	0.169	0.169	Yes
Public capital depreciation	0.056	0.038	No
Government investment	0.056	0.056	Yes
Private investment	0.152	0.152	Yes
Oil sector investment	0.073	0.073	Yes
Total imports	0.348	0.348	Yes
Imports by importing firms	0.276	0.276	Yes
Residual imports	0.071		No
Exports	0.224	0.224	Yes
Changes in inventory	-0.037	0.052	No
Stocks (ratio to mainland yearly GDP)			
Private capital stock	2.302	2.302	Yes
Public capital stock	0.694	0.694	Yes
Private equity	3.325	5.44	No
Net foreign debt	0.504	0.504	Yes
Government Debt	0.397	0.397	Yes
Government budget (ratio to mainland GDP unless otherwise indicated)			
Unemployment benefits	0.006	0.006	Yes
Transfers	0.196	0.196	Yes
Transfers to liquidity-constrained household	0.143		No
Transfers to Ricardian household	0.054		No
Oil fund withdrawals	0.06	0.058	No
Lump-sum taxation	0.029		No
Labor surtax tax base	0.654	0.654	Yes
Ordinary income (household) tax base	0.518	0.518	Yes
Social security rate (firms) tax base	0.464	0.479	No
Corporate profit tax base	0.124	0.124	Yes
Consumption value-added tax rate	0.191	0.191	Yes
Consumption volume fees tax rate	0.063	0.063	Yes
Ordinary income tax rate	0.205	0.205	Yes
Bracket tax rate	0.028	0.028	Yes
Social security rate (households)	0.077	0.077	Yes
Social security rate (firms)	0.150	0.150	Yes
Corporate profit tax rate	0.242	0.242	Yes
Labor market (ratio to population unless otherwise indicated)			
Total employment rate	0.685	0.685	Yes
Public sector employment rate	0.204	0.204	Yes
Private sector employment rate	0.481	0.481	Yes
Unemployment rate (percent of labor force)	0.039	0.039	Yes
Labor force participation rate	0.713	0.713	Yes
Labor income share	0.494	0.471	Yes

Note: Empirical targets are based on the 2010-17 mean of the relevant empirical moments we take from Statistics Norway databases. The exception is the tax base for the social security tax (households) where data is only available from 2015, and the labor surtax tax base where data is only available from 2016. Note that we set steady-state tax rates equal to the most current effective rate, i.e. the rate from 2017.

not informative about the relative size of price adjustment costs in the domestic manufacturing (χ_M) and service sectors (χ_S) in our model. As a result, the parameters capturing the cost of changing prices in these sectors are assumed to be identical during the matching procedure. The point estimate of 977.6 is somewhat higher than the value of 669 in NEMO. The higher estimate of price stickiness may be partially compensating for the relatively weaker internal propagation mechanisms (e.g. the lack of financial frictions) in our model compared to NEMO.

Table 4: Overview on dynamic parameters - TO BE UPDATED

Parameter	Description	Value	Source
Labor market			
ρ^E	Persistence in employment	0.8	Authors' choice
Risk premia			
χ_A	Risk premium parameter for net foreign assets	0.00005	IRF matching
χ_e	Risk premium parameter for nominal exchange rate	0.01	IRF matching
χ_{GPF}	Risk premium parameter for sovereign wealth fund proxy	0.018	IRF matching
ρ^{GPF}	Persistence in wealth fund proxy	0.54	IRF matching
χ_B	Risk premium parameter on firm borrowing	0.025	Authors' choice
Habits			
h	Habit persistence in consumption utility	0.95	IRF matching
Adjustment costs			
χ_M	Adjustment cost parameter for manufacturing sector	977.6	IRF matching
χ_S	Adjustment cost parameter for service sector	977.6	IRF matching
χ_f	Adjustment cost parameter for imports	808.8	IRF matching
χ_x	Adjustment cost parameter for exports	1000	IRF matching
χ_a	Degree of indexation in price adjustments	0.91	IRF matching
χ_K	Adjustment cost parameter for investments	14.9	IRF matching
Monetary policy			
ψ_r	Persistence in interest rate	0.67	NEMO 2019
ψ_p	Interest rate response to annual inflation	0	NEMO 2019
ψ_{p1}	Interest rate response to one-quarter-ahead annual inflation	0.29	NEMO 2019
ψ_w	Interest rate response to nominal wage inflation	0.87	NEMO 2019
ψ_y	Interest rate response to output	0.24	NEMO 2019
ψ_q	Interest rate response to real exchange rate	0.02	NEMO 2019
ρ^X	Persistence in target	10	Authors' choice
Shock processes			
ρ_a	Persistence in technology shock	0.804	NEMO 2019
ρ_p	Persistence in risk premium shock	0.737	NEMO 2019
ρ_{oil}	Persistence in oil price shock	0.874	NEMO 2019
$\rho_{Y*,NTP}$	Persistence in global demand shock	0	NEMO 2019
Foreign sector			
α^{glob}	Weight of trading partner output in global output	0.1	NEMO 2019
ρ_{Y*}	Persistence in trading partners' output	0.615	NEMO 2019
$\rho_{Y*,NTP}$	Persistence in non-trading partners' output	0.926	NEMO 2019
$\rho_{\pi*}$	Persistence in foreign inflation	0.886	NEMO 2019
ρ_{r*}	Persistence in foreign interest rate	0.841	NEMO 2019
ρ_{Yf*}	Persistence in forward-looking foreign output	1	NEMO 2019
ψ_{Y_f,R^*}	Effect of real interest rate on foreign IS curve	0.757	NEMO 2019
$\psi_{Y*,oil}$	Effect of oil price on trading partners output	0.0048	NEMO 2019
$\psi_{Y*,NTP,oil}$	Effect of oil price on non-trading partners output	0.0012	NEMO 2019
$\psi_{Y*,NTP}$	Effect of non-trading partner on trading partner output	1.0994	NEMO 2019
ψ_{Y*}	Effect of trading partner on non-trading partner output	0.0114	NEMO 2019
$\rho_{\pi^*_f}$	Effect of inflation in foreign forward-looking Philips curve	0.1497	NEMO 2019
$\psi_{\pi_f Y^*}$	Effect of output in foreign forward-looking Philips curve	0.0462	NEMO 2019
$\psi_{\pi*,oil}$	Effect of oil price on foreign price level	0.0006	NEMO 2019
ψ^*_π	Responsiveness of inflation in foreign Taylor rule	1.4606	NEMO 2019
ψ^*_y	Responsiveness of output in foreign Taylor rule	0.04	NEMO 2019
ρ_{oil}	Persistence in oil price	0.2026	NEMO 2019
$\psi_{oil,Y*,glob}$	Effect of global output on oil price	4.0027	NEMO 2019
ψ_{ioil}	Effect of oil price on oil sector investment	0.0962	IRF matching
ρ_{oil}	Persistence in oil sector investment	0.7368	IRF matching

The cost of changing import prices (χ_f) is estimated at 808.8, which is slightly lower than the NEMO estimate of 830.1. A relatively low price adjustment parameter would tend to increase the pass-through of exchange rate movements to local-currency import prices and thus CPI inflation. The upper bound of 1000 imposed during the matching procedure is binding for export prices in foreign currency (χ_x). This is significantly higher than the value of 285.6 found in NEMO. In the presence of a downward-sloping demand curve, a relatively high cost of changing export prices reduces the volatility of export volumes. The cost of adjusting nominal wages

(χ_W) is estimated at 253.4 which is significantly less than the value of 666.9 estimated in NEMO. A relatively low wage adjustment cost would tend to increase the volatility of wages and dampen movements in hours worked.

The parameters determining the degree of backward indexation of prices (χ_a) and wages (χ_{aW}) are important for generating the hump-shaped response of inflation and wages to shocks that is typically observed in empirical models. The point estimate for (χ_a) is 0.91 compared to a value of 1 in NEMO.[63] The point estimate for (χ_{aW}) is 1 as in NEMO, implying full backward indexation.

The point estimate of the adjustment cost parameter for investment (χ_K) in the services and manufacturing sectors is 14.9. Due to differences in the functional form of the investment adjustment cost function this can not be directly compared to the estimate in NEMO. However, the estimate is somewhat higher than the value of 4.95 estimated for Germany in Gadatsch et al. (2016) using a similar functional form. A relatively high investment adjustment cost parameter would tend to increase the amount of inertia in investment. The estimate of the elasticity of the demand for mainland investment goods by the oil production sector (ψ_{oili}) is 0.096. We further estimate the persistence parameter of oil sector investments (ρ_{ioil}) to be 0.7368. Because in NEMO the offshore oil production sector and a onshore oil supply sector are modelled in greater detail, we are not able to compare these estimates to the NEMO parametrization.

The risk premium parameters in the model have a significant bearing on the response of the exchange rate, interest rates, and inflation in the model. The point estimate for the elasticity of the risk premium to net foreign assets (χ_A) is at the lower bound of 0.00005 imposed during the matching procedure. This is significantly lower than the 0.0016 estimated in NEMO. A relatively low risk premium tends to amplify exchange rate movements and thus imported inflation. The point estimate for the elasticity of the risk premium to movements in the nominal exchange rate is at the upper bound of 0.01.[64]. We impose an upper bound of 0.01 on this parameter despite evidence from other studies (e.g. Adolfson et al. (2008) and Akkaya et al. (2019)) that values as high as 0.6 may be appropriate. We do this to avoid hard-to-interpret short-term oscillations in the real exchange rate during simulations of permanent shocks using the nonlinear model. Finally, we estimate the role of oil price movements on the risk premium via the introduced wealth fund proxy and find a point estimate for the persistency of the wealth fund proxy (ρ^{GPF}) to be 0.54 and the elasticity of changes in the wealth fund with respect to the risk premium (χ_{GPF}) to be 0.018. The parameter governing the risk premium for firm borrowing (χ_B) is set to 0.025, which gives rise to realistic movements in firm borrowing, but still needs to be more rigorously estimated at a later point.

The parameters governing the reduced-form labor market block ($\rho^L, \phi^W, \phi^U, \rho^E$) are not estimated since NEMO cannot provide, due to a lack of modeling of the corresponding variables, any information about movements in the participation, employment and unemployment rate. At the moment, the parameters are chosen to be broadly in line with empirical evidence and economic intuition. For example, we chose ρ^E to obtain a response of employment and unemployment to a permanent government spending shock which is line with Holden and Sparrman (2018), see more details in section 4.2.1. A more rigorous estimation strategy will be discussed in a future documentation of the model.

The parameters of the monetary policy rule are from NEMO's 2017 version, but are not reported as they are not publically available. In the presence of permanent shocks, see section 2.6.1, there is a role for the parameters governing the speed at which monetary policy moves to new targets for output and nominal interest rate. Due to our matching procedure relying only on temporary shocks we can not identify these directly. Instead, we set both ρ^Y and ρ^R to 10, implying a rather slow transition to new targets. This way we ensure that the movements in the targets (necessary to settle at a new steady state) only play a role in the long-run.

[63]In NEMO the degree of backward indexation is set equal to 1 and not estimated

[64]In NEMO this parameter is set to zero.

Apart from fiscal policy shocks we are considering five additional shocks in this paper, each following an auto-regressive process. The parameter governing the degree of auto-regression (ρ_a for a technology shock, ρ_p for a risk premium shock, ρ_{oil} for an oil-price shock and $\rho_{Y^*,NTP}$ for a global demand shock) directly follow from NEMO and are given in table 4. The same table provides an overview of all dynamic parameters in the model, including the complete set of foreign sector parameters that correspond one to one to our parameters and can thus be directly copied.

3.3 Fiscal sector parameters

The model contains a number of dynamic parameters that relate to the tax and spending rules introduced in section 2.6.3 and 2.6.4. The autoregressive parameters ρ_X in (48) and (49) capture the persistence of the various spending components and tax rates and can be freely chosen by the model user depending on the desired smoothness of these variables.[65] Another set of parameters ϕ^X measure the responsiveness of spending components and tax rates to deviations in the the government debt-to-gdp ratio from its steady-state value. These are only relevant if debt is used as a (temporary) financing instrument, and can be freely chosen by the model user. Finally, the spending weights ϕ_n in equation (50) are specified by the model user when running a public investment shock to capture the time-to-build profile of the relevant project.

The steady-state value of the scale-up factor on dividend taxation, $\alpha^{OI,H}$ is set to 1.44, in accordance with the statuary scale-up factor from the Norwegian tax code. The fixed rate of return of the oil fund is set to the steady-state riskless return on foreign bonds $\overline{R}^*$.

4 Simulations

In this section we will present some simulation results to illustrate the properties of the model. Section 4.1 will examine the impulse responses of the main macroeconomic variables in the model to selected macroeconomic shocks. In section 4.2 we conduct a number of fiscal policy experiments, including simulations to illustrate the fiscal multipliers in the model and simulations that illustrate the effect of permanent changes to fiscal policy, for example a permanent increase in government spending or public employment. The simulations illustrate possible ways the model can be used to study the quantitative implications of changes in fiscal policy.

4.1 Impulse responses to selected macroeconomic shocks

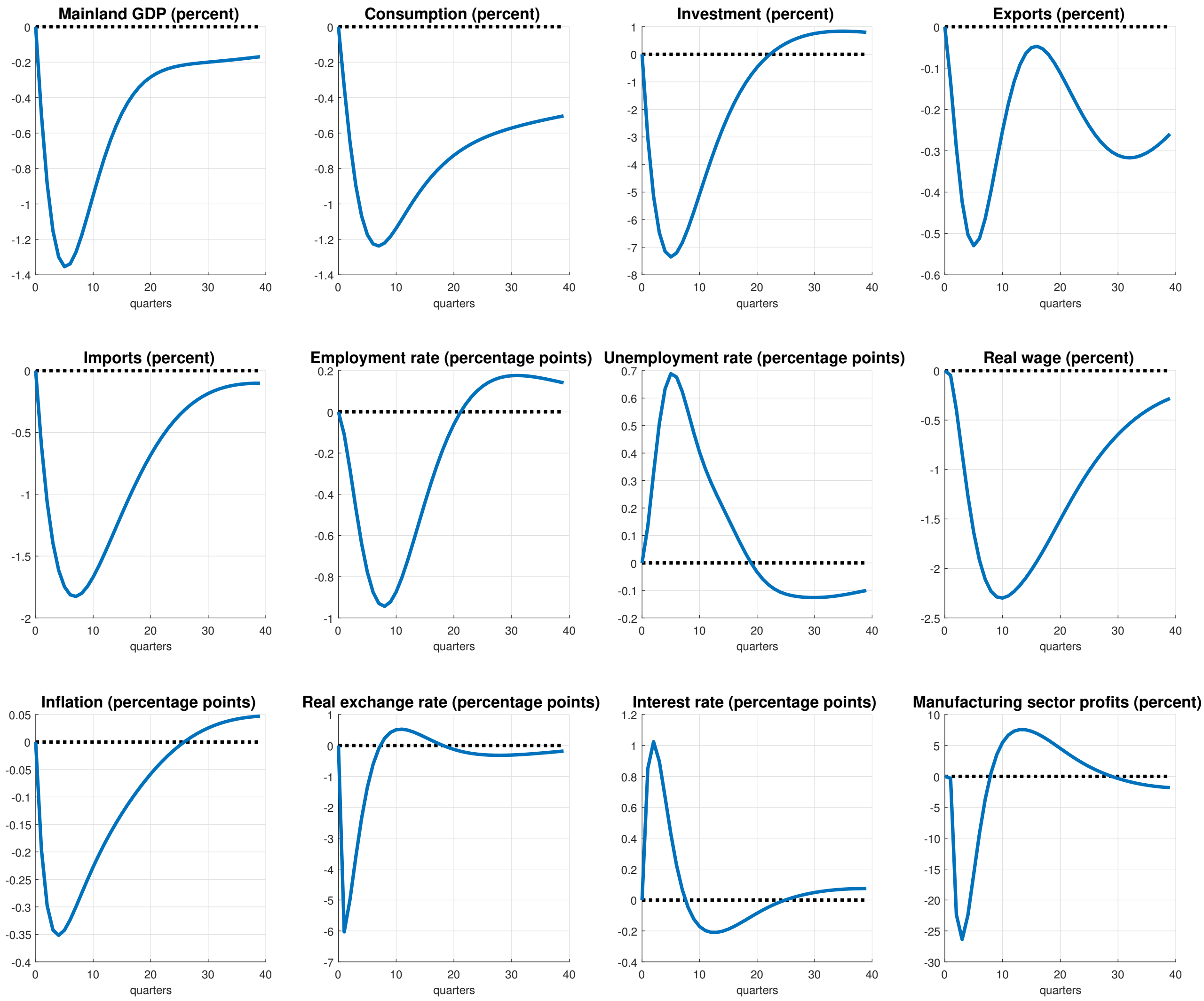
This section presents impulse response a monetary policy shock (i.e. an increase in policy interest rate), a shock to the external risk premium (i.e. a depreciation of the real exchange rate), and a technology shock in the manufacturing and service sectors (i.e. a shock to total factor productivity).

4.1.1 Monetary policy shock

Figure 4 shows the response of the main macroeconomic variables to a 1 percentage point increase in the nominal interest rate. Due to price stickiness, higher nominal interest rates are accompanied by an increase in the real interest rate. The increase in the real interest rate has a dampening effect on aggregate demand in the economy. Households respond to higher deposit rates by increasing savings, thus resulting in a decline in private consumption. Firms, on the other hand, respond to higher lending rates by cutting back on private investment.

