NORA - A Microfounded Model for Fiscal Policy Analysis in Norway*

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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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Contents

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). NORA has been developed by the Norwegian Ministry of Finance in collaboration with Statistics Norway and Norges Bank, and 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 such as 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, NORA contains a rich model of the fiscal authority in Norway, including a realistic description of corporate taxes and the taxation of shareholder income, which exceeds the level of detail found in most existing DSGE models, as well as a simple model of the Government Pension Fund Global (GPFG) — the Norwegian sovereign wealth fund — and related constraints on the use of resources from the Government Pension Fund Global for fiscal financing purposes. NORA also includes a number of distinctive features of the Norwegian economy in order to better describe the functioning of the Norwegian economy, most notably wage bargaining between a union representing workers and firms in the exposed sector to capture the institutional framework for wage setting in Norway.

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. A detailed derivation of the model equations is provided in appendix A. Section 3 describes the current calibration of the model.[1] Section 4 compares the magnitude of fiscal multipliers in NORA and those in Statistics Norway's large-scale macroeconometric model MODAG/KVARTS (Boug and Dyvi, 2008), and assesses the sensitivity of the multipliers to some key parameters and model features. The remainder of section 4 describes a number of fiscal policy simulations that illustrate typical use cases for the model. Section 5 concludes.

2 The model

Figure 1 provides a graphical overview NORA. NORA 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.

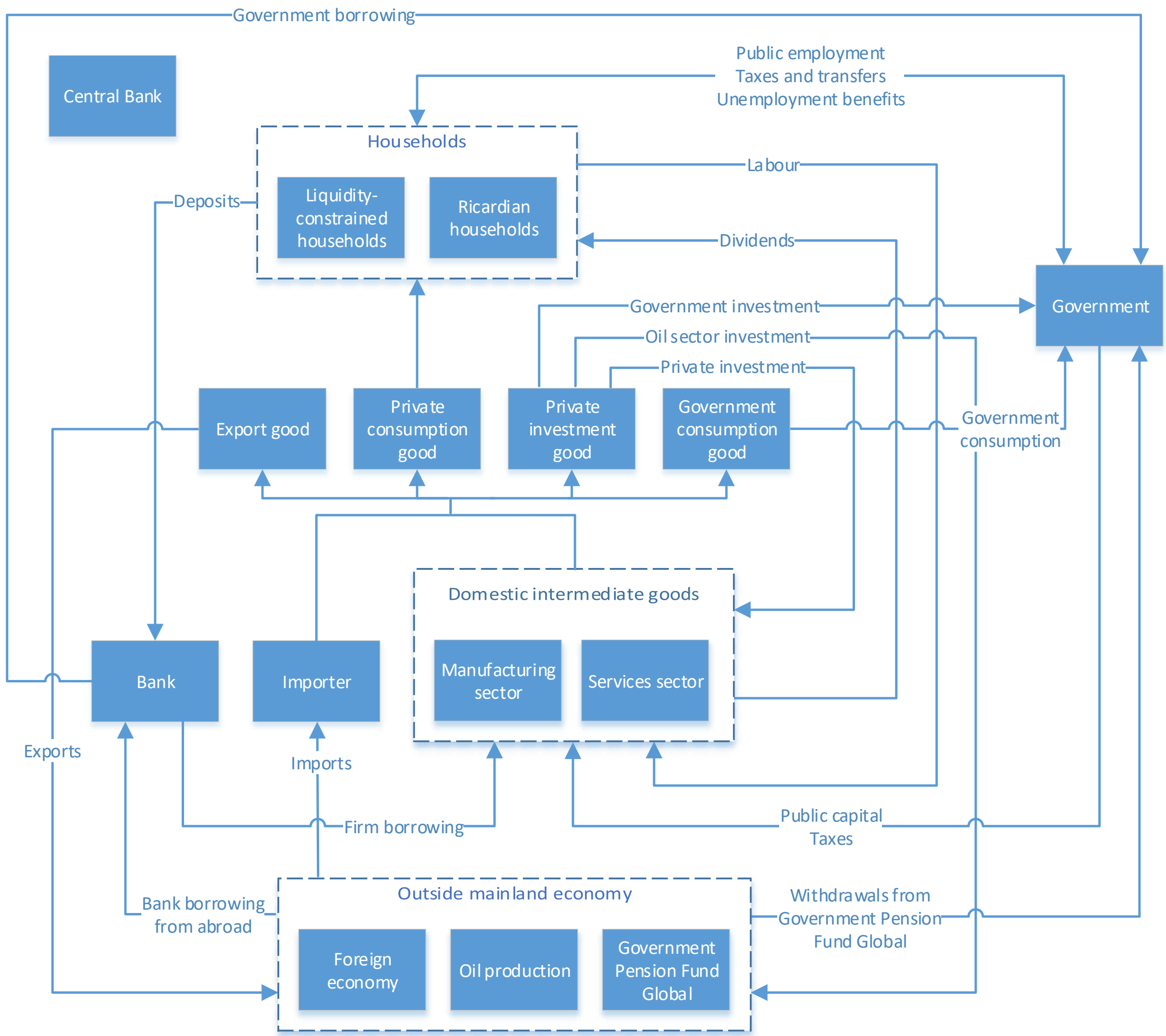
Consistent with most analysis of the Norwegian economy NORA focuses on developments in the mainland economy, i.e. excluding the off-shore oil sector. The production and taxation of the off-shore oil sector is not modeled. However, we include interlinkages between the off-shore oil sector and the mainland 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 on consumption and how much to save in bank deposits as well as firm stocks 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 firm stocks, and receives unemployment benefits and other public transfers.