[65] For example, a model user might be interested in simulating a sudden increase in the tax rate from one period to the another, implying setting the relevant autoregressive parameter to zero. In another run the user may want to study a gradual increase in fiscal spending over a number of periods and thus set the relevant autoregressive parameter to a value between zero and one.

Figure 4: Impulse responses to a monetary policy shock



Higher nominal interest rates increase capital inflows, putting upwards pressure on the nominal and (because of price stickiness) real exchange rate. The stronger real exchange rate undermines competitiveness by pushing up the foreign-currency price of exports, leading to a decline in export demand. The fall in both domestic and external demand results in a 1.4 percent decline in mainland output which reaches its trough after 5 quarters. This is in line the peak decline in mainland output in the most recently-estimated version of NEMO (Kravik and Mimir, 2019), and broadly consistent with the findings in Bjørnland and Halvorsen (2014) who find a peak decline in GDP of 0.7-1.8 percent after 8 quarters.[66]

Firms respond to lower aggregate demand by reducing labor demand. This results in a decline in total hours worked and employment, and an increase in unemployment. Deteriorating competitiveness and higher borrowing costs put downward pressure on the profitability of firms in the exposed sector which, combined with the increase in unemployment, leads to a decline in the real wage negotiated during wage bargaining between firms in the manufacturing sector and labor unions.

[66] Note that the shock required to generate a one percentage point increase in the nominal interest rate will depend on contemporaneous movements in the variables that enter the monetary policy rule. For this reason, the impulse responses shown in figure 4 differ from those in figure 9 where, for calibration purposes, we impose that the magnitude of the monetary policy is the same as in the NEMO.

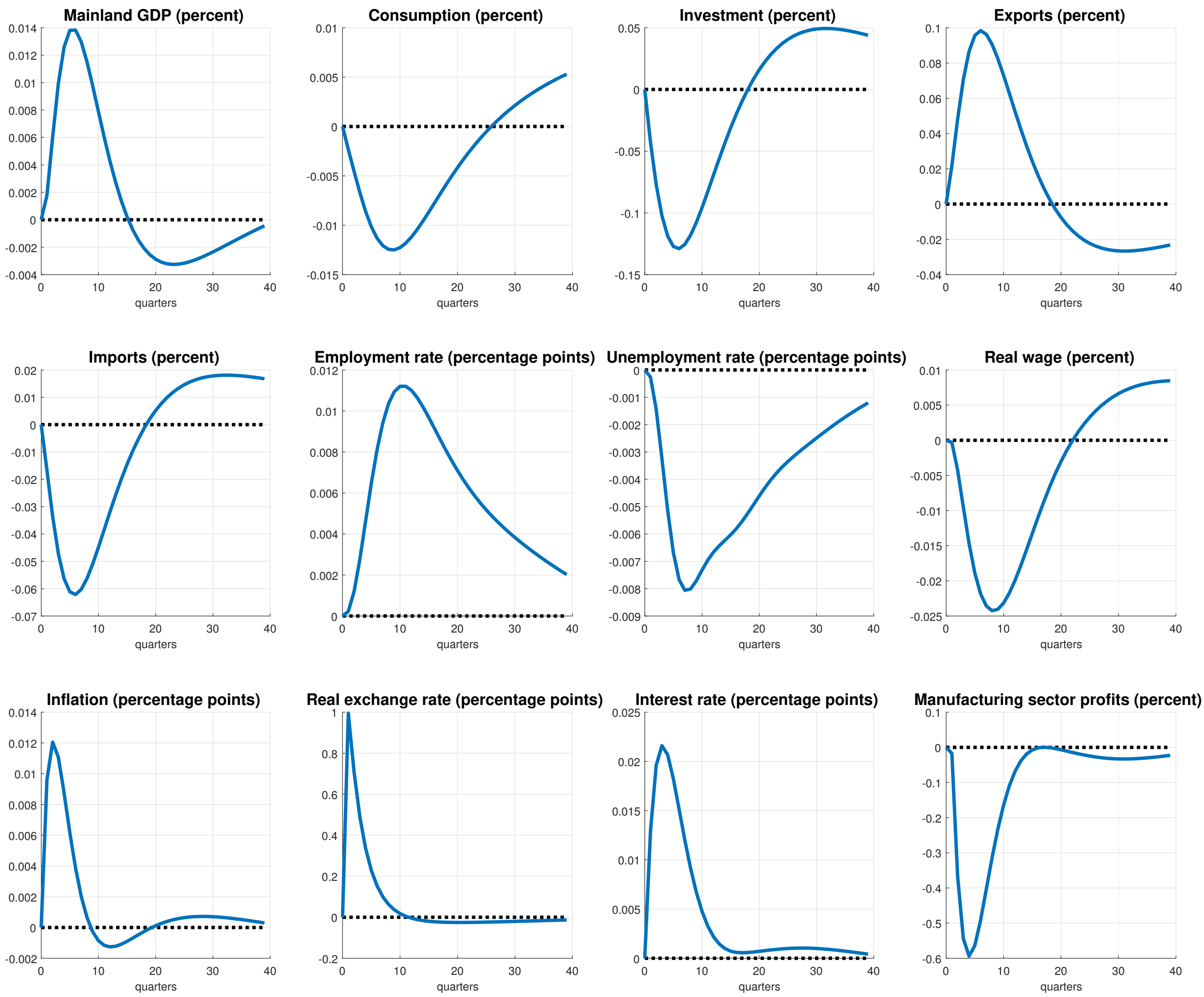
Lower wages reduce firms' marginal costs. This combined with lower import prices due to the appreciating exchange rates results in a peak decline in inflation of 0.35 percentage points after 5 quarter. This is slightly more than in NEMO but in line with the empirical evidence in Bjørnland and Halvorsen (2014) who find a peak decline in inflation of 0.1-0.8 percent after 8 quarters.

4.1.2 Shock to the external risk premium

Figure 5 shows impulse responses following a shock to the external risk premium. An increase in the external risk premium increases the return on foreign relative to domestic assets. This reduces the demand for Norwegian kroners and hence induces a weakening (depreciation) of the nominal and (because of stick prices) real exchange rate. The shock is normalized such that it induces a 1 percent depreciation of the real exchange rate on impact.

The real exchange rate depreciation results in an increase in import prices that causes an increase in CPI inflation and triggers the central bank to increase the interest rate. The increase in the policy rate will, through the same channels as discussed in section 4.1.1, depress private consumption and private investment, hence putting downward pressure on aggregate demand. This is more than offset, however, by the decline in the foreign-currency price of export triggered by the depreciation of the real exchange rate, which results in an increase in export demand. This, coupled with a substitution away from imports due to the increase in im-

Figure 5: Impulse responses to a temporary increase in the external risk premium



port prices, helps ensure that mainland output initially increases before falling below its initial steady-state level.

The expansion in output triggers an increase in labor demand, with the result that total hours worked and employment increases while unemployment falls. Real wages fall, however, as the profitability of firms in the exposed sector declines. The decline in profitability reflects higher debt servicing costs which more than offset the improvement in competitiveness resulting from the depreciation of the real exchange rate.

4.1.3 Technology shock

Figure 6 shows the impulse responses of key macroeconomic variables following a shock to total factor productivity in the manufacturing sector (blue line) and the service sector (red line). The shocks are scaled in such a way that total factor productivity in the overall economy increases by 1 percent on impact.[67]

An increase in total factor productivity makes it possible for firms to produce the same amount of output with fewer inputs. It can thus be interpreted as a decline in marginal costs, which tends to increase firm profitability in the affected sector. If the technology shock materializes in the wage-setting manufacturing sector the increase in manufacturing-sector profits is shared with workers through wage bargaining, with the result that real wages increase. If the technology shock manifests itself in the wage-following service sector, real wages fall. This occurs because, with sticky prices, aggregate demand does not adjust immediately to the new productivity level. Hence firms require less labor and unemployment increases. The dampening effect of higher unemployment on labor union's wage demand more than offsets the positive effect on wages from higher manufacturing sector profits (which in this scenario results from the real exchange rate depreciation triggered by the decline in interest rates).[68]

The decline in marginal costs induces firms to cut prices. Hence CPI inflation falls if the increase in total factor productivity originates in the service sector. On the other hand, if the technology shock occurs in the manufacturing sector the increase in real wages pushes up marginal costs in the service sector, with the result that CPI inflation (which consists primarily of service sector goods, see table 2 for further details) increases slightly after a few periods.

The decline in inflation when the technology shock occurs in the service sector induces the central bank to cut the policy rate. This reduces the return of domestic bonds relative to foreign assets and triggers a depreciation of the nominal and (because prices are sticky) real exchange rate. If the shock originates in the manufacturing sector, however, interest rates increase slightly on account of the rise in inflation, with the result that the real exchange rate appreciates in the short-run.

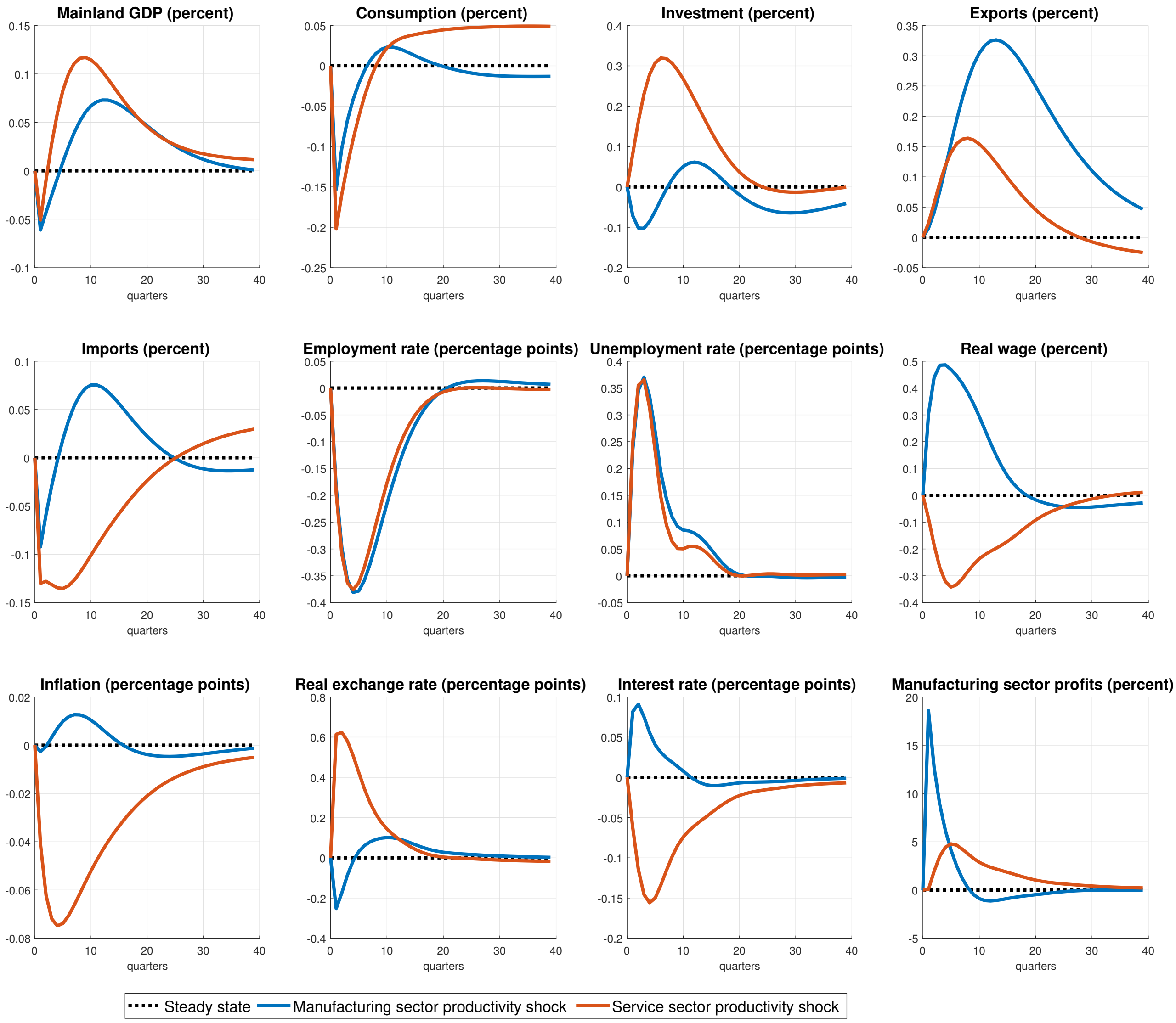
In the case where the increase in total factor productivity originates in the service sector, declining real interest rates put upward pressure on private investment. Investment oscillates around zero, however, in the case where the technology shock originates in the manufacturing sector due to the lack of movement in real interest rates.

The decline in hours worked, which (in the case where the shock originates in the service sector) is compounded

[67] Economy-side total factor productivity is defined as the output-weighted sum of sector-specific total factor productivity. Because the service sector is nearly 6 times as large as the manufacturing sector the shock required to generate a 1 percent increase in total factor productivity in the overall will also be smaller.

[68] The result that real wages decline following a technology shock in the sheltered service sector is at first glance at odds with the discussion in the Holden III commission (NOU, 2013), where it is argued that real wages increase due to the improvement in manufacturing sector profitability. They do not discuss how movements in unemployment may affect this outcome. In subsequent discussions Professor Holden noted that this is because he believes the effect of higher productivity on unemployment itself is unclear.

Figure 6: Impulse responses to a temporary increase in total factor productivity in the manufacturing and service sector



by the decline in real wages, results in lower real labor income. Lower real labor income forces liquidity-constrained households to cut back on their consumption with the result that overall consumption falls. As prices slowly adjust, aggregate demand starts to increase, prompting firms to increase labor demand and unwind the initial decline in employment, labor income, and consumption by liquidity-constrained households. This, coupled with a positive wealth effect for Ricardian households stemming from the increase in production when the productivity shock materializes in the service sector, results in a gradual recovery in aggregate consumption back towards its initial level.

The increase in total factor productivity results in an unambiguous increase in exports, regardless of whether the shock originates in the manufacturing and service sector. This is driven by a decline in the foreign-currency price of Norway's exports. If the technology shock originates in the service sector this decline in the foreign-currency export price follows directly from the depreciation of the real exchange rate, while if the shock originates in the manufacturing sector it is driven by the decline in the price of manufacturing sector goods used to produce the final export good.[69] Imports decline in the short run on account of the decline in consumption. In the case where the increase in total factor productivity originates in the service sector the decline in imports is amplified by a substitution toward domestic goods caused by the depreciation of the real exchange rate.

The initial decline in consumption demand leads to a short-term decline in output, which is quickly reversed as consumption recovers and net exports increase. Output is significantly higher if the technology shock originates in the service sector than if it originates in the manufacturing sector. This reflects the additional boost to aggregate demand from higher private investment which in turn is driven by the movement in interest rates.

4.2 Fiscal policy simulations

In this section we simulate the effect of fiscal policy shocks on the economy. We focus on permanent rather than transitory shocks as changes to fiscal policy are often, but by no means always, structural in nature. Examples include a change in the structure of taxation or permanent changes to the level of social benefits.[70]

4.2.1 Permanent increase in government spending

Figure 7 illustrates the impact of a permanent one percent of GDP increase in government purchases of goods and services (blue line), the government wage bill (red line), and targeted transfers to liquidity-constrained households (green line). The increase in government spending is financed in each case by an increase in the labor surtax that responds endogenously such that the government budget is balanced in every period. The three simulations have quite different effects on the economy. The increase in government purchases is a pure increase in aggregate demand, the government employment shock affects mainly the labor market and household income, while the transfer shock is a redistribution of income from Ricardian to liquidity-constrained households since the labor surtax used to finance the transfers are levied also on Ricardians.[71]

The increase in government spending results in an immediate increase in mainland GDP in all three simulations. The effect is direct following an increase in government purchases and government employment, as both of these are components of GDP. The effect is more indirect (and smaller) following an increase in targeted transfers to liquidity-constrained households. This is because a significant share of the increase in transfers is immediately returned to the government budget through higher tax revenue, so that the net increase in transfers is significantly muted. The taxation of transfer explains why the long-run increase in the labor surtax rate necessary to balance the budget is lower following an increase in transfer to liquidity-constrained households compared to the other scenarios. In the medium- to long-run the increase in government spending is crowded out by a decline in private sector output. This is particularly true in the case of an expansion in public employment, as the resulting decrease in unemployment triggers a sizeable increase in real wages that reduces private employment (not shown) and private sector output.[72]

To understand the transmission channels of these three fiscal shocks it is instructive to look at movements in the demand components of GDP. Private consumption falls following an increase in government purchases and an expansion of public employment because of a decline in after-tax wages (not shown). Consumption increases, on the other hand, following an increase in targeted transfers, as the additional income is immediately

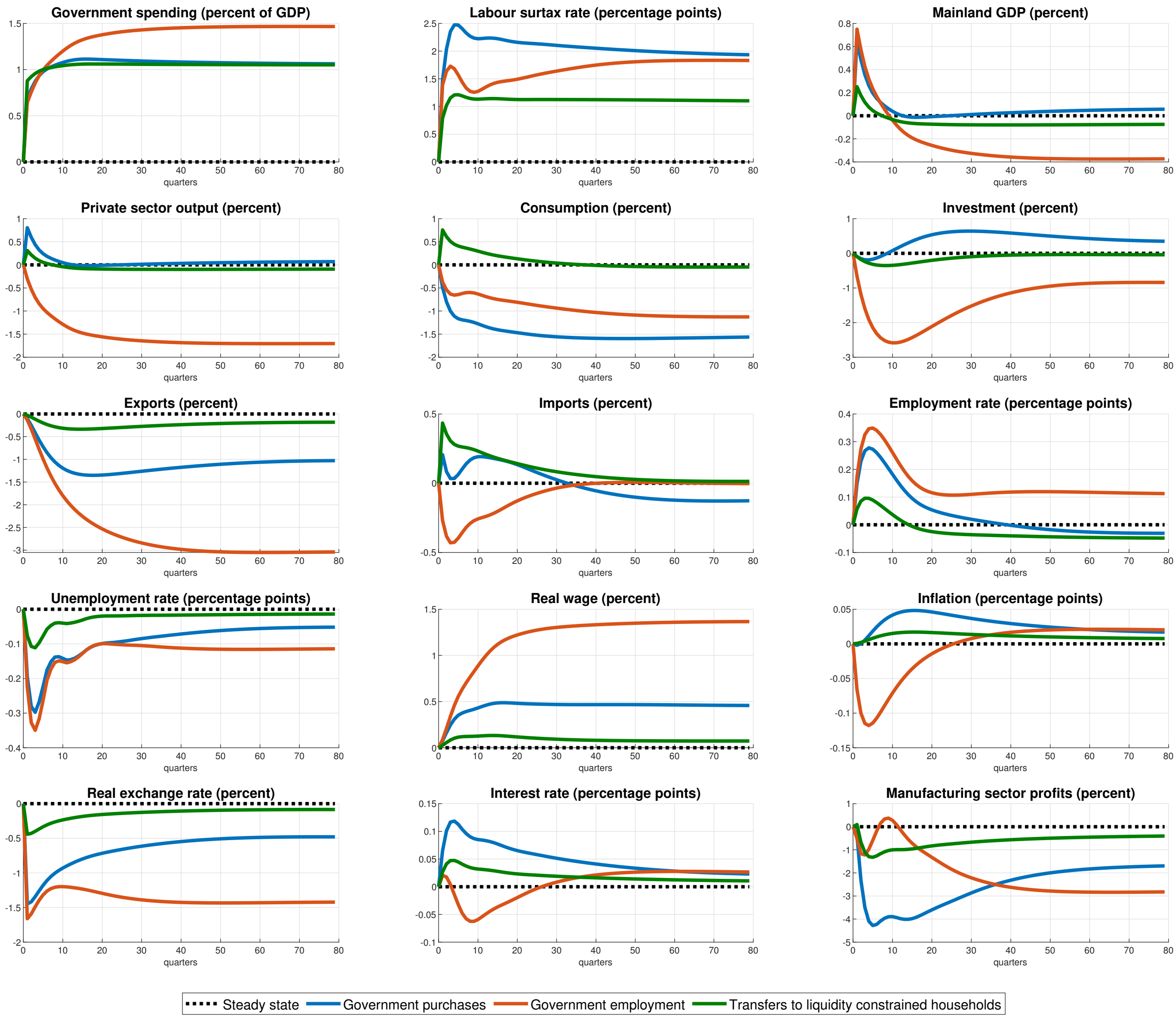
[69] The latter effect is also present when the shock originates in the service sector. However, because the service sector is much bigger than the manufacturing sector the magnitude of the shock required to increase productivity in the overall economy by 1 percent is much smaller. Hence, the decline in the price of service sector goods used to produced the final export good is relatively modest.

[70] Fiscal policy simulations are deterministic (rather than stochastic), i.e. with perfect foresight and no uncertainty. This is because the solution method underlying stochastic simulations typically require shocks to be temporary so that the model economy can return to its original steady state.

[71] A real-world example of a transfer shock to liquidity-constrained households could be an increase in the minimum pension level.

[72] We do not model potential positive spillovers effects from higher public employment on the private sector. The response of mainland GDP in our model should therefore be considered a lower bound.

Figure 7: Permanent increase in government purchases financed by the labor surtax



spent by liquidity-constrained households who by assumption consume all of their disposable income each period. In all three scenarios private consumption trends downwards in the medium-run as Ricardian households gradually (due to consumption habits) adjust their consumption to reflect the higher tax burden.

Private investment falls initially in all three scenarios due to higher interest rates. The decline in private sector employment following an expansion in public employment reduces the marginal productivity of capital, putting additional downward pressure on investment in this scenario. In the medium- to long-run investment stays subdued following an expansion in public employment due to the persistent decline in private sector output. Following an expansion of government purchases of good and services, however, investment increases in the long-run as the increase in real wages induces firms to become more capital intensive.

Exports decline across all three simulations due to an appreciation of the real exchange rate that increases the foreign-currency price of exports, and an increase in the real wage that increase marginal costs. Imports increase following an expansion in government purchases of goods and services and the increase in private consumption triggered by higher transfers to liquidity-constrained households. On the other hand, the significant fall in private investment that follows an expansion in public employment results in a decline in imports.

The increase in government spending triggers an increase in employment and a decline in unemployment across all three simulations. The increase in aggregate employment is direct following an increase in public employment. However, the response of employment is more indirect (and muted) following an expansion in government purchases of goods and services and an increase in transfers to liquidity-constrained households, which triggers an outward shift in the private sector labor demand curve. Following a permanent increase in government purchases of goods and services, the unemployment rate declines by 0.3 percentage points after 3 quarters. The peak response in unemployment is broadly consistent with empirical work by Holden and Sparrman (2018) although the decline in the unemployment rate in their study is significantly slower and more persistent than in our model.

Despite a decline in manufacturing sector profits, real wages increase across all three simulations. This reflects the decline in unemployment which increase the labor unions' reference utility and encourages them to increase their wage claims. The increase in real wages adds to the government wage bill and explains why government spending to GDP increases more following an expansion in government employment that in the other scenarios.

The response of inflation across the three scenarios follows broadly developments in private sector output. In particular, domestic firms raise their prices in response to the increase in demand resulting from an expansion in government purchases of goods and services and an increase in transfers to liquidity-constrained households, but reduce prices in response to the crowding-out of private output following an expansion of public employment. However, in all three scenarios the response of inflation is relatively small. This reflects the offsetting effect of a decline in import prices resulting from the appreciation of the real exchange rate following the increase in government purchases and targeted transfers, and the increase in marginal costs resulting from the rise in real wages following an expansion in government employment. As a result, the nominal interest rate is broadly unchanged.

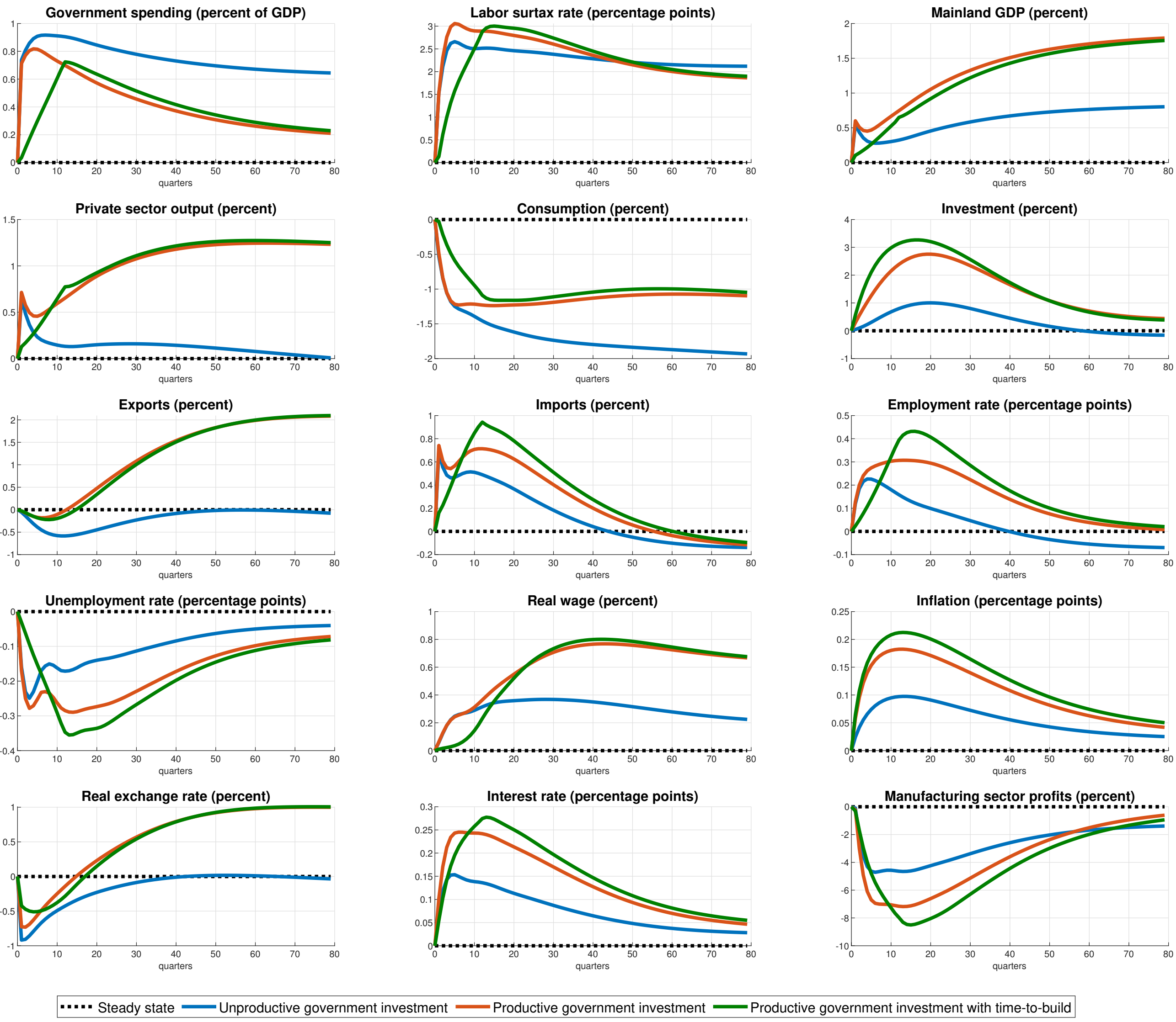
Figure 8 simulates the impact of a permanent one percent of GDP increase in government authorized investment financed by an increase in labor surtaxes. The first simulation (blue line) assumes that the additional public capital is unproductive in the sense that it does not increase firms' total factor productivity. The second simulation (red line) assumes that the additional public capital increases total factor productivity, while the third simulation (green line) assumes additionally that it takes 12 quarters (time-to-build) to complete the public investment project and for the additional productive public capital to become available to firms.[73]

The increase in authorized public investment leads to an increase in government spending paid for by an increase in the labor surtax rate. In the two scenarios where there is no time-to-build (red and blue lines) this increase in spending materializes after one period, while in the scenario with time-to-build of 12 quarters (green line) the increase in government spending and the labor surtax rate is phased in gradually over the period it takes to complete the project.

The increase in government authorized investment is first and foremost a shock to aggregate demand. Hence private sector output and mainland GDP increases across all three simulations. The shock to aggregate demand increases labor demand and employment and reduces unemployment. The increase in employment is immediate when there is no time-to-build (blue and red lines) and gradual when the increase in authorized public investment is phased in gradually. The decline in unemployment puts upward pressure on real wages (lower unemployment encourages unions to increase their wage demands during wage bargaining) with the result that the initial increase in employment is gradually reversed. In the scenario where public capital is unproductive

[73]The parameters κ^M and κ^S that determine the extent to which public capital increase total factor productivity are set to 0 in the simulation with unproductive capital (blue line) and 0.05 in the simulations with productive public capital (red and green lines).

Figure 8: Permanent increase in government investment financed by the labor surtax



(blue line) employment falls below its initial level in the medium- to long-run (not shown) as higher labor taxes pushes workers to leave the labor force, triggering a permanent decline in the unemployment rate that encourages unions to keep demanding higher real wages. In the scenario where public capital is productive (red and green lines) the increase in total factor productivity encourages firms to keep employment above its initial level in the long run, putting additional downward pressure on unemployment. The permanently lower level of unemployment coupled with a gradual improvement in manufacturing sector profits in the long-run (not shown) puts upward pressure on real wages.

Over time the increase in government investment is partially crowded out by an increase in real wages and higher nominal interests that result in a gradual decline in private sector output. In the scenario where public capital is unproductive (blue line) private sector output falls below its initial level in the long-run (not shown) as permanently higher real wages put a dampener on labor demand and employment. Mainland GDP keeps increasing, however, due to depreciation of the augmented public capital stock whose treatment in the national accounts statistics does not depend on whether the additional public capital is productive or not. In the scenarios where public capital is productive (red and green lines) the increase in firms' total factor productivity gradually encourages private sector firms to expand production (see below). As a result, private sector output keeps increasing in the medium- and long-run, increasing the overall size of the mainland economy.[74]

Consumption falls in all three scenarios due to the decline in after-tax wages. The increase in private sector output boosts private sector investment across all three simulations. In the simulations where public capital is productive (red and green lines) the increase in investment is amplified by the increase in total factor productivity and by the large increase in real wages which encourage firms to become more capital intensive. The increase in investment coupled with the appreciation of the real exchange rate is sufficient to trigger an increase in imports. Exports fall initially due to the appreciated real exchange rate, but gradually recover as the real exchange rate depreciation is reversed. In the scenarios where public capital is productive (red and green lines) higher total factor productivity lowers marginal costs and boosts the profitability of final goods exports, encouraging them to increase exports beyond their initial value in the medium- to long-term.

The increase in aggregate demand results in a persistent increase in inflation across all three scenarios. The increase is higher in the scenarios where public capital is productive (red and green lines) as the appreciation of the real exchange rate (and resulting decline in imported inflation) is not as pronounced in those simulations. The increase in inflation triggers a modest increase in the nominal interest rate.

5 Summary and future work

In this paper we have presented a microfounded macroeconomic model for fiscal policy analysis in Norway, which we have called NORA. Unlike most DSGE models that have been developed to analyse monetary policy, our framework features a rich government sector including the most important sources of government revenue and public expenditures in Norway. We also modify the standard framework significantly, most notably by characterizing wage setting in the economy as the outcome of Nash bargaining between firms in the exposed sector of the economy and a labor union, to better describe the functioning of the Norwegian economy. The model thus allows for a detailed analysis of the transmission channels of various fiscal policy instruments in Norway and the effect of alternative assumptions regarding financing of these measures.

The model presented here is still work in progress. A full estimation of the model is ongoing and will be presented at a later date. Theoretical extensions being considered include (but are not limited to) adding an oil services industry as recommended by Bjørnland et al. (2019) to better capture the effects of changes in the oil price on the Norwegian economy, allowing for steady-state growth in the model, and incorporating public ownership of firms.

The model described in this report is part of an ongoing project at the Ministry of Finance to develop a microfounded model for fiscal policy analysis. The project is expected to run till end-2019. This report is part of the regular reporting on progress with the modelling project to the Ministry of Finances's Advisory Panel on Macroeconomic Models and Methods.

[74]The increase in public investment raises the steady-state level of mainland GDP by 0.9 percent in the scenario where public capital is not productive (due to higher public capital depreciation) and by 2 percent in the scenarios where public capital is productive. It takes approximately 50 years for the economy to reach its new steady-state.

6 Appendix

6.1 First-order conditions of the Ricardian household

1. First-order conditions with respect to deposits: $\frac{\partial L}{\partial DP_t^r} = 0$ yields

$$\begin{aligned} 0 &= \beta^{t+1} E_t \left[\frac{\lambda_{t+1}}{\pi_{t+1}} (1 + (R_t - 1)(1 - \tau_{t+1}^{OI,H})) \right] - \beta^t \lambda_t \\ \Leftrightarrow \lambda_t &= \beta E_t \left[\frac{\lambda_{t+1}}{\pi_{t+1}} (1 + (R_t - 1)(1 - \tau_{t+1}^{OI,H})) \right] \end{aligned} \tag{57}$$

2. First-order conditions with respect to consumption: $\frac{\partial L}{\partial C_t^r} = 0$ yields

$$\begin{aligned} 0 &= Z_t^U (C_t^r - hC_{t-1}^r)^{-\sigma} \frac{1}{(1-h)^{-\sigma}} - \lambda_t (1 + \tau_t^C + \tau_t^f) \\ \lambda_t &= \frac{Z_t^U (C_t^r - hC_{t-1}^r)^{-\sigma}}{(1 + \tau_t^C + \tau_t^f)(1-h)^{-\sigma}} \end{aligned}$$

3. First-order conditions with respect to stocks:
We first note, that the return on holding a stock $S_t^{M,r}$ (and of $S_t^{S,r}$ due to no-arbitrage) is given by

$$r_t^S = \frac{\left[(1 - \tau_{t+1}^D)(P_{t+1}^{e,M} - \frac{P_t^{e,M}}{\pi_{t+1}} + DIV_{t+1}^M) + RRA_{t+1} \frac{P_t^{e,M}}{\pi_{t+1}} \tau_{t+1}^D \right] S_t^{M,r}}{P_t^{e,M} S_t^{M,r}}$$

with the numerator capturing total income associated with owning the stock and the denominator capturing the value of the principal, i.e. the stock. To enable a better comparison with the gross nominal interest rate on deposits, we define

$$R_t^S := 1 + r_t^S \pi_{t+1}$$

as the gross nominal return on stocks. The first-order derivative $\frac{\partial L}{\partial S_t^{M,r}} = 0$ then yields

$$\begin{aligned} \beta^t \lambda_t P_t^{e,M} (1 + F_t^S) &= \beta^{t+1} E_t \left[\lambda_{t+1} \left(\frac{P_t^{e,M}}{\pi_{t+1}} + (1 - \tau_{t+1}^D)(P_{t+1}^{e,M} - \frac{P_t^{e,M}}{\pi_{t+1}} + DIV_{t+1}^M) + RRA_{t+1} \frac{P_t^{e,M}}{\pi_{t+1}} \tau_{t+1}^D \right) \right] \\ \lambda_t (1 + F_t^S) &= \beta E_t \left[\lambda_{t+1} \left(\frac{1}{\pi_{t+1}} + (1 - \tau_{t+1}^D)(P_{t+1}^{e,M} - \frac{P_t^{e,M}}{\pi_{t+1}} + DIV_{t+1}^M)/P_t^{e,M} + RRA_{t+1} \frac{1}{\pi_{t+1}} \tau_{t+1}^D \right) \right] \\ \lambda_t (1 + F_t^S) &= \beta E_t \left[\frac{\lambda_{t+1}}{\pi_{t+1}} \left(1 + \pi_{t+1} (1 - \tau_{t+1}^D)(P_{t+1}^{e,M} - \frac{P_t^{e,M}}{\pi_{t+1}} + DIV_{t+1}^M)/P_t^{e,M} + RRA_{t+1} \tau_{t+1}^D \right) \right] \\ \lambda_t (1 + F_t^S) &= \beta E_t \left[\frac{\lambda_{t+1}}{\pi_{t+1}} R_t^S \right] \end{aligned} \tag{58}$$

Subtracting equation (58) with equation (57) yields $F_t^S = E_t \left[\frac{\Delta_{t+1}}{\pi_{t+1}} \left(R_t^S - (1 + (R_t - 1)(1 - \tau_{t+1}^{OI,H})) \right) \right]$. Hence, the gap between the after-tax return on stocks and deposits is a function of financial fees F_t^S. In particular, absent any uncertainty about the future it holds that the gap in real returns equals F_t^S / Δ_{t+1}.