[1] A complete estimation of NORA is ongoing and will be presented at a later stage.

[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.

Figure 1: Graphical overview of NORA



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 (notably the sensitivity of consumption to current income), and to 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 NORA. Hence, household members in NORA 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 government consumption and investment goods that differ in their composition and degree of substitutability across inputs. Monopolistically-competitive exporters combine 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. Final good consumption firms also possess market power and are subject to consumption taxes which are passed over to households through the retail price. We assume that domestic intermediate goods firms, importers, final consumption sector firms 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, NORA 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 as well as social security contributions. Firms pay taxes on their profits net of deductions as well as social security contributions. The government in NORA 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 employment, and public investment. NORA allows for the possibility that public capital increases private sector productivity. The central bank is assumed to follow a rule mimicking optimal monetary policy.

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 appendix A.

[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.

2.1 Variable and parameter naming conventions

Appendix D provides a full overview of all variable names used in the model alongside with descriptions. In general, we follow the following naming conventions

1. Variables are written using uppercase Latin letters, while parameters use lowercase Greek letters. Exceptions are made in rare cases to conform to standard naming conventions in the literature, e.g. π_t is inflation and Π_t is profits.

2. Variable subscripts capture the time indicator while superscripts capture various modifiers (e.g. Π_t^M is profits in the manufacturing sector at time t). Steady-state values of variables are given by a ss-subscript (e.g. Y_{ss} denotes steady-state output)

3. If not mentioned explicitly variables are given in real terms. Nominal prices are indicated by a Nom-superscript (e.g. $P_t^{Nom,M}$ is the nominal price in the manufacturing sector, while P_t^M is the nominal price relative to the numeraire price in the economy)

4. Shocks in the model are given by Z with a corresponding superscript to indicate the type of shock (e.g. Z_t^R is a monetary policy shock). Exogenous innovations to the shock processes are given by E with a corresponding superscript.

2.2 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. Anderson et al. (2016) argue that a modeling approach using these two types of households captures well the empirical aggregate consumption response to a government spending shock.[4]

2.2.1 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).[5] Expected lifetime utility of the Ricardian household at time 0, denoted by U_0, is given by

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

The term G_t^u consists of government purchases $P_t^{G^C} G_t^C$, government capital depreciation $P_t^I \delta_{KG} K_t^G$ and the government wage bill $W_t^G N_t^G$, see section 2.7.2 for further details.[6] The parameter σ is the inverse of the intertemporal elasticity of substitution and ω_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.[7]

[4] Using US consumption expenditure panel data they show that rich households tend to lower consumption expenditures following a government spending expansion while poorer households tend to increase consumption. The behavior of the former group is proxied by Ricardians in NORA, while the later is captured by liquidity-constrained households.