In order to further simplify equation (58) we resort to certainty equivalence that holds to a first-order approximation and in perfect foresight.

$$\Leftrightarrow \quad \lambda_t(1+F_t^S)P_t^{e,M} = \beta\lambda_{t+1}\left(\frac{P_t^{e,M}}{\pi_{t+1}} + (1-\tau_{t+1}^D)(P_{t+1}^{e,M} - \frac{P_t^{e,M}}{\pi_{t+1}} + DIV_{t+1}^M) + RRA_{t+1}\frac{P_t^{e,M}}{\pi_{t+1}}\tau_{t+1}^D\right)$$

$$\Leftrightarrow \quad P_t^{e,M} = \frac{1}{1+F_t^S}\Delta_{t+1}\left((1-\tau_{t+1}^D)P_{t+1}^{e,M} + \tau_{t+1}^D\frac{P_t^{e,M}}{\pi_{t+1}} + DIV_{t+1}^M(1-\tau_{t+1}^D) + RRA_{t+1}\frac{P_t^{e,M}}{\pi_{t+1}}\tau_{t+1}^D\right)$$

$$\Leftrightarrow \quad P_t^{e,M}\left(1 - \frac{1}{1+F_t^S}\frac{\Delta_{t+1}}{\pi_{t+1}}\tau_{t+1}^D(1+RRA_{t+1})\right) = \frac{\Delta_{t+1}}{1+F_t^S}\left((1-\tau_{t+1}^D)P_{t+1}^{e,M} + DIV_{t+1}^M(1-\tau_{t+1}^D)\right)$$

$$\Leftrightarrow \quad P_t^{e,M}\frac{1+F_t^S - \Delta_{t+1}/\pi_{t+1}\tau_{t+1}^D(1+RRA_{t+1})}{\Delta_{t+1}(1-\tau_{t+1}^D)} = P_{t+1}^{e,M} + DIV_{t+1}^M$$

The above equation can be integrated forward to obtain

$$P_t^{e,M} = \sum_{j=1}^{\infty}\frac{1}{R_{t+j}^e}DIV_{t+j}^M$$

where $R_{t+j}^e = \prod_{l=1}^{j}\frac{1+F_{t+l-1}^S - \Delta_{t+l}/\pi_{t+l}\tau_{t+l}^D(1+RRA_{t+l})}{\Delta_{t+l}(1-\tau_{t+l}^D)}$.
3b. $\frac{\partial L}{\partial S_t^{S,r}} = 0$ yields
Completely analogously, we can derive, that

$$P_t^{e,S} = \sum_{j=1}^{\infty}\frac{1}{R_{t+j}^e}DIV_{t+j}^S$$

6.2 Wage bargaining

Defining the Nash product as $\Phi^{NP}(W) := (V-v_0)^\gamma(\Pi_t^M)^{1-\gamma}$, we take the first derivative of it and set it to zero to obtain a condition which the Nash bargaining wage needs to fulfill

$$\begin{aligned} & \frac{\partial}{\partial W}\Phi^{NP}(W) = 0 \\ \Leftrightarrow \quad & \gamma(V-v_o)^{\gamma-1}\frac{\partial V}{\partial W}(\Pi_t^M)^{1-\gamma} + (1-\gamma)(V-v_0)^\gamma(\Pi_t^M)^{-\gamma}\frac{\partial}{\partial W}\Pi_t^M = 0 \end{aligned}$$

Dividing by each component of the Nash product yields

$$\frac{\partial}{\partial W}\Phi^{NP}(W) = \gamma\frac{\frac{\partial V}{\partial W}}{V-v_o} + (1-\gamma)\frac{\frac{\partial}{\partial W}\Pi_t^M}{\Pi_t^M} = 0 \tag{59}$$

which can be rearranged to obtain

$$\frac{\frac{\partial V}{\partial W}}{V-v_o} = -\frac{1-\gamma}{\gamma}\frac{\frac{\partial}{\partial W}\Pi_t^M}{\Pi_t^M}.$$

Applying the functional forms of union utility and firm profits then yield

$$\frac{W^{-\sigma^N}}{V(W)-v_o} = \frac{1-\gamma}{\gamma}\frac{(1+\tau_t^{SS,F})N_t^M}{\Pi_t^M(W)}.$$

Equation (59) represents the necessary first-order condition for the Nash bargaining solution. The sufficient condition is given by the second-order derivative being negative, i.e.

$$\frac{\partial^2}{\partial W^2}\Phi^{NP}(W) < 0. \tag{60}$$

Given this, it can be observed that any increase in $\frac{\frac{\partial V}{\partial W}}{V-v_o}$ (for example caused by increase in the reference utility) is accompanied by an increase in the equilibrium wage as this will reduce $\frac{\partial}{\partial W}\Phi^{NP}(W)$ such that equation (59) holds again. This is because $\frac{\partial}{\partial W}\Phi^{NP}(W)$ falls with the wage, see equation (60).
Equivalently any increase in the term $\frac{\frac{\partial}{\partial W}\Pi_t^M}{\Pi_t^M}$ will lead to an increase in the equilibrium wage. Expanding the term yields

$$\begin{aligned}\frac{\frac{\partial}{\partial W}\Pi_t^M(W)}{\Pi_t^M(W)} &= \frac{-(1+\tau_t^{SS,F})N_t^M}{\Pi_t^M(W)} \\ &= \frac{-(1+\tau_t^{SS,F})N_t^M}{P_t^m Y_t^M - (1+\tau_t^{SS,F})WN_t^M - \delta P_t^i K_t^M - (R_{t-1}^L\phi_{t-1}^m - 1)\frac{B_{t-1}^M}{\pi_t} - (AC_t^M + \gamma_t^K)}.\end{aligned}$$

It then becomes clear that a reduction in $\tau_t^{SS,F}$, an increase in the selling price P_t^m, an increase in output Y_t^M or a reduction in the debt interest rate R_{t-1}^L, in other words anything improving the profitability of firms, will increase $\frac{\frac{\partial}{\partial W}\Pi_t^M}{\Pi_t^M}$ and thus the Nash bargaining wage.[75]

6.3 Final good sector cost minimization

In the following, we will solve the cost minimization problem for the second stage of the final good sector. The cost minimization for the first stage is completely analogous and, for the sake of brevity, omitted. Cost minimization implies

$$\min_{Z_t^M, Z_t^S} P_t^{z,m} Z_t^M + P_t^{z,s} Z_t^S$$

giving rise to the Langrangian

$$\mathcal{L} = P_t^{z,m} Z_t^M + P_t^{z,s} Z_t^S + P_t^z \left(Z_t - \left[(1-\alpha_Z)^{1/\eta_Z} (Z_t^M)^{\frac{\eta_Z - 1}{\eta_Z}} + \alpha_Z^{1/\eta_Z} (Z_t^S)^{\frac{\eta_Z-1}{\eta_Z}} \right]^{\frac{\eta_Z}{\eta_Z - 1}} \right).$$

Note, that the Lagrange multiplier is identified to be P_t^z since the marginal cost (which is the economic interpretation of the Lag. mult.) equals the final good price due to perfect competition.
1. $\frac{\partial \mathcal{L}}{\partial Z_t^M} = 0$ implies

$$\begin{aligned} P_t^{z,m} &= P_t^z \frac{\eta_z}{\eta_z - 1} [...]^{\frac{\eta_z}{\eta_z - 1} - 1} (1-\alpha_Z)^{1/\eta_z} \frac{\eta_z - 1}{\eta_z} (Z_t^M)^{\frac{\eta_z - 1}{\eta_z} - 1} \\ \Leftrightarrow \frac{P_t^{z,m}}{P_t^z} &= [...]^{\frac{1}{\eta_z - 1}} (1-\alpha_Z)^{1/\eta_z} (Z_t^M)^{\frac{-1}{\eta_z}} \\ \Leftrightarrow \left(\frac{P_t^{z,m}}{P_t^z}\right)^{\eta_z} &= [...]^{\frac{\eta_z}{\eta_z - 1}} (1-\alpha_Z)(Z_t^M)^{-1} \\ \Leftrightarrow Z_t^M &= (1-\alpha_Z)\left(\frac{P_t^{z,m}}{P_t^z}\right)^{-\eta_c} Z_t \end{aligned}$$

[75] The fact that $\frac{\frac{\partial}{\partial W}\Pi_t^M(W)}{\Pi_t^M(W)}$ falls with the payroll tax is less obvious to see. However, when taking the derivative with respect to the tax one can easily show that it is negative given that profits and wage costs are positive in the steady state, which we ensure to hold by calibration.

2. $\frac{\partial \mathcal{L}}{\partial Z_t^S} = 0$ implies analogously

$$Z_t^S = \alpha_Z \left(\frac{P_t^{z,s}}{P_t^z}\right)^{-\eta_Z} Z_t$$

It then follows through the profit function of final good firm (using the fact that these are perfectly competitive), that

$$\begin{aligned}
P_t^z Z_t &= P_t^{z,m} Z_t^M + P_t^{z,s} Z_t^S \\
&= (1-\alpha_Z) P_t^{z,m} \left(\frac{P_t^{z,m}}{P_t^z}\right)^{-\eta_Z} Z_t + \alpha_Z P_t^{z,s} \left(\frac{P_t^{z,s}}{P_t^z}\right)^{-\eta_Z} Z_t \\
\Leftrightarrow P_t^z &= (\frac{1}{P_t^z})^{-\eta_Z} \left((1-\alpha_Z)\,(P_t^{z,m})^{1-\eta_Z} + \alpha_Z\,(P_t^{z,s})^{1-\eta_Z}\right) \\
\Leftrightarrow P_t^z &= \left((1-\alpha_Z)\,(P_t^{z,m})^{1-\eta_Z} + \alpha_Z\,(P_t^{z,s})^{1-\eta_Z}\right)^{1/(1-\eta_Z)}
\end{aligned}$$

6.4 Intermediate sector export price setting

The optimization problem of the exporter is

$$\max_{P_t^x(i)} E_t \sum_{j=0}^{\infty} \Delta_{t,t+j} (1-\tau_t^{OI,F}) \left[(P_t^x(i) Q_t - MC_t^X) X_t(i) - AC_t^X(i)\right].$$

The first-order condition for the price set $P_t^x(i)$ is given by

$$\begin{aligned}
0 = \; & \beta^t \lambda_t (1-\tau_t^{OI,F}) \Bigg\{ Q_t X_t(i) + P_t^x(i) Q_t (-\epsilon_X) \left(\frac{P_t^x(i)}{P_t^x}\right)^{-\epsilon_X - 1} \frac{X_t(i)}{P_t^x} - MC_t^X (-\epsilon_X) \frac{(P_t^x(i))^{-\epsilon_X - 1}}{(P_t^x)^{-\epsilon_X}} X_t(i) \\
& -\chi_x X_t P_t^x Q_t \left[\frac{\frac{P_t^x(i)}{P_{t-1}^x(i)} \pi_t^*}{\left(\frac{P_{t-1}^x}{P_{t-2}^x} \pi_{t-1}^*\right)^{\chi_a} (\overline{\pi}^*)^{1-\chi_a}} - 1 \right] \left[\frac{\pi_t^*}{\left(\frac{P_{t-1}^x}{P_{t-2}^x} \pi_{t-1}^*\right)^{\chi_a} (\overline{\pi}^*)^{1-\chi_a} P_{t-1}^x(i)} \right] \Bigg\} \\
& -\beta^{t+1} \lambda_{t+1} (1-\tau_{t+1}^{OI,F}) \Bigg\{ \chi_x X_{t+1} P_{x,t+1}^* Q_{t+1} \left[\frac{\frac{P_{x,t+1}^*(i)}{P_t^x(i)} \pi_{t+1}^*}{\left(\frac{P_t^x}{P_{t-1}^x} \pi_t^*\right)^{\chi_a} (\overline{\pi}^*)^{1-\chi_a}} - 1 \right] \\
& \times \left[\frac{\pi_{t+1}^* P_{x,t+1}^*(i)}{\left(\frac{P_t^x}{P_{t-1}^x} \pi_t^*\right)^{\chi_a} (\overline{\pi}^*)^{1-\chi_a} (-1) (P_t^x(i))^2} \right] \Bigg\}
\end{aligned}$$

Since all the firms have the same optimization problem, the optimum price for each firm will be $P_t^x(i) = P_t^x$. We can then drop the firm index (i) and simplify to

$$
\begin{aligned}
0 &= \beta^t \lambda_t (1-\tau_t^{OI,F}) \Bigg\{ (1-\epsilon_X) Q_t X_t - MC_t^X (-\epsilon_X)(P_t^x)^{-1} X_t \\
&\quad -\chi_x X_t P_t^x Q_t \left[\frac{\frac{P_t^x}{P_{t-1}^x}\pi_t^*}{\left(\frac{P_{t-1}^x}{P_{t-2}^x}\pi_{t-1}^*\right)^{\chi_a} (\overline{\pi}^*)^{1-\chi_a}} - 1 \right] \left[\frac{\pi_t^*}{\left(\frac{P_{h,t-1}^*}{P_{h,t-2}^*}\pi_{t-1}^*\right)^{\chi_a} (\overline{\pi}^*)^{1-\chi_a} P_{t-1}^x} \right] \Bigg\} \\
&\quad -\beta^{t+1} \lambda_{t+1} (1-\tau_{t+1}^{OI,F}) \Bigg\{ \chi_x X_{t+1} P_{x,t+1}^* Q_{t+1} \left[\frac{\frac{P_{x,t+1}^*}{P_t^x}\pi_{t+1}^*}{\left(\frac{P_t^x}{P_{t-1}^x}\pi_t^*\right)^{\chi_a} (\overline{\pi}^*)^{1-\chi_a}} - 1 \right] \\
&\quad \times \left[\frac{\pi_{t+1}^* P_{x,t+1}^*}{\left(\frac{P_t^x}{P_{t-1}^x}\pi_t^*\right)^{\chi_a} (\overline{\pi}^*)^{1-\chi_a} (-1)(P_t^x)^2} \right] \Bigg\}
\end{aligned}
$$

dividing all terms by X_t, Q_t, λ_t and β^t can simplify above as

$$
DAC_t^X = (1-\epsilon_X) + \epsilon_X \frac{MC_t^X}{Q_t P_t^x} + \beta \frac{\lambda_{t+1}}{\lambda_t} \frac{X_{t+1}}{X_t} \frac{Q_{t+1}}{Q_t} \frac{(1-\tau_{t+1}^{OI,F})}{(1-\tau_t^{OI,F})} \left(\frac{P_{x,t+1}^*}{P_t^x} \right) DAC_{t+1}^X \tag{61}
$$

where

$$
DAC_t^X = \chi_x \left[\frac{\frac{P_t^x}{P_{t-1}^x}\pi_t^*}{\left(\frac{P_{t-1}^x}{P_{t-2}^x}\pi_{t-1}^*\right)^{\chi_a} (\overline{\pi}^*)^{1-\chi_a}} - 1 \right] \left[\frac{\pi_t^* P_t^x}{\left(\frac{P_{h,t-1}^*}{P_{h,t-2}^*}\pi_{t-1}^*\right)^{\chi_a} (\overline{\pi}^*)^{1-\chi_a} P_{t-1}^x} \right].
$$

6.5 The first-order conditions of firms in manufacturing sector

The problem of firm i (without using the index i unless necessary) is then given by the Lagrangian

$$
\begin{aligned}
&\mathcal{L} = E_0 \sum_{t=0}^{\infty} \frac{1}{R_t^e} \Bigg\{ \Big[P_t^m Y_t^M - (1+\tau_t^{SS,F}) W_t N_t^M - \delta P_t^i K_t^M - (R_{t-1}^L \phi_{t-1}^m - 1) \frac{B_{t-1}^M}{\pi_t} \\
&-(AC_t^M + \gamma_t^K + \gamma_t^{BN}) \Big] (1-\tau_t^{OI,F}) + \tau_t^{OI,F} TD^{OI,F} - \left[P_t^i (I_t^M - \delta K_t^M) - BN_t^M \right] + \\
&+\mu_t^M \left[I_t^M + (1-\delta) K_t^M - K_{t+1}^M \right] \\
&+\lambda_t^{B^M} \left[BN_t^M + B_{t-1}^M/\pi_t - B_t^M \right] \\
&+\lambda_t^{Y,M} \left[Y_t^M(i) - \left(\frac{P_t^m(i)}{P_t^m} \right)^{-\epsilon_M} Y_t^M \right] \Bigg\},
\end{aligned}
$$

1. $\frac{\partial L}{\partial N_t^M} = 0$ yields

$$
\begin{aligned}
0 &= \frac{1+\tau_t^{SS,F}}{R_t^e} (-W_t)(1-\tau_t^{OI,F}) + \lambda_t^{Y,M} (1-\alpha^M) \frac{Y_t^M(i) + FC^M}{N_t^M} \frac{1}{R_t^e} \\
\Leftrightarrow (1+\tau_t^{SS,F}) W_t &= \lambda_t^{Y,M} (1-\alpha^M) \frac{Y_t^M(i) + FC^M}{(1-\tau_t^{OI,F}) N_t^M}
\end{aligned}
$$

2. $\frac{\partial L}{\partial I_t^M} = 0$ yields

$$
\begin{aligned}
0 &= -\frac{1}{R_t^e}P_t^i - \frac{(1-\tau_t^{OI,F})}{R_t^e}\left(\chi_K(\frac{I_t^M}{I_{t-1}^M}-1)I_t^M/I_{t-1}^M + \frac{\chi_K}{2}(\frac{I_t^M}{I_{t-1}^M}-1)^2\right) \\
&+ \frac{\mu_t^M}{R_t^e} - \frac{(1-\tau_{t+1}^{OI,F})}{R_{t+1}^e}\chi_K(\frac{I_{t+1}^M}{I_t^M}-1)I_{t+1}^M\frac{-I_{t+1}^M}{(I_t^M)^2} \\
\Leftrightarrow P_t^i &= -(1-\tau_t^{OI,F})\left(\chi_K(\frac{I_t^M}{I_{t-1}^M}-1)I_t^M/I_{t-1}^M + \frac{\chi_K}{2}(\frac{I_t^M}{I_{t-1}^M}-1)^2\right) \\
&+ \mu_t^M + \frac{(1-\tau_{t+1}^{OI,F})}{\Theta_{t+1}}\chi_K(\frac{I_{t+1}^M}{I_t^M}-1)I_{t+1}^M\frac{I_{t+1}^M}{(I_t^M)^2} \qquad (62)
\end{aligned}
$$

3. $\frac{\partial L}{\partial BN_t^M} = 0$ yields

$$
\begin{aligned}
0 &= \frac{1}{R_t^e} + \frac{\lambda_t^{B^M}}{R_t^e} - \frac{1-\tau_t^{OI,F}}{R_t^e}\chi_{BN}\left(\frac{BN_t^M}{BN_{t-1}^M}-1\right)\frac{BN_t^M}{BN_{t-1}^M} - \frac{1-\tau_{t+1}^{OI,F}}{R_{t+1}^e}\chi_{BN}\left(\frac{BN_{t+1}^M}{BN_t^M}-1\right)\frac{(BN_{t+1}^M)^2}{(-1)(BN_t^M)^2} \\
\Leftrightarrow \lambda_t^{B^M} &= -1 + (1-\tau_t^{OI,F})DACBN_t - \frac{1-\tau_{t+1}^{OI,F}}{\Theta_{t+1}}DACBN_{t+1}\frac{BN_{t+1}^M}{BN_t^M}
\end{aligned}
$$

where $DACBN_t = \chi_{BN}\left(\frac{BN_t^M}{BN_{t-1}^M}-1\right)\frac{BN_t^M}{BN_{t-1}^M}$. In the absence of new borrowing adjustment costs ($\chi_{BN}=0$), it holds that $\lambda_t^{B^M} = -1$.

4. $\frac{\partial L}{\partial K_{t+1}^M} = 0$ yields

$$
\begin{aligned}
0 &= -\frac{\mu_t^M}{R_t^e} + \frac{(1-\tau_{t+1}^{OI,F})}{R_{t+1}^e}(-\delta P_{t+1}^i) + \frac{1}{(R_{t+1}^e)}P_{t+1}^i + \frac{\mu_{t+1}^M(1-\delta)}{(R_{t+1}^e)} + \frac{\lambda_{t+1}^{Y,M}}{(R_{t+1}^e)}\alpha^M\frac{Y_{t+1}^M(i)+FC^M}{K_{t+1}^M} \\
\Leftrightarrow \mu_t^M\Theta_{t+1} &= (1-\tau_{t+1}^{OI,F})\left((-\delta P_{t+1}^i))\right) + P_{t+1}^i\delta + \mu_{t+1}^M(1-\delta) + \lambda_{t+1}^{Y,M}\alpha^M\frac{Y_{t+1}^M(i)+FC^M}{K_{t+1}^M} \qquad (63)
\end{aligned}
$$

5. $\frac{\partial L}{\partial B_t^M} = 0$ yields

$$
\begin{aligned}
0 &= -\frac{\lambda_t^{B^M}}{R_t^e} - \frac{(1-\tau_{t+1}^{OI,F})}{(R_{t+1}^e)}(R_t^L\phi_t^m - 1 + R_t^L\frac{\partial\phi_t^m}{\partial B_t^M}B_t^M)/\pi_{t+1} + \frac{\lambda_{t+1}^{B^M}}{(R_{t+1}^e)\pi_{t+1}} \\
\Leftrightarrow \lambda_t^{B^M}\Theta_{t+1}\pi_{t+1} &= -(1-\tau_{t+1}^{OI,F})(R_t^L\phi_t^m(1+\chi_B b_t^M)-1) + \lambda_{t+1}^{B^M}
\end{aligned}
$$

In the absence of new borrowing adjustment costs ($\lambda_t^{B^M} = -1$) it holds that

$$
\Theta_{t+1}\pi_{t+1} - 1 = (1-\tau_{t+1}^{OI,F})(R_t^L\phi_t^m(1+\chi_B b_t^M)-1)
$$

The main results from the text are derived under this condition, while the numerical implementation of the model allows for adjustment costs on new borrowing.

6. $\frac{\partial L}{\partial P_t^m} = 0$ yields

$$
\begin{aligned}
0 &= \frac{1}{R_t^e}\Bigg((1-\tau_t^{OI,F})(1-\epsilon_M)\left(\frac{P_t^m(i)}{P_t^m}\right)^{-\epsilon_M} Y_t^M + \lambda_t^{Y,M}\left[-\frac{-\epsilon_M}{P_t^m(i)}Y_t^M(i)\right] \\
&-(1-\tau_t^{OI,F})\chi_M P_t^m Y_t^M(i)\left[\frac{\frac{P_t^m(i)}{P_{t-1}^m(i)}\pi_t}{\left(\frac{P_{t-1}^m}{P_{t-2}^m}\pi_{t-1}\right)^{\chi_a}\overline{\pi}^{1-\chi_a}}-1\right]\left[\frac{\pi_t}{\left(\frac{P_{t-1}^m}{P_{t-2}^m}\pi_{t-1}\right)^{\chi_a}\overline{\pi}^{1-\chi_a}P_{t-1}^m(i)}\right]\Bigg) \\
&-\frac{1}{R_{t+1}^e}(1-\tau_{t+1}^{OI,F})\chi_M P_{t+1}^m Y_{H,t+1}^M(i)\left[\frac{\frac{P_{t+1}^m(i)}{P_t^m(i)}\pi_{t+1}}{\left(\frac{P_t^m}{P_{t-1}^m}\pi_t\right)^{\chi_a}\overline{\pi}^{1-\chi_a}}-1\right]\left[\frac{\pi_{t+1}P_{t+1}^m(i)}{\left(\frac{P_t^m}{P_{t-1}^m}\pi_t\right)^{\chi_a}\overline{\pi}^{1-\chi_a}(-1)(P_t^m(i))^2}\right]
\end{aligned}
$$

For simplicity we introduce

$$
DAC_t^M = \chi_M\left[\frac{\frac{P_t^m}{P_{t-1}^m}\pi_t}{\left(\frac{P_{t-1}^m}{P_{t-2}^m}\pi_{t-1}\right)^{\chi_a}\overline{\pi}^{1-\chi_a}}-1\right]\left[\frac{\pi_t P_t^m}{\left(\frac{P_{t-1}^m}{P_{t-2}^m}\pi_{t-1}\right)^{\chi_a}\overline{\pi}^{1-\chi_a}P_{t-1}^m}\right].
$$

Since all firms arrive at this same optimal pricing equation, we can drop the firm index (i) and obtain from above

$$
\begin{aligned}
0 &= (1-\tau_t^{OI,F})(1-\epsilon_M)Y_t^M + \lambda_t^{Y,M}\left[-\frac{-\epsilon_M}{P_t^m}Y_t^M\right] \\
&\quad -(1-\tau_t^{OI,F})Y_t^M DAC_t^M + \frac{R_t^e}{R_{t+1}^e}(1-\tau_{t+1}^{OI,F})\frac{P_{t+1}^m}{P_t^m}Y_{t+1}^M DAC_{t+1}^M \\
\Leftrightarrow DAC_t^M &= (1-\epsilon_M)+\epsilon_M\frac{\lambda_t^{Y,M}}{P_t^m(1-\tau_t^{OI,F})}+\frac{R_t^e}{R_{t+1}^e}\frac{Y_{t+1}^M}{Y_t^M}\frac{P_{t+1}^m}{P_t^m}\frac{1-\tau_{t+1}^{OI,F}}{1-\tau_t^{OI,F}}DAC_{t+1}^M \qquad (64)
\end{aligned}
$$

6.6 Relieve of double taxation of corporate profits

The purpose of the rate-of-return allowance RRA_t is to relieve shareholders from double taxation on the risk-free return on their equity investments. To see this, we consider a simplified example of the model, where we interpret the sum of capital gains and dividends stemming from the manufacturing sector (analogously for the service sector) as a return to equity investments net of the profit tax paid at the corporate level, i.e.

$$
(1-\tau_t^{OI,F})\underbrace{(R_{t-1}^{E,M}-1)}_{\text{Return on equity}}\underbrace{E_{t-1}^M}_{\text{stock of equity}} = DIV_t^M E_{t-1}^M + AV_t^M.
$$

In the absence of RRA_t, households after-tax income from ownership of manufacturing sector shares is $(1-\tau_t^{OI,H})(1-\tau_t^{OI,F})(R_{t-1}^{E,M}-1)E_{t-1}^M$ since shareholder income is taxed as personal income and hence at the ordinary income tax rate. However, then returns on equity are double-taxed, whereas the return on other financial assets in form of deposits is only taxed once, at the ordinary income tax rate.[76] The Norwegian tax code aims at avoiding that shareholders are taxed twice on the risk-free share of the equity return. Hence, only the equity premium is to be taxed at the household level. This is the case if

$$
RRA_t = (R_{t-1}-1)(1-\tau_t^{OI,H}).
$$

Now, the return on equity is split into two components:

$$
(1-\tau_t^{OI,F})(R_{t-1}^{E,M}-1)E_{t-1}^M = \left[(1-\tau_t^{OI,F})(R_{t-1}^{E,M}-1)E_{t-1}^M - RRA_t E_{t-1}^M\right] + (R_{t-1}-1)(1-\tau_t^{OI,H})E_{t-1}^M
$$

[76] For example, the after-tax return on deposits is given by $(R_t-1)(1-\tau_t^{OI,H})$.

The first component relates to the return on equity (after corporate tax) exceeding the after-tax rate of return on bank deposits, i.e. it represents the equity premium.[77] The second component equals the rate of return achieved with deposits. The set-up of the ordinary income tax base, see equation (4) in the main text, then ensures that only the first component, the equity premium, is taxed as personal income while the risk-free component remains untaxed.

In the following, we will show for the context of the full model, that if RRA_t is set to $(R_{t-1}-1)(1-\tau_t^{OI,H})$, transaction costs $F_t^S = 0$, and $\tau_t^{OI,F} = \tau_t^{OI,H}$ holds, then

- The stream of dividends is discounted at the same rate as the stream of other income of households. Hence, firms discount the future in the same way as households.
- The blow-up factor $\alpha_t^{OI,H}$ is non-distortionary and does not affect the decision of firms.
- There is no tax-induced distortion towards debt-financing of new investments.

Using the definition of Θ it holds that

$$\Theta_{t+1} = \frac{(1+F_t^S) - \Delta_{t+1}/\pi_{t+1}\tau_{t+1}^D(1+RRA_{t+1})}{\Delta_{t+1}(1-\tau_{t+1}^D)} = \frac{(1+F_t^S)/\Delta_{t+1} - 1/\pi_{t+1}\tau_{t+1}^D(1+RRA_{t+1})}{(1-\tau_{t+1}^D)}.$$

Using the first-order condition for deposits, equation (57), and above value of RRA_t we obtain

$$\begin{aligned}
\Theta_{t+1} &= \frac{F_t^S/\Delta_{t+1}}{(1-\tau_{t+1}^D)} + \frac{(1+(R_t-1)(1-\tau_{t+1}^{OI,H}))/\pi_{t+1} - \tau_{t+1}^D(1+(R_t-1)(1-\tau_{t+1}^{OI,H}))/\pi_{t+1}}{(1-\tau_{t+1}^D)} \\
&= \frac{F_t^S/\Delta_{t+1}}{(1-\tau_{t+1}^D)} + \frac{1-\tau_{t+1}^D + (R_t-1)(1-\tau_{t+1}^{OI,H})(1-\tau_{t+1}^D))}{(1-\tau_{t+1}^D)\pi_{t+1}} \\
&= \frac{F_t^S/\Delta_{t+1}}{(1-\tau_{t+1}^D)} + \frac{1+(R_t-1)(1-\tau_{t+1}^{OI,H})}{\pi_{t+1}} = \frac{F_t^S/\Delta_{t+1}}{(1-\tau_{t+1}^D)} + \frac{1}{\Delta_{t+1}}
\end{aligned}$$

If fixed costs are set to zero, then the discount factor of the household, Δ_{t+1}, equals the discount factor on dividends, $\frac{1}{\Theta_{t+1}}$ and thus the discount factor underlying the firm's decisions. Moreover, the discount factor is independent of $\alpha_t^{OI,H}$ and does consequently not affect the decision of firms.
Inserting this into the first-order condition for borrowing of firms, equation (39), we obtain

$$\begin{aligned}
(\Theta_{t+1}\pi_{t+1}-1) &= (1-\tau_{t+1}^{OI,F})(R_t^L\phi_t^m(1+\chi_B b_t^M)-1) \\
\Leftrightarrow (R_t-1)(1-\tau_{t+1}^{OI,H})/(1-\tau_{t+1}^{OI,F}) &= (R_t^L\phi_t^m(1+\chi_B b_t^M)-1) \\
\Leftrightarrow 1 &= \phi_t^m(1+\chi_B b_t^M) \Leftrightarrow 0 = b_t^M
\end{aligned}$$

where we have used previously derived results, that $R_t = R_t^L$. The last equation follows from the fact, that for $b_t^M > 0$, the agency cost ϕ_t^m will be larger than 1 and for $b_t^M < 0$, ϕ_t^m will be smaller than 1, such that only for $b_t^M = 0$ the equation holds. Hence, firms will not use any debt as a financing instrument under the conditions stated above.