[5] 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 2.4.

[6] 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 Konjunkturinstitutet (2019) and Coenen et al. (2012b) the amount of public goods does not affect the consumption-saving decision of the household.

[7] All shocks in NORA are collectively discussed in section 2.10.

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.[8]

Budget constraint Before we introduce the Ricardian household's budget constraint we introduce as the numeraire in NORA the nominal (pre-tax) price of the final consumption good P_t. In general, nominal prices of good Z are defined as $P_t^{Nom,Z}$ whereas the real price (i.e. relative to the numeraire in the model) of good Z is given by P_t^Z.

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 (in real terms) by

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

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 2.3 and the firm section 2.6.3. 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. $W_t^G = MARKUP^{GW} W_t$, where $MARKUP^{GW}$ 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 2.7.2.

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 household as it holds shares in firms in the manufacturing (denoted by superscript M) and service (denoted by superscript S) sector. The total amount of dividend income is determined by the number of shares held at the end of the last period, $S_{t-1}^{R,M}$ and $S_{t-1}^{R,S}$. Real capital gains (per equity) in the manufacturing sector (and equivalently in the service sector) are given by $AV_t^M = \frac{P_t^{Nom,E,M} - P_{t-1}^{Nom,E,M}}{P_t}$, where $P_t^{Nom,E,M}$ denotes the nominal price of a share in the manufacturing sector (price of equity).[9] The term $DP_{t-1}^R(R_{t-1} - 1)$ captures

[8]Note, that, as usual in DSGE models, the household does not take into account that its current consumption level will affect the utility from future consumption.

[9]Note that nominal (not real) capital gains are taxed. AV_t^M converts these nominal capital gains into real terms.

(nominal) interest income on bank deposits held at the end of the last period, which we convert into this period's value by dividing through by the (pre-tax) inflation rate $\pi_t^{ATE} = \frac{P_t}{P_{t-1}}$.[10] The gross nominal interest rate on deposits R_t is set by the monetary authority and will be discussed further below.

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

$$\begin{aligned} TB_t^{OIH,R} = \quad & LI_t^R + UB_t(L_t - E_t) + TR_t^R + \frac{P_{t-1}}{P_t} DP_{t-1}^R (R_{t-1} - 1) - TD^{OIH} \\ & + (DIV_t^M + AV_t^M - RRA_t \frac{P_{t-1}^{Nom,E,M}}{P_t}) S_{t-1}^{R,M} \alpha_t^{OIH} \\ & + (DIV_t^S + AV_t^S - RRA_t \frac{P_{t-1}^{Nom,E,S}}{P_t}) S_{t-1}^{R,S} \alpha_t^{OIH}. \end{aligned} \tag{4}$$

The tax base for the ordinary income tax differs from actual ordinary income, see equation (2), due to two deductions. The first deduction TD^{OIH} 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 equity premium and a risk-free portion

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

where RRA_t is a (net) rate-of-return allowance applied to the nominal value of stock holdings given by $P_{t-1}^{Nom,E,M} S_{t-1}^{R,M}$, see for a more detailed exposition appendix A.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 $\alpha_t^{OIH} > 1$ 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.[11]

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

$$T_t^R = \tau_t^{OIH} TB_t^{OIH,R} + (\tau_t^{LS} + \tau_t^{SSH})(LI_t^R + UB_t(L_t - E_t) + TR_t^R - TD^{LS}) + T_t^{L,R},$$

where τ_t^{OIH} is the household ordinary income tax rate , τ_t^{LS} is a labor surtax (trinnskatt) on labor income and transfers, and τ_t^{SSH} is the rate of social security contributions (trygdeavgift).[12] The term TD^{LS} captures a

[10] π_t^{ATE} is a measure of inflation adjusted for tax changes and excluding energy products compiled by Statistics Norway. NORA does not model energy products separately and the difference between π_t and π_t^{ATE} is therefore simply tax changes.

[11] 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 NORA.