6.7 Import sector price setting

The problem of the firm is

[77] Since the tax rate on corporate profits approximately equal the tax rate on household ordinary income, the equity premium measured as difference between pre-tax returns on equity and deposits would be nearly identical.

$$\max_{P_t^f(i)} E_t \sum_{j=0}^{\infty} \Delta_{t,t+j}(1-\tau_t^{OI,F}) \left[(P_t^f(i) - Q_t) IM_t(i) - AC_t^F(i) \right].$$

Profit maximization then yields

$$\begin{aligned}
0 \quad = \quad & \beta^t \lambda_t (1-\tau_t^{OI,F}) \Bigg\{ (1-\epsilon_f) \left(\frac{P_t^f(i)}{P_t^f} \right)^{-\epsilon_f} IM_t(i) - Q_t(-\epsilon_f) \frac{(P_t^f(i))^{-\epsilon_f - 1}}{(P_t^f)^{-\epsilon_f}} IM_t(i) \\
& -\chi_f P_t^f IM_t \left[\frac{\frac{P_t^f(i)}{P_{t-1}^f(i)} \pi_t}{\left(\frac{P_{t-1}^f}{P_{t-2}^f} \pi_{t-1} \right)^{\chi_a} \overline{\pi}^{1-\chi_a}} - 1 \right] \left[\frac{\pi_t}{\left(\frac{P_{t-1}^f}{P_{t-2}^f} \pi_{t-1} \right)^{\chi_a} \overline{\pi}^{1-\chi_a} P_{t-1}^f(i)} \right] \Bigg\} \\
& -\beta^{t+1} \lambda_{t+1} (1-\tau_{t+1}^{OI,F}) \Bigg\{ \chi_f P_{f,t+1} IM_{t+1} \left[\frac{\frac{P_{f,t+1}(i)}{P_t^f(i)} \pi_{t+1}}{\left(\frac{P_t^f}{P_{t-1}^f} \pi_t \right)^{\chi_a} \overline{\pi}^{1-\chi_a}} - 1 \right] \\
& \times \left[\frac{\pi_{t+1} P_{f,t+1}(i)}{\left(\frac{P_t^f}{P_{t-1}^f} \pi_t \right)^{\chi_a} \overline{\pi}^{1-\chi_a} (-1) (P_t^f(i))^2} \right] \Bigg\}
\end{aligned}$$

Since all firms arrive at this same optimal pricing equation, we can drop the firm index (i) and simplify to

$$DAC_t^F = (1-\epsilon_f) + \epsilon_f Q_t (P_t^f)^{-1} + \beta \frac{\lambda_{t+1}}{\lambda_t} \frac{IM_{t+1}}{IM_t} \frac{P_{f,t+1}}{P_t^f} \frac{(1-\tau_{t+1}^{OI,F})}{(1-\tau_t^{OI,F})} DAC_{f,t+1} \tag{65}$$

where

$$DAC_t^F = \chi_f \left[\frac{\frac{P_t^f}{P_{t-1}^f} \pi_t}{\left(\frac{P_{t-1}^f}{P_{t-2}^f} \pi_{t-1} \right)^{\chi_a} \overline{\pi}^{1-\chi_a}} - 1 \right] \left[\frac{\pi_t P_t^f}{\left(\frac{P_{t-1}^f}{P_{t-2}^f} \pi_{t-1} \right)^{\chi_a} \overline{\pi}^{1-\chi_a} P_{t-1}^f} \right].$$

6.8 Törnqvist-Index

The total value of domestic production is given by

$$\begin{aligned}
P_t^Y Y_t^D &= P_t^M Y_t^M + P_t^S Y_t^S + P_t V A_t^X X_t, \text{ or equivalently} \\
P_t^y Y_t^D &= P_t^m Y_t^M + P_t^s Y_t^S + V A_t^X X_t
\end{aligned}$$

where prices with capital letter superscript denote nominal prices and prices with lower letter superscript denote relative (to CPI) prices, for example $P_t^y = P_t^Y / P_t$, where P_t is the CPI. Following the IMF's Producer Price Index Manual, see IMF (2004), we define the Törnqvist price index for total domestic production. In the context of our model, the price index of domestic production is given by[78]

$$P_t^Y = \left(P_t^M / \overline{P^M} \right)^{\left([s_t^M + \overline{s^M}]/2 \right)} \left(P_t^S / \overline{P^S} \right)^{\left([s_t^S + \overline{s^S}]/2 \right)} \left(P_t V A_t^X / (\overline{PVA^X}) \right)^{\left([s_t^X + \overline{s^X}]/2 \right)}$$

where s_t^M denotes the share of value added in the manufacturing sector, i.e. $s_t^M = (P_t^M Y_t^M)/(P^Y Y_t^D)$, and s_t^S the share of value added in the service sector, i.e. $s_t^S = (P_t^S Y_t^S)/(P^Y Y_t^D)$. Consequently, $s_t^X = 1 - s_t^M - s_t^S$.

[78] The expression can equivalently be expressed as

$$\Delta \log(P_t^Y) = \left([s_t^M + \overline{s^M}]/2 \right) \Delta \log(P_t^M) + \left([s_t^S + \overline{s^S}]/2 \right) \Delta \log(P_t^S) + \left([s_t^X + \overline{s^X}]/2 \right) \Delta \log(P_t V A_t^X)$$

where $\Delta log(X_t) = log(X_t) - log(\overline{X})$.

The notation $\overline{X}$ denotes the steady-state value of X. It can be easily verified, that the relationship also holds for relative prices (under the assumption that $\overline{P} = 1$), i.e:

$$P_t^y = \left(P_t^m/\overline{P^m}\right)^{\left([s_t^M+\overline{s^M}]/2\right)} \left(P_t^s/\overline{P^s}\right)^{\left([s_t^S+\overline{s^S}]/2\right)} \left(VA_t^X/\overline{VA_t^X}\right)^{\left([s_t^X+\overline{s^X}]/2\right)}.$$

6.9 Steady-state Solution and Calibration

In this section variables without a t-subscript denote the steady-state values of the corresponding endogenous variables of the model.

1. **Inflation:** We impose a steady state on domestic and foreign inflation

$$\pi = \pi_{SS}$$
$$\pi^* = \pi^*_{SS}$$

where π_{SS} and π^*_{SS} can be freely chosen.

2. **Taxes:** Since the tax rates in the model can be pinned down by the data, we set the steady-state tax rates to these empirically determined values.

$$\tau^i = \tau^i_{SS}$$

where $i \in \{C; BT; OI, H; OI, F; SS, H; SS, F\}$.

3. **Relative prices, exchange rate, markup:** Rearranging the steady-state version of equation (24) for $Z = C$, we obtain

$$P^{c,m} = \left(\frac{P^{c,m}C^M}{C}\frac{1}{1-\alpha_C}\right)^{1/(1-\eta_C)}$$

where the value of $\frac{P^{c,m}C^M}{C}$ is taken from the data and reflects the manufacturing share of the final consumption good. The parameter α_C is set to $1-\frac{P^{c,m}C^M}{C}$ such that $P^{c,m} = 1$. It follows then from (25), that $P^{c,s} = 1$, as $\alpha_C = 1 - \frac{P^{c,m}C^M}{C} = \frac{P^{c,m}C^M}{C}$. Setting $1 - \alpha_{C^M} = \frac{P^m Y^{C,M}}{P^{c,s}C^S}$, reflecting the share of the domestic service good in the composite service good for consumption, yields ,using equation (20), that $P^m = 1$. Similarly, one obtains $P^s = 1$ after setting $1-\alpha_{C^S} = \frac{P^s Y^{C,S}}{P^{c,s}C^S}$. From (21), it follows then directly, that $P^f = 1$. For all other final good we set α_{Z^M} and α_{Z^S} accordingly and obtain $P^{z,m} = P^{z,s} = 1$. Finally, and returning to the second stage of the final good sector we find that, $P^z = 1$ for all final goods. To match the service share of the final goods, α_Z is set to the corresponding empirical value.

It follows from the steady-state version of the optimal import pricing equation, (65), that

$$Q = P_f \frac{\epsilon_f - 1}{\epsilon_f}.$$

Using the optimal home good pricing equation, (64), we derive the steady-state shadow value of production as

$$\lambda^{Y,M} = P^m \frac{\epsilon_M - 1}{\epsilon_M}(1 - \tau^{OI,F})$$

and the steady-state value of capital using equation (62) as $\mu^M = P^i$. The corresponding variables for the service sector can be derived analogously.

Using the optimal pricing decisions for exports from equation (61), we obtain

$$P_x = \frac{\epsilon_X}{\epsilon_X - 1}\frac{MC^X}{Q}.$$

where $MC^X = 1$ as follows from equation (27).

4. **Interest rates:**

   Using (57) we obtain

   $$R = \frac{\frac{\pi}{\beta} - 1}{1 - \tau^{OI,H}} + 1.$$

   Solving this expression for β allows us to set this parameter to be consistent with the imposed steady-state tax rate on ordinary income, the inflation target π and the target for the nominal interest rate R.

   Using (19) we then obtain

   $$R^* = \frac{R}{\pi}\pi^*$$

   where we have used the fact that the risk premium $\phi(A) = 1$ in the steady state as follows from the definition of ϕ_t. From equation (18) we obtain that $R^L = R$. The rate-of-return allowance RRA as well as the discount variables θ and Θ follow then directly from their definitions.

5. **Adjustment costs:** It follows directly from the definitions of adjustment costs in the model, that these are zero in the steady state.

6. **Depreciation:** From the sum of steady-state versions of the capital accumulation equation in the manufacturing sector, equation (31), and the corresponding equation for the service sector, it follows, that

   $$\delta = \frac{P^i I}{Y^{CPI}}\left(\frac{P^i K}{Y^{CPI}}\right)^{-1},$$

   where both $\frac{P^i I}{Y^{CPI}}$ and $\frac{P^i K}{Y^{CPI}}$ can be determined empirically. Hence, we choose δ such that we obtain the correct investment share over GDP.

7. **Firm borrowing and risk premium:** We set b^M to the empirical value of debt to capital ratio in Norwegian firms. Using the steady-state version of the first-order condition for borrowing, equation (39), we can then determine the steady-state value of the firm risk premium as

   $$\phi^M = (\frac{\Theta\pi - 1}{1 - \tau^{OI,F}} + 1)/(R^L(1 + \chi_B b^M)).$$

   We then use equation (33) to set $\beta^M = b^M - \log(\phi^M)/\chi_B$ which ensures that the risk premium obtains the value set above in the steady state.

8. **Capital-to-output ratio:** We first identify empirically $\frac{P^i K^M}{Y^M}$, the capital intensity in the manufacturing sector.[79] Using equation (63), we then obtain in steady state that

[79] To arrive at this value, we first determine the GDP share of each sector using the sector shares of each final good and the GDP shares of each final good (both can be identified from national accounts data). We then calculate the overall capital intensity of both sectors combined using their GDP share and the aggregate capital to GDP ratio which can be empirically obtained. We then assume that both sectors have this same capital intensity.

$$\mu^M\Theta = (1-\tau^{OI,F})\left(-\delta P^i\right) + P^i\delta + \mu^M(1-\delta) + \lambda^{Y,M}\alpha^M\frac{Y^M + FC^M}{K^M}$$

$$\underbrace{\mu^M(\Theta - 1 + \delta) + (1-\tau^{OI,F})\left(\delta P^i\right) - P^i\delta}_{:=\theta_{K,M}} = \lambda^{Y,M}\alpha^M\frac{Y^M + FC^M}{K^M}$$

$$\underbrace{\mu^M(\Theta - 1 + \delta) + (1-\tau^{OI,F})\left(\delta P^i\right) - P^i\delta}_{:=\theta_{K,M}} = \lambda^{Y,M}\alpha^M\frac{Y^M}{K^M}(1 + \frac{FC^M}{Y^M}) \tag{66}$$

Rearranging the first-order condition for labor demand, equation (38), we obtain the expression

$$(1 + \frac{FC^M}{Y^M}) = \frac{(1+\tau^{SS,F})WN^M}{P^m Y^M}P^m\frac{1-\tau^{OI,F}}{\lambda^{Y,M}}\frac{1}{(1-\alpha^M)}.$$

Having identified empirically the labor share in the manufacturing sector, $\frac{(1+\tau^{SS,F})WN^M}{P^m Y^M}$, we thus obtain an equation expressing the ratio of fixed costs to output $\frac{FC^M}{Y^M}$ as a function of knowns and α^M. We can thus insert this expression in equation (66) and obtain an equation which can be solved (numerically) for α^M, which implies also a value for $\frac{FC^M}{Y^M}$, again using equation (66). This choice of the parameters then ensures that manufacturing firms have the capital to output ratio as well as labor share as found in the data. Since we assume the same capital to output ratio in the service sector and the same mark-up it holds that $\alpha^M = \alpha^S$.

Dividing the steady-state version of equation (38) by (66), we obtain

$$\frac{W}{\theta_{K,M}} = \frac{1}{(1-\tau^{OI,F})(1+\tau^{SS,F})}\frac{(1-\alpha^M)}{\alpha^M}\frac{K^M}{N^M} \tag{67}$$

From the steady-state version of equation (30), we obtain

$$\begin{aligned} Y^M + FC^M &= (K^G)^{\kappa^M}(K^M)^{\alpha^M}(N^M)^{1-\alpha^M} \\ \frac{Y^M + FC^M}{K^M}\frac{1}{(K^G)^{\kappa^M}} &= \left(\frac{K^M}{N^M}\right)^{\alpha^M - 1} \end{aligned}$$

Using this and equation (67) one can express the steady-state wage rate as a function of tax rates, the price of investment, the shadow price of capital and the output to capital ratio.[80] We obtain the same wage rate in the service sector due to the assumptions made above.

9. **Wage and output:** As discussed in the calibration section, we normalize hours worked per worker to $NpW = 1$, with the consequence that $N = E$ in steady-state and the value of hours can be interpreted as employment rates. The total employment rate N, the private and public sector rate, N^P and N^G as well as the participation rates for sub-populations are taken from the data and set directly. Dividing the first-order condition for labor demand, equation (38), of the manufacturing sector by the same equation of the service sector we obtain a relationship between N^M and N^S based on the output share of each sector. Hence, knowing the sum $N^P = N^M + N^S$, the sector specific employment rates can be calculated, such that equation (38) in turn can be used to determine Y^M and Y^S.

10. **Aggregate variables:** Knowing sector-specific output, we can now easily determine fixed costs, capital and debt stocks in each sector by multiplying the corresponding ratio by output, e.g. $FC^M = \frac{FC^M}{Y^M}Y^M$.

[80] Note, that in the numerical implementation of the model we replace the term $(K^G)^{\kappa^M}$ with $\kappa_2^M(K^G)^{\kappa^M}$ where we set κ_2^M to a value such that $\kappa_2^M(K^G)^{\kappa^M} = 1$ once K^G is known. This enables us to calculate the wage irrespective of K^G.

Since $\frac{Y^M}{Y^{CPI}}$ is known from sector-share data of final goods, we also obtain aggregate GDP in steady state, which enables us to pin down a number of variables known as GDP shares in the data, including the public capital stock and investment, unemployment benefits, government spending, oil sector investment and others. Investments in the manufacutring and service sector follow from the capital stock and the depreciation rate.

11. **Exports:** Having identified the export share in the data $\frac{P_x^* QX}{Y^{CPI}}$, we set $X = \frac{P_x^* QX}{Y^{CPI}} Y^{CPI}/(P_x^* Q)$. Using equation (26), we then chose Y^*, such that the imposed level of X is consistent with foreign demand, i.e.

$$Y^* = X/\left((P_x^*)^{-\eta_x}\right).$$

.

12. **Government wages and total GDP** To obtain government wages, we obtain the government wage bill as a share of GDP empirically, i.e. $\frac{(1+\tau^{SS,F})W^G N^G}{Y^{CPI}}$. Then it follows, that

$$W^G = \frac{(1+\tau^{SS,F})W^G N^G}{Y^{CPI}} \frac{Y^{CPI}}{N^G(1+\tau^{SS,F})}.$$

13. **Sector inputs, consumption and labor supply** Given that the final goods I, CG, X and C can be calculated knowing their empirical GDP shares and the GDP determined above, and all prices in the economy are already known, we can calculate the shares of manufacturing, service and import content for each final good. Assuming $C = C^r = C^l$ (which we will later show to hold), λ follows from the steady-state version of equation (7), i.e.

$$\lambda = \frac{C^{-\sigma}}{1+\tau^C+\tau^f}.$$

14. **Wage bargaining:** The unemployment rate U follows directly from E and L. Knowing the unemployment rate, we can determine the steady-state level of the reference utility. We then determine numerically the value for b^N such that equation (15) holds in steady state.

15. **Liquidity-constraint budget constraint:** As mentioned above, we are assuming that $C = C^l = C^r$ (in the steady state only). To ensure this is the case, we choose lump-sum transfers to liquidity-constraint households, TR^l, in such a way, that $C^l = C$. Following the aggregation rules, it then follows $C^r = C^l = C$. Using an empirical aggregate transfer to GDP-ratio, TR/Y^{CPI}, we set $TR = (TR/Y^{CPI})Y^{CPI}$. Using the aggregation equation (10), we can then derive lump-sum transfers to Ricardian households. Hence, we chose the aggregate level of transfers according to the data and derive the necessary split between TR^l and TR^r such that consumption of liquidity-constraint and Ricardian households are equal.

16. **Government budget constraint and balance of payments:** Given empirical targets $\frac{D}{Y^{CPI}}$ and $\frac{QB}{Y^{CPI}}$ we set $D = \frac{D}{Y^{CPI}} Y^{CPI}$ and $B^F = \frac{QB^F}{Y^{CPI}} \frac{Y^{CPI}}{Q}$. In order for the balance of payments to hold, we solve (55) for OILR and derive

$$OILR = B^F Q(R^* \phi(A)/\pi^* - 1) - NX - P^i I^{OIL}.$$

The government budget constraint from equation (46) can then be resolved to obtain T^L, since all other components of the budget constraint are known at this point.

6.10 Derivation of the Market Clearing Condition

In the following we derive the good market clearing, starting from the budget constraint of Ricardian households given by equation (5), expressed in real terms. Note, that we drop expectation operator everywhere to simplify notation.

$$
\begin{aligned}
&DP_t^r + P_t^e \frac{1}{(1-\omega)} = 1/\pi_t (DP_{t-1}^r + P_{t-1}^e \frac{1}{(1-\omega)}) \\
&+(LI_t^r + UB_t(L_t - N_t) + TR_t^r)(1-\tau_t^W) + (DIV_t + AV_t)\frac{1}{(1-\omega)}(1-\alpha_t^{OI,H}\tau_t^{OI,H}) \\
&+(1/\pi_t DP_{t-1}^r (R_{t-1}-1))(1-\tau_t^{OI,H}) \\
&+\tau_t^{OI,H} RRA_t P_{t-1}^e \alpha_t^{OI,H} \frac{1}{(1-\omega)} - T_t^{L,r} - C_t^r(1+\tau_t^C+\tau_t^f) + AVT_t^r + \Pi_t^{X,r} - \gamma_t^W
\end{aligned}
$$

where we have expanded the terms of ordinary income and taxes paid by Ricardian households. Additionally we have exploited the fact that the number of stocks held (in either sector) is normalized to one (implying the number of stocks held by Ricardians is $1/(1-\omega)$ and set $DIV_t = DIV_t^M + DIV_t^S$, $AV_t = AV_t^M + AV_t^S$ and $P_t^e = P_t^{e,M} + P_t^{e,S}$. Multiplying the overall expression by $(1-\omega)$ and inserting the aggregate transfer equation (10), we obtain

$$
\begin{aligned}
&DP_t + P_t^e = 1/\pi_t (DP_{t-1} + P_{t-1}^e) \\
&+(1-\omega)(LI_t^r + UB_t(L_t - N_t))(1-\tau_t^W) + (TR_t - \omega TR_t^l)(1-\tau_t^W) \\
&+(DIV_t + AV_t)(1-\alpha_t^{OI,H}\tau_t^{OI,H}) + (1/\pi_t DP_{t-1}(R_{t-1}-1))(1-\tau_t^{OI,H}) \\
&+\tau_t^{OI,H} RRA_t P_{t-1}^e \alpha_t^{OI,H} - T_t^L - (1-\omega)C_t^r(1+\tau_t^C+\tau_t^f) + AVT_t + \Pi_t^X - (1-\omega)\gamma_t^W
\end{aligned}
$$

Note, that we employed the aggregation rules from section 2.1.3. Now, we insert the liquidity-constraint household's budget constraint, see equation (9), which yields

$$
\begin{aligned}
&DP_t + P_t^e = 1/\pi_t (DP_{t-1} + P_{t-1}^e) \\
&+(1-\omega)(LI_t^r + UB_t(L_t - N_t))(1-\tau_t^W) \\
&+(TR_t - (\omega C_t^l(1+\tau_t^C+\tau_t^f) - \omega(1-\tau_t^W)(W_t N_t^{l,P} + W_t^G N_t^{l,G} + UB_t(L_t - E_t))))(1-\tau_t^W) \\
&+(DIV_t + AV_t)(1-\alpha_t^{OI,H}\tau_t^{OI,H}) + (1/\pi_t DP_{t-1}(R_{t-1}-1))(1-\tau_t^{OI,H}) \\
&+\tau_t^{OI,H} RRA_t P_{t-1}^e \alpha_t^{OI,H} - T_t^L - (1-\omega)C_t^r(1+\tau_t^C+\tau_t^f) + AVT_t + \Pi_t^X - (1-\omega)\gamma_t^W
\end{aligned}
$$

Using again the aggregation rules from section 2.1.3, we obtain

$$
\begin{aligned}
&DP_t + P_t^e = 1/\pi_t (DP_{t-1} + P_{t-1}^e) \\
&+(W_t N_t^P + W_t^G N_t^G + UB_t(L_t - E_t) + TR_t)(1-\tau_t^W) \\
&+(DIV_t + AV_t)(1-\alpha_t^{OI,H}\tau_t^{OI,H}) + (1/\pi_t DP_{t-1}(R_{t-1}-1))(1-\tau_t^{OI,H}) \\
&+\tau_t^{OI,H} RRA_t P_{t-1}^e \alpha_t^{OI,H} - T_t^L - C_t(1+\tau_t^C+\tau_t^f) + AVT_t + \Pi_t^X - (1-\omega)\gamma_t^W
\end{aligned}
$$

In the next step we extend $-T_t^L$ with $-(T_t^L - T_t) - T_t$ and replace T_t with the government budget constraint from (46), which yields

$$
\begin{aligned}
&DP_t + P_t^e = 1/\pi_t (DP_{t-1} + P_{t-1}^e) \\
&+(W_t N_t^P + W_t^G N_t^G + UB_t(L_t - E_t) + TR_t)(1-\tau_t^W) \\
&+(DIV_t + AV_t)(1-\alpha_t^{OI,H}\tau_t^{OI,H}) + (1/\pi_t DP_{t-1}(R_{t-1}-1))(1-\tau_t^{OI,H}) + \tau_t^{OI,H} RRA_t P_{t-1}^e \alpha_t^{OI,H} \\
&-(T_t^L - T_t) + OILR_t - G_t - DI_t - (D_{t-1}/\pi_t - D_t) - C_t(1+\tau_t^C+\tau_t^f) + AVT_t + \Pi_t^X - (1-\omega)\gamma_t^W.
\end{aligned}
$$

We now use equation (44) to replace the remaining T_t term which leads to a number of tax terms dropping out

$$
\begin{aligned}
&DP_t + P^e_t = 1/\pi_t(DP_{t-1} + P^e_{t-1})\\
&+(W_tN^P_t + W^G_tN^G_t + UB_t(L_t - E_t) + TR_t) + DIV_t + AV_t + 1/\pi_tDP_{t-1}(R_{t-1} - 1)\\
&+(W_tN^P_t + W^G_tN^G_t)\tau^{SS,F}_t + (\Pi^{M,TB} + \Pi^{S,TB})\tau^{OI,F}_t\\
&+OILR_t - G_t - DI_t - (D_{t-1}/\pi_t - D_t) - C_t + AVT_t + VA^x_tX_t - AC^X_t - (1-\omega)\gamma^W_t.
\end{aligned}
$$

Applying the definition of AV, using the equation for government spending, see (45), and the definition of debt interest payments we obtain

$$
\begin{aligned}
&DP_t = 1/\pi_tDP_{t-1} + (W_tN^P_t + W^G_tN^G_t) + DIV_t + 1/\pi_tDP_{t-1}(R_{t-1} - 1)\\
&+(W_tN^P_t)\tau^{SS,F}_t + (\Pi^{M,TB} + \Pi^{S,TB})\tau^{OI,F}_t\\
&+OILR_t - (P^{cg}_tC^G_t + P^i_tI^G_t + W^G_tN^G_t) - (\frac{R^L_{t-1} - 1}{\pi_t}D_{t-1}) - (D_{t-1}/\pi_t - D_t) - C_t + VA^x_tX_t - AC^X_t - (1-\omega)\gamma^W_t.
\end{aligned}
$$

We now use the bank balance sheet equation (16) and the fact that $R_t = R^L_t$ to simplify to

$$
\begin{aligned}
&B^M_t + B^S_t - Q_tB^F_t = 1/\pi_t(B^M_{t-1} + B^S_{t-1} - Q_{t-1}B^F_{t-1})\\
&+(W_tN^P_t + W^G_tN^G_t) + DIV_t + 1/\pi_t(B^M_{t-1} + B^S_{t-1} - Q_{t-1}B^F_{t-1})(R_{t-1} - 1)\\
&+(W_tN^P_t)\tau^{SS,F}_t + (\Pi^{M,TB} + \Pi^{S,TB})\tau^{OI,F}_t\\
&+OILR_t - (P^{cg}_tC^G_t + P^i_tI^G_t + W^G_tN^G_t) - C_t + VA^x_tX_t - AC^X_t - (1-\omega)\gamma^W_t.
\end{aligned}
$$

Rearranging yields

$$
\begin{aligned}
&B^M_t + B^S_t - Q_tB^F_t = (B^M_{t-1} + B^S_{t-1} - Q_{t-1}B^F_{t-1})R_{t-1}/\pi_t\\
&+(W_tN^P_t + W^G_tN^G_t) + DIV_t + (W_tN^P_t)\tau^{SS,F}_t + (\Pi^{M,TB} + \Pi^{S,TB})\tau^{OI,F}_t\\
&+OILR_t - (P^{cg}_tC^G_t + P^i_tI^G_t + W^G_tN^G_t) - C_t + VA^x_tX_t - AC^X_t - (1-\omega)\gamma^W_t.
\end{aligned}
$$

We now use the definition of dividends and profits (equation 35) to cancel out remaining tax terms and obtain

$$
\begin{aligned}
&B^M_t + B^S_t - Q_tB^F_t = (B^M_{t-1} + B^S_{t-1} - Q_{t-1}B^F_{t-1})R_{t-1}/\pi_t\\
&+(W_tN^P_t + W^G_tN^G_t) + P^m_tY^M_t + P^s_tY^S_t - W_tN^P_t - \delta P^i_tK_t\\
&-(R^L_{t-1}\phi^m_{t-1} - 1)\frac{B^M_{t-1}}{\pi_t} - (R^L_{t-1}\phi^s_{t-1} - 1)\frac{B^S_{t-1}}{\pi_t} - AC^M_t - AC^S_t - \gamma^K_t - \Pi^{M,R}_t - \Pi^{S,R}_t\\
&+OILR_t - (P^{cg}_tC^G_t + P^i_tI^G_t + W^G_tN^G_t) - C_t + VA^x_tX_t - AC^X_t - (1-\omega)\gamma^W_t.
\end{aligned}
$$

where we have already, where possible, aggregated up the M and S sector. Simplifying and applying the definition of $\Pi^{M,R}_t$ we obtain[81]

$$
\begin{aligned}
&B^M_t + B^S_t - Q_tB^F_t = -Q_{t-1}B^F_{t-1}R_{t-1}/\pi_t\\
&+P^m_tY^M_t + P^s_tY^S_t + \frac{B^M_{t-1}}{\pi_t} + \frac{B^S_{t-1}}{\pi_t} - AC^M_t - AC^S_t - \gamma^K_t - P^i_tI^{ML}_t + BN^M_t + BN^S_t\\
&+OILR_t - P^{cg}_tC^G_t - C_t + VA^x_tX_t - AC^X_t - (1-\omega)\gamma^W_t.
\end{aligned}
$$

[81] Note, that we have not documented the lump-sum redistribution to Ricardians of agency-cost revenue stemming from ϕ^m_{t-1} and ϕ^s_{t-1}. This is taken account for in the numerical simulation but due to its minor importance omitted herein.

Applying the definitions of BN_t we obtain

$$
\begin{aligned}
&-Q_t B_t^F = -Q_{t-1} B_{t-1}^F R_{t-1}/\pi_t \\
&+P_t^m Y_t^M + P_t^s Y_t^S - AC_t^M - AC_t^S - \gamma_t^K - P_t^i I_t^{ML} + OILR_t - P_t^{cg} C_t^G - C_t + VA_t^x X_t - AC_t^X - (1-\omega)\gamma_t^W.
\end{aligned}
$$

We now use the balance of payments equation (55) as well as the UIP condition which yields

$$
\begin{aligned}
&NX_t + P_t^i I_t^{OIL} + OILR_t = \\
&+P_t^m Y_t^M + P_t^s Y_t^S - AC_t^M - AC_t^S - \gamma_t^K - P_t^i I_t^{ML} + OILR_t - P_t^{cg} C_t^G - C_t + VA_t^x X_t - AC_t^X - (1-\omega)\gamma_t^W.
\end{aligned}
$$

which after rearranging and using the definition of domestic output gives

$$
P_t^y Y_t^D = C_t + NX_t + P_t^i I_t + P_t^{cg} C_t^G + AC_t + (1-\omega)\gamma_t^W.
$$

where $AC_t = AC_t^M + AC_t^S + AC_t^X + (1-\omega)\gamma_t^W$ are total adjustment costs in the economy.

6.11 Constructing Effective Tax Rates

The effective marginal tax rates are calculated using annual data. The data are taken from several tables available on Statistics Norway's web pages. Table 5 reports the tables used. Whenever the data table contains variable names they are kept (third column). If the original table does not come with complete variable names, but only numbers for each variable (tables 08564 and 08603) we add a letter in front of the number. Table 07603 only have variable names for industries, hence we came up with names with close interpretations. Table 5 reports the formulas used and the period considered when calculating the average rate.

Table 5: Data sources

Category/Units	Variable description	Variable code
Table 07603 All limited companies. Tax bases, taxes and tax deductions		
	Taxable income, all industries	TI_{A_U}
	Income tax, all industries	IT_{A_U}
Table 08121 Balance sheet for non-financial limited companies		
	Total assets, all industries	TA_{A_U}
	Liabilities, all industries	L_{A_U}
Table 08564 Survey of tax assessment for all persons		
All persons		
	Basis for surtaxbracket tax	$Z01$
	Ordinary income after special deduction	$Z03$
	Personal income wages	$Z05$
	Personal income pension	$Z04$
	Personal income disability benefits	$Z36$
	Personal income from fishing etc.	$Z31$
	Personal income from other industry	$Z35$
	County income tax	$Z09$
	Bracket tax	$Z40$
	Community tax	$Z12$
	Membership contribution to the national insurance	$Z13$
Table 08603 Taxable income and property		
All persons		
	Personal income from wages and salaries	$W11$
	Unemployment Benefits	$W115$
	Work Assessment Allowance	$W116$
Table 08931 Employment and unemployment for persons aged 15-74		
Both sexes, aged $15 - 74$		
	Labour Force in per cent of the population, seasonally adjusted	$LF1574$
	Employed persons in per cent of the population, seasonally adjusted	$ER1574$
Table 09174 Wages and salaries, employment and productivity		
Compensation of employees and self-employed		
	Mainland Norway	$Y.nr23\_6fn$
	General Government	$Y.nr24\_5$
Hours worked employees and self-employed		
	Mainland Norway	$N.nr23\_6fn$
	General Government	$N.nr24\_5$

Table 5: Data sources

Category/Units	Variable description	Variable code
Table 09177 Exports of goods and services		
Current prices		
	Other goods	$x.nrtradvare$
	Petroleum activities, various services	$x.puboljdiv$
	Travel	$x.pubreise$
	Other services	$x.nratjen$
Table 09178 Imports of goods and services		
	Total, current prices	$im.nrtot$
Table 09181 Gross fixed capital formation and capital stocks		
Current prices		
Fixed assets		
	Mainland Norway	$FA.nr24\_5$
	General Government	$FA.nr24\_$
Consumption of fixed capital		
	General Government	$D.nr24\_$
Table 09189 Final expenditure and gross domestic product		
Current prices		
	Final consumption expenditure of households and NPISHs	$koh.nrpriv$
	Final consumption expenditure of general government (FCEGG)	$koo.nroff$
	GFCF, Mainland Norway excluding general government	$bif.nr83\_6fnxof$
	GFCF, General government	$bif.nr84\_5$
	GFCF, Extraction and transport via pipelines	$bif.nr83oljroer$
	Imports, traditional goods	$imp.nrtradvare$
	Gross domestic product Mainland Norway (market values)	$bnpb.nr23\_9fn$
Table 10644 Foreign assets and liabilities		
Foreign assets, stock		
	Sum total	FA3
	Portfolio investment, general government (GG)	$FA32101RS3$
	Investment Fund shares, GG	$FA32102RS3$
	Debt securities, short-term, GG	$FA322SRS3$
	Debt securities, long-term, GG	$FA322LRS3$
	Currency and deposits, GG	$FA342RS3$
	Loans, GG	$FA343RS3$
	Other accounts recievable/payable, GG	$FA346RS3$
	Reserve assets (IMF breakdown), GG	$FA35$
Liabilities, stock		
	Sum total	$FL3$
	Debt securities, short-term, GG	$FL322SRS3$
	Debt securities, long-term, GG	$FL322LRS3$
	Loans, GG	$FL343RS3$

Table 5: Data sources

Category/Units	Variable description	Variable code
	Other accounts receivable/payable, GG	$FL346RS3$
Table 10722 General government. Taxes and social security contributions		
	Value added tax	$A21$
	Customs duties	$A22$
	Taxes on motor vehicles	$A24$
	Motor vehicle registration tax	$A241$
	Energy and pollution taxes	$A25$
	Taxes on alcohol, tobacco, pharmaceuticals and gambling	$A26$
	Employers' contributions (to insurance schemes)	$A42$
Table 10725 General government. Total expenditure.		
Sector: general government		
	Unemployment	$COF105$
Table 10909 General government. Historical data. Revenue and expenditure.		
Sector: general government		
	Compensation of employees	$B1$
	Social benefits in kind	$B5$
	Social benefits in cash	$B6$
Table 11559 Gross public debt, face value.		
Sector: general government		
	Gross public debt in total	C_OFF999

Ratio	Forumula	Time Period	Comment
$P^C C/P^Y Y$	$koh.nrpriv/bnpb.nr23\_9fn$	$2010-2017$	
$P^{I,P} I^P/P^Y Y$	$bif.nr83\_6fnxof/bnpb.nr23\_9fn$	$2010-2017$	
$P^{I,G} I^G/P^Y Y$	$bif.nr84\_5/bnpb.nr23\_9fn$	$2010-2017$	
$P^I I^{OIL}/P^Y Y$	$bif.nr83oljroer/bnpb.nr23\_9fn$	$2010-2017$	
$\delta_G P^K K_G/P^Y Y$	$W3/bnpb.nr23\_9fn$	$2010-2017$	
$P^G G/P^Y Y$	$(koo.nroff - B1 - W3)/bnpb.nr23\_9fn$	$2010-2017$	
$\left(1+\tau^{SS,F}\right) W_G N_G/P^Y Y$	$B1/bnpb.nr23\_9fn$	$2010-2017$	
$P^X X/P^Y Y$	$(x.nrtradvare + x.puboljdiv + x.pubreise + x.nratjen)/bnpb.nr23\_9fn$	$2010-2017*$	
$P^{IM} IM/P^Y Y$	$im.nrtot/bnpb.nr23\_9fn$	$2010-2017*$	
$D/P^Y Y$	$C\_OFF999/bnpb.nr23\_9fn$	$2010-2017*$	
$B/P^Y Y$	$\left[\left(FA3 - \sum_{j\neq 3} FAj\right) - \left(FL3 - \sum_{i\neq 3} FLi\right)\right]/bnpb.nr23\_9fn$	$2010-2017*$	
$UB/P^Y Y$	$COF\_105/bnpb.nr23\_9fn$	$2010-2017$	
L	$LF1574$	$2010-2017**$	
N	$ER1574$	$2010-2017**$	
UR	$(LF1574 - ER1574)/LF1574$	$2010-2017**$	
$OILREV/P^Y Y$	From Harildstad		
$P^f C_F/C$	Number from Aadne		
$P^f I_F/P^i I$	Number from Aadne		
$P^K K_P$	$(FA.nr24\_5 - FA.nr24\_)/bnpb.nr23\_9fn$	$2010-2017$	
$P^K K_G$	$FA.nr24\_/bnpb.nr23\_9fn$	$2010-2017$	
N_G/N	$N.nr24\_5/N.nr23\_6fn$	$2010-2017$	
W_G/W_P	$\left(\frac{Y.nr23\_6fn}{N.nr23\_6fn} - \frac{N_G}{N}\frac{Y.nr24\_5}{N.nr24\_5}\right)/\left(1-\frac{N_G}{N}\right)$	$2010-2017$	
$Lab.Share$	$(Y.nr23\_6fn - Y.nr24\_5)/(bnpb.nr23\_9fn - D.nr24\_ - Y.nr24\_5)$	$2010-2017$	
b_f Debt to asset ratio	L_{A_U}/TA_{A_U}	$2010-2017$	Accounting based. Use GDP as denominator. Use Mainland instead table 08141.