[12] 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. NORA 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

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 $\tau_t^W = \tau_t^{OIH} + \tau_t^{LS} + \tau_t^{SSH}$ as the overall effective tax rate on labor income and $\tau_t^D = \alpha_t^{OIH}\tau_t^{OIH}$ as the overall tax rate on dividend and capital gains income.

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

$$P_t DP_t^R + (P_t^{Nom,E,M} S_t^{R,M} + P_t^{Nom,E,S} S_t^{R,S})(1+F_t^S) = P_{t-1} DP_{t-1}^R + P_{t-1}^{Nom,E,M} S_{t-1}^{R,M} + P_{t-1}^{Nom,E,S} S_{t-1}^{R,S}$$
$$+P_t OI_t^R - P_t T_t^R - P_t^{Nom,C} C_t^R - P_t^{Nom,I} Inv_t^{H,R} + \underbrace{P_t(AVT_t^R + \Pi_t^{X,R} + \Pi_t^{C,R} + \Pi_t^{F,R} + \Pi_t^{B,R})}_{\text{other income and costs}}. \quad (5)$$

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.[13] 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 as well as housing investment expenditures and other income and costs.[14] The nominal retail price of the consumption good (including taxes and fees) is given by P_t^C and set by the final consumption good sector, which will be derived later. Housing investments are specified reduced-form and discussed further below. For reporting purposes we define the total (real) value of household savings as

$$SV_t^R = DP_t^R + P_t^{E,M} S_t^{R,M} + P_t^{E,S} S_t^{R,S},$$

where $P^{E,M} = \frac{P_{t-1}^{Nom,E,M}}{P_t}$ (and equivalently for the service sector) is the relative price of a share in the manufacturing firm to the (pre-tax) 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

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

where λ_t is the real shadow value of one unit of savings (or one unit of foregone consumption). Note, that we divide the nominal budget constraint (5) by the price level in the economy P_t to obtain real values. 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

nature of the labor surtax, see Dagsvik et al. (2008).

[13] 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 NORA we interpret these fees as a stand-in for an equity premium due to risk in the productivity of firms. Modeling risk directly, however, would involve computationally burdensome solution and estimation methods. Hence, we resort to this relatively simple modeling device to generate an equity premium.

[14] Other income and costs consist of an asset valuation tax refund AVT_t, profits from exporting firms ($\Pi_t^{X,R}$) and consumption retailers ($\Pi_t^{C,R}$) as well as profits from financial intermediaries ($\Pi_t^{F,R}$) providing stocks and the banking sector ($\Pi_t^{B,R}$). The asset valuation tax refund is a pragmatic solution to the fact that capital gains in NORA 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, implying that capital gains tax revenue can be very volatile. To avoid this we redistribute capital gains tax revenue back to the Ricardian household in a lump-sum fashion in each period. 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 then not affect their decision-making process strongly. Profits from monopolistically-competitive exporting, consumption firms and banks are included to close the model, see appendix A.9 for more details. The definitions of the profit function will follow later in the corresponding sections. Finally, the financial fees imposed on stock holdings are payed to an unmodelled financial intermediary whose profits $\Pi_t^{F,R} = P_t^{E,M} F_t^S S_t^{R,M} + P_t^{E,S} F_t^S S_t^{R,S}$ are redistributed lump-sum to the Ricardian household.

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 A.1) is given by

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

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 real after-tax return on their deposits $1/\Delta_{t+1} = 1/\pi_{t+1}^{ATE}(1 + (R_t - 1)(1 - \tau_{t+1}^{OIH}))$.

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

$$\lambda_t = \frac{\exp(Z_t^U)(C_t^R - H_t)^{-\sigma}}{P_t^C (1-h)^{-\sigma}}. \tag{7}$$

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

$$\frac{\exp(Z_t^U)(C_t^R - H_t)^{-\sigma}}{P_t^C} = \beta E_t \left[\frac{\exp(Z_{t+1}^U)(C_{t+1}^R - H_{t+1})^{-\sigma}}{P_{t+1}^C} \frac{1}{\pi_{t+1}^{ATE}} (1 + (R_t - 1)(1 - \tau_{t+1}^{OIH})) \right],$$

which under certainty equivalence simplifies to

$$\left(\frac{C_{t+1}^R - H_{t+1}}{C_t^R - H_t} \right)^{\sigma} = \beta \frac{P_t^C}{P_{t+1}^C} \frac{1 + (R_t - 1)(1 - \tau_{t+1}^{OIH})}{\pi_{t+1}^{ATE}}.$$

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 retail price in the future encourages the Ricardian household to 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 $R_{t+j}^e = \prod_{l=1}^{j} \frac{1 - \Delta_{t+l}/\pi_{t+l}^{ATE} \tau_{t+l}^D (1 + RRA_{t+l})}{\Delta_{t+l}(1 - \tau_{t+l}^D)}$. 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.[15]

2.2.2 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

[15] It is not possible in NORA 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.

$$
\begin{aligned}
P_t^C C_t^L = \quad & P_t(W_t N_t^P + W_t^G N_t^G + UB_t(L_t - E_t) + TR_t^L) \\
- \quad & P_t(W_t N_t^P + W_t^G N_t^G + UB_t(L_t - E_t) + TR_t^L - TD^{OIH})\tau_t^{OIH} \\
- \quad & P_t(W_t N_t^P + W_t^G N_t^G + UB_t(L_t - E_t) + TR_t^L - TD^{LS})(\tau_t^{LS} + \tau_t^{SSH}), \qquad (9)
\end{aligned}
$$

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. The income is taxed applying the identical deductions and tax rates as in the case of labor (and transfer) income of Ricardians.

2.2.3 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

$$
\begin{aligned}
C_t &= \omega C_t^L + (1 - \omega) C_t^R, \\
TR_t &= \omega TR_t^L + (1 - \omega) TR_t^R. \qquad (10)
\end{aligned}
$$

We implicitly assume that the total amount of hours worked in the private and public sector is proportional to the size of the household.[16]

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 $X_t \in \{DP_t, T_t^L, S_t^M, S_t^S, Inv_t^H, AVT_t, \Pi_t^X, \Pi_t^C, \Pi_t^F, \Pi_t^B, SV_t\}$.

2.3 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.[17,18] Participation rates in each population group j are a function of lags of the participation rate, a positive function of lags of the real after-tax wage and a negative function of lags of the unemployment rates.[19] 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

[16] 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.

[17] In a previous version of NORA (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.

[18] 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.

[19] 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.

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.[20] 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 or unemployment rate will result in permanent changes to the participation rate.

The number of hours worked per employee in the economy NE_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

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

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).[21] In particular, we rely on the following reduced-form relationship between the employment rate and the total number of hours worked in the economy

$$E_t = \rho_E E_{t-1} + (1 - \rho_E) N_t / NE_{ss},$$

where ρ_E captures the degree of persistence in the employment rate and NE_{ss} is the steady-state number of hours per employee. 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 labor demand, which captures the number of workers that would be needed to satisfy the aggregate demand for hours if all employees worked the steady-state number of hours per employee NE_{ss}. A shock that increases demand for hours N_t will therefore result in an immediate increase in hours worked per employee 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, the unemployment rate, which 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. NORA is therefore silent on whether unemployment is voluntary or involuntary.

[20] 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).

[21] 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 employee as in NORA. The modeling approaches are otherwise similar.

2.4 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.[22] 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). Indeed, Bjørnstad and Nymoen (1999) 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, over time, 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 NORA is proxied by the manufacturing sector. We assume that the payoff function of the union is a utility function that increases with worker's pre-tax real wages.[23] 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.[24,25] 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.

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

[23] 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.

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

[25] 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.

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

$$W_t^{NB} = \arg\max_{W^{NB}} [V(W) - V^0(U_t)]^{\gamma} [\Pi_t^M(W)]^{1-\gamma}, \tag{13}$$

where $V(W)$ captures the payoff function of the union given a real wage W, V_t^0 denotes the union's reference utility, and the payoff function of firms equals profits in the manufacturing sector Π_t^M.[26] 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

$$V(W) = c^N + \frac{\frac{(1-I^{\tau}\tau_t^W)}{(1-I^{\tau}\tau_t^C)}(W)^{1-\sigma_N}}{1-\sigma_N}, \tag{14}$$

where σ_N determines the curvature of the utility function while c_N is a constant that ensures a positive value of V at relevant wage levels. The labor union cares about real after-tax (taking into account both labor and consumption taxes) wages only if the indicator parameter I^r is set to one. In the benchmark calibration of NORA, we assume $I^r = 0$, which is in line with empirical findings that tax changes only have a limited or weak effect on wages, see. e.g. Sparrman (2016).[27] 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 2.6.3. The union's reference utility is given by

$$V_t^0 = \nu_U \log(U_t) + Z_t^V,$$

where $\nu_U < 0$ 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

$$\frac{\frac{(1-I^{\tau}\tau_t^W)}{(1-I^{\tau}\tau_t^C)}^{1-\sigma_N}(W_t^{NB})^{-\sigma_N}}{V(W_t^{NB}) - V^0(U_t)} = \frac{1-\gamma}{\gamma}\frac{(1+\tau_t^{SSF})N_t^M}{\Pi_t^M(W_t^{NB})}, \tag{15}$$

where τ_t^{SSF} 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 A.2, the Nash bargaining wage increases with the value of V_t^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 firms or by increased demand for manufacturing goods. Conversely changes detrimental to the profitability of manufacturing-sector firms will depress the Nash bargaining wage.

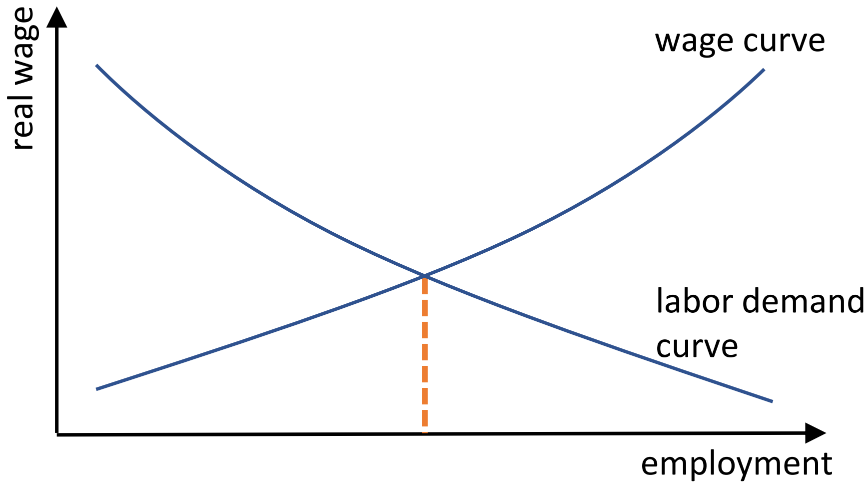
The wage bargaining model thus yields a downward-sloping relationship between the real wage and the level of unemployment which corresponds to the aforementioned wage curve. At the same time, the labor demand

[26] As shown in appendix A.2, assuming instead that the payoff function of firms is given by the firm profit share $\frac{\Pi_t^M}{P_t^M Y_t^M}$, where $P_t^M Y_t^M$ captures total earnings, does not change our results.

[27] The model user may want to study a situation in which tax changes do have an impact on wage formation. Such an assumption may be warranted if for example an increase in labor or consumption taxes is used for a purpose that is not viewed as providing additional public services which compensate wage earners for their loss in purchasing power.

function in equation (45) 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 (45) determines the level of employment in NORA.

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:

$$W_t^M = \rho_W W_{t-1}^M + (1-\rho_W) W_t^{NB}, \tag{16}$$

where W_t^M is the real wage in the manufacturing sector in period t and ρ_W captures the persistence of wages and thus $(1-\rho_W)$ the speed of adjustment of wages towards the Nash bargaining equilibrium.[28] Wages in this setup react, despite the lack of an explicit forward-looking term in equation (16), to news shocks (i.e. shocks known prior to their realization) as both Ricardian households and firms are forward-looking and take decisions that affect the level of unemployment, prices and profitability in anticipation of future economic developments.[29]

Wages in the service sector The Nash bargaining solution in equation (15) determines wages in the manufacturing sector over time, see equation (16). To keep NORA 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):

$$W_t := W_t^S = W_t^M,$$

[28]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.

[29]Assuming that labor union utility is a function of the negotiated nominal wage deflated by the expected future price level only marginally affected the path of wages relative to the presented model setup for two reasons. First, sticky wages slow down the response of today's wages to future price changes considerably. Second, price setting by firms (both domestic and importers) is already forward-looking such that future increases in prices are usually accompanied by increases in the current price level.

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.[30]

2.5 Banking sector

To simplify the Ricardian household's portfolio choice problem it is convenient to include simple banking sector in NORA. 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

$$\underbrace{DP_t}_{\text{Deposits of opt. household}} + \underbrace{RER_t B_t^F}_{\text{Foreign debt of bank}} = \underbrace{B_t^M + B_t^S}_{\text{Loans to firms}} + \underbrace{D_t}_{\text{Loans to government}}, \tag{17}$$

where the real exchange rate is defined as $RER_t := EX_t P_t^{TP}/P_t$, where EX_t is the nominal exchange rate and P_t^{TP} the foreign price level. The representative bank aims to maximize the present discounted value of profits

$$E_t \sum_{j=0}^{\infty} \Delta_{t,t+j} \Bigg[\frac{R_{t-1+j}^L}{\pi_{t+j}^{ATE}} \left(B_{t-1+j}^M + B_{t-1+j}^S + D_{t-1+j}\right) - \frac{R_{t-1+j}}{\pi_{t+j}^{ATE}} DP_{t-1+j} - \frac{R_{t-1+j}^{TP} RP_{t-1+j}}{\pi_{t+j}^{TP}} RER_{t+j} B_{t-1+j}^F \Bigg], \tag{18}$$

subject to the balance sheet constraint in equation (17). 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 (18) captures the cost of foreign borrowing where the foreign gross interest rate R_t^{TP} is subject to a debt-elastic risk premium RP_t.

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

$$RP_t := \exp\left(\xi_{NFA}(A_t - A_{ss}) + \xi_{EX}(E_t(\Delta EX_{t+1})\Delta EX_t - (\Delta EX_{ss})^2) - \xi_{OF}(OF_t^{RP} - OF_{ss}^{RP}) + Z_t^{RP}\right),$$

where $A_t = \frac{RER_t B_t^F}{Y_{ss}}$ is the domestic-currency value of private sector net foreign liabilities as a ratio to long-run GDP and $\Delta EX_t = \frac{EX_t}{EX_{t-1}}$ is the nominal exchange rate depreciation. The risk premium on foreign borrowing increases with private sector foreign indebtedness ($\xi_{NFA} > 0$) and with expected changes in the nominal exchange rate ($\xi_{EX} < 0$).[31] 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

$$OF_t^{RP} = \rho_{OF,RP} OF_{t-1}^{RP} + (1 - \rho_{OF,RP})\left(P_t^{Oil}/P_{ss}^{Oil} - 1\right).$$

Hence, we capture in a reduced-form fashion that an increase in the oil price would, over time, increase our proxy of the GPFG (OF_t^{RP}) and thus reduce the risk-premium on foreign borrowing by the private sector ($\xi_{OF} > 0$).

[30] 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.

[31] 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 ΔEX captures the nominal exchange rate appreciation in the model that can potentially be different from 1 in steady state.

This is similar in spirit to NEMO (Kravik and Mimir, 2019), where the value of the GPFG affects the risk premium directly, and to KVARTS (Boug and Dyvi, 2008), where a higher oil price is assumed to reduce the risk premium.[32] Z_t^{RP} is shock to the risk premium.

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

$$E_t \left[\frac{\Delta_{t+1}}{\pi_{t+1}^{ATE}} (R_t^L - R_t) \right] = 0, \tag{19}$$

$$E_t \left[\Delta_{t+1} \left(\frac{R_t}{\pi_{t+1}^{ATE}} - \frac{R_t^{TP} RP_t}{\pi_{t+1}^{TP}} \frac{RER_{t+1}}{RER_t} \right) \right] = 0. \tag{20}$$

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.

2.6 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.[33] This modification is motivated by the importance Norwegian policymakers