Table 6: Formulas for calculating great ratios. Yearly data unless noted otherwise. $*$ indicates quarterly data in the numerator, $**$ indicates monthly data.

Tax Rate	Formula	Time period	Comment
τ^C	$A21/koh.nrpriv$	2017	
τ^f	$(A24 + A25 + A26)\,/koh.nrpriv$	2017	
τ^{IM}	$A22/imp.nrtradvare$	2017	
$\tau^{SS,F}$	$A42/\,(W11 - W115 - W116)$	2017	
$\tau^{SS,H}$	$Z13/\,(Z05 + Z04 + Z36 + Z31 + Z35)$	2017	
$\tau^{OI,H}$	$(Z09 + Z12)\,/Z03$	2017	
$\tau^{OI,F}$	IT_{A_U}/TI_{A_U}	2017	
τ^{BT}	$Z40/Z01$	2017	
TR/Y	$(B5 + B6 - COF105)\,/bnpb.nr23\_9fn$	$2010 - 2017$	

Table 7: Formulas and periods used to calculated effective marginal tax rates. $*$ is annual data. $**$ is monthly data. Otherwise quarterly.

6.12 Impulse response matching

As already mentioned above we implement a IRF matching procedure in which we determine 16 dynamic parameters, see the fourth column in table 4 for an overview. More specifically, we match in our model NEMO's responses to a monetary policy shock, a stationary technology shock, an external risk premium shock, a foreign demand shock, and an oil price shock for 10 key macroeconomic variables for 40 quarters. The 10 variables included in the matching procedure include mainland GDP, private consumption, private investment, oil sector investments, exports, imports, hours worked, nominal interest rates, CPI inflation, and the real exchange rate.

In the matching procedure we impose equality between the considered shocks to ensure direct comparability in magnitude and duration of the shock across our model and NEMO. We do so adopting directly the persistence parameter in the five shocks under consideration and then finding the innovation size in the first period which yield identical shock processes. Regarding fiscal policy, we assume that the government budget is balanced in each point of time by the lump-sum tax on Ricardians. In the following we will illustrate the differences in shock responses across NEMO and our model for four of these shocks.[82] We will also compare the model results for these shocks with existing empirical findings where possible.

Figure 9 shows a monetary policy shock in NEMO 2019 as well as in our model. The shock is normalized to obtain a 1 percentage point increase in the quarterly policy rate in the first quarter. While qualitatively the transmission channels are very similar and correspond to the usual way monetary policy shocks operate in DSGE models[83], there are quantitative differences across the two models. In general, the responses of real variables (for the same underlying monetary policy shock) seem to be stronger in our model. An important source of differences is the presence of liquidity-constrained agents that react strongly to temporary reductions in labor income (caused by fewer hours worked and smaller wages), depressing consumption, production and inflation more than it is the case in NEMO. It is important to add, that a better fit to NEMO's monetary policy shock would theoretically be possible if we were to only match the impulse responses to that particular shock. Instead, we are also targeting four other shocks that introduce trade-offs. Despite these difference to NEMO's model the responses are nevertheless broadly in line with empirical findings based on a structural VAR study on Norway by Bjørnland and Halvorsen (2014).[84]

[82] We refrain from discussing the technology shock in NEMO as this shock has not yet been officially published by Norges Bank.

[83] For in-depth explanations how a monetary policy shock operates in DSGE models see for example Christiano et al. (2005) or, closer to the context of NEMO (Kravik and Mimir, 2019), or our current model (Frankovic et al., 2018). In general Kravik and Mimir (2019) provide an interpretation of economic mechanisms underlying all the impulse responses discussed in this section.

[84] Note, Figure 4 from Bjørnland and Halvorsen (2014) shows responses to a monetary policy shock in Norway, indicating a peak fall of GDP of 1-1.5% after 8 quarters, a fall in the exchange rate by initially about 2 to 6 % and a peak fall in inflation by about 0.25 to 0.75 % following a 1 % increase in the nominal interest rate. Comparing these figures with our impulse responses indicates a reasonably well fit between our model and the empirical study.

Figure 9: Monetary policy shock

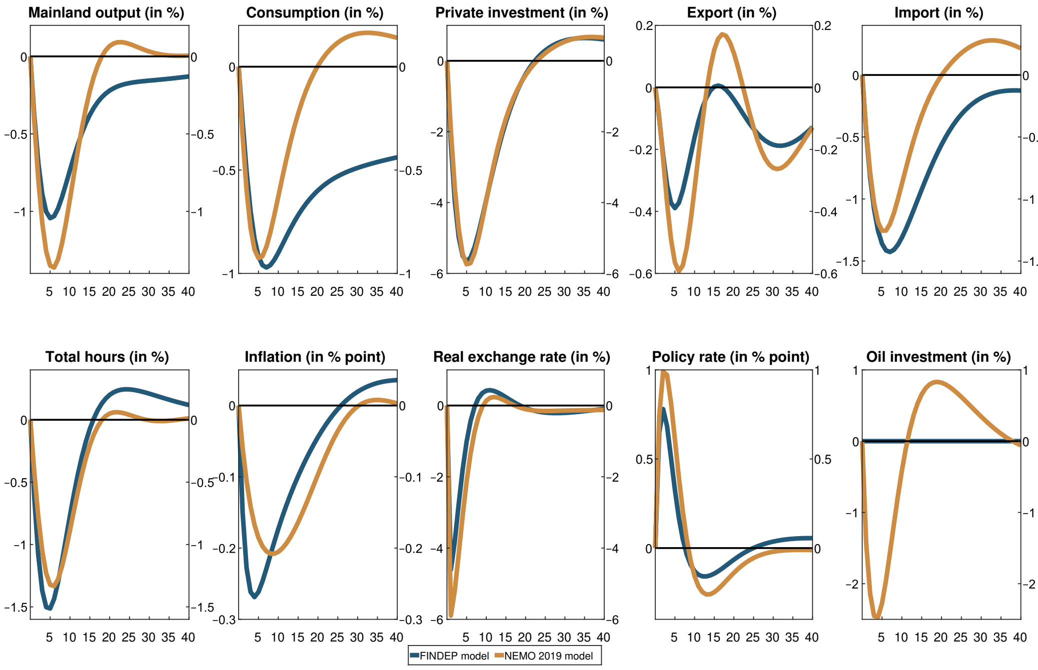
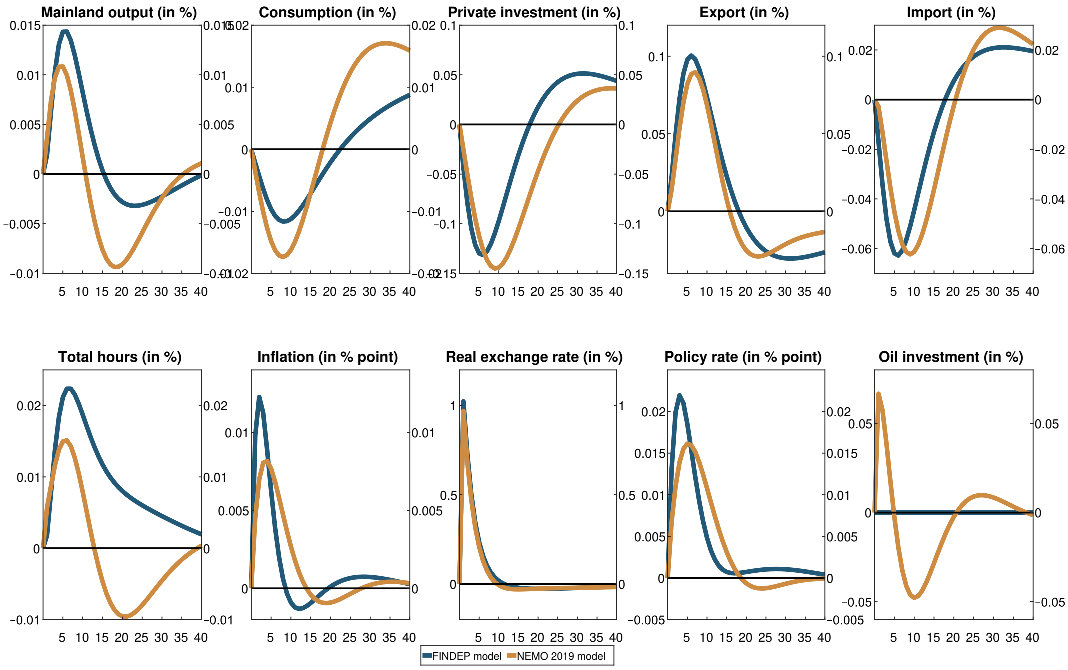


Figure 10 illustrates a risk premium shock, normalized to yield a 1 percent point depreciation of the real exchange rate. Again, the qualitative comparison across models shows few differences, while quantitavely our model exhibits somewhat stronger responses in some of the variables, most notably in exports and consequently in output. The difference is likely due to our differing calibration of η_x where NEMO assumes a lower value, implying a lower sensitivity of export demand to prices (perturbed by the real exchange rate in this simulation). When comparing this risk premium shock to the exchange rate shock discussed in Bjørnland and Halvorsen (2014), we find very similar effects on the policy rate in magnitude and direction. While our model finds that the response to inflation and output is weakly positive, the VAR study finds a weakly negative but insigificant effect on output and inflation.

Figure 11 illustrates a oil price shock (normalized to a 10 % increase in the real oil price), which leads to higher demand for oil investments produced in the mainland economy. The traditional export industry, however, is adversely affected through the appreciating real exchange rate. Overall, the increase in oil prices increases economic activity in Norway, increases private investment and leads to higher wages. The differences in inflation and consumption across the models follow from the different monetary policy rule specification. More importantly, the responses are consistent with the empirical analysis by Bjørnland and Thorsrud (2016) (based on a Bayesian dynamic factor model), finding a real exchange appreciation by about 1% as well as a weak boost to employment (0.1 % on impact, further intensifying and reaching a peak response of 0.3 % after 10-15 quarters) and GDP (0.1 % on impact, dying out quickly) following a increase of real oil prices by 10 %, which is broadly in line with our results.

Finally, figure 12 shows a global demand shock (originating from non-trading partners, but affecting also trading partners) boosting global demand by about 2 %. The shock has similar spill-overs to the Norwegian economy across the two models considered. Oil investments increase due to the higher oil price. Traditional exports increase due to higher world demand. Overall Norway's GDP is boosted by about 0.5 %. As before, the differential responses in consumption follow from the differences in the Taylor rule. We are again able to compare these results to the study by Bjørnland and Thorsrud (2016). Consistent with the empirical study, GDP and employment rise strongly following the global demand shock, and more so than in the case of the

Figure 10: Risk premium shock



mere oil price shock.[85] Hence, we can reproduce the result from Bjørnland and Thorsrud (2016), that oil price increases stimulate the Norwegian economy, but particularly so if commodity prices are a response to an associated boom in global demand. Quantitatively, we are, however, not able to match their results that are are more than double as large for the response of GDP and employment to a global demand shock compared to our model. This is, however, likely a consequence of somewhat different shock design as in our case the shock originates from non-trading partners.

[85]Note, that the global demand shock has also been normalized to a 10% increase in the real oil price.

Figure 11: Oil price shock

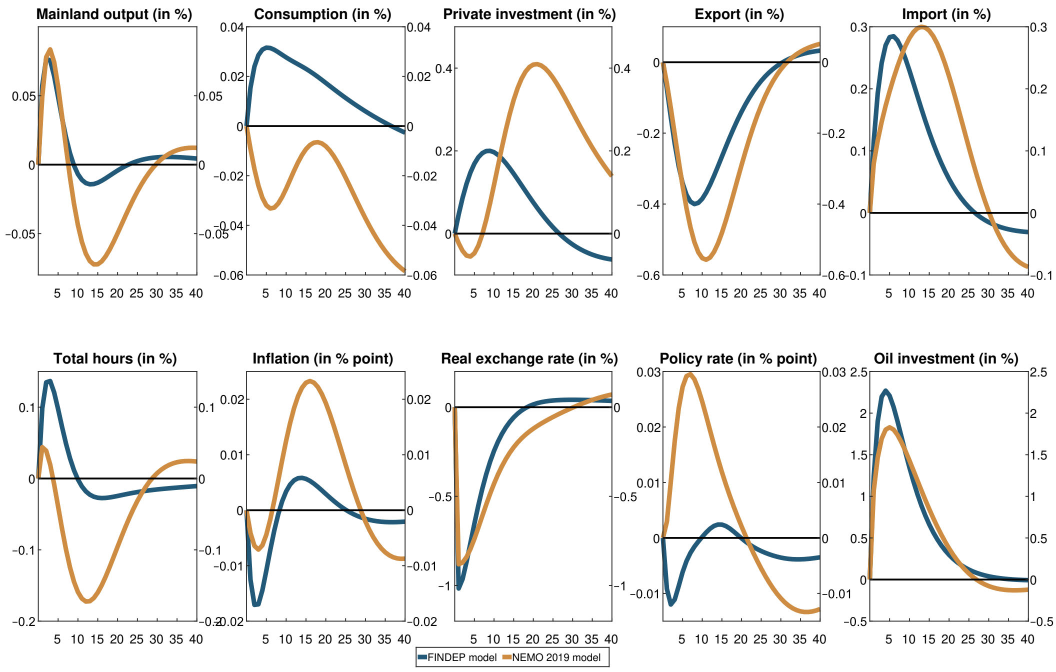
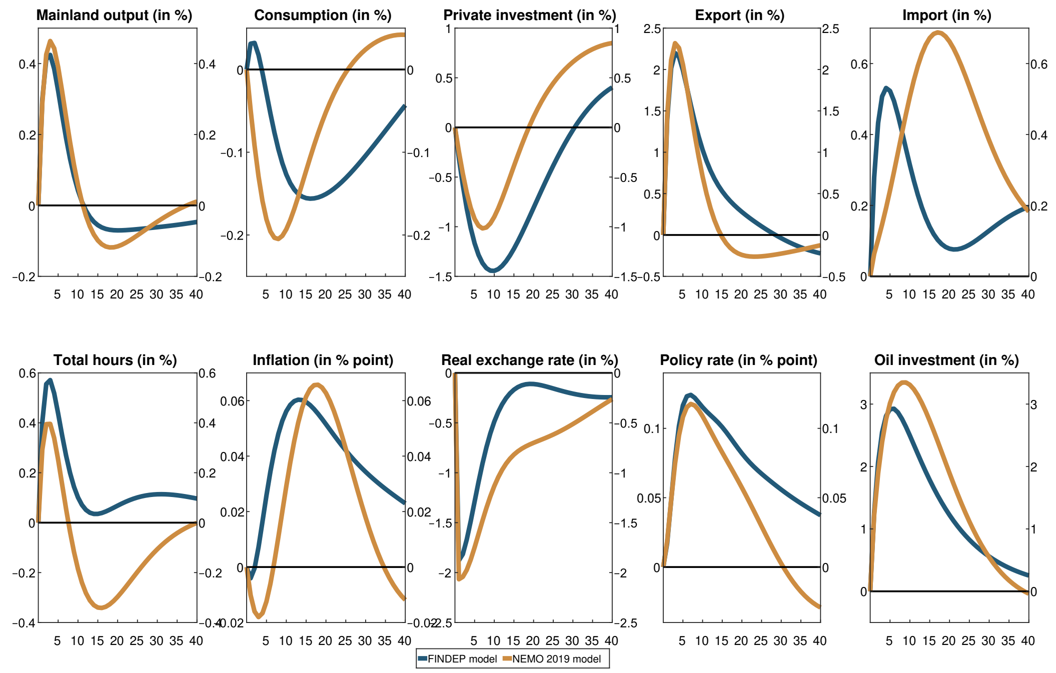


Figure 12: Global demand shock



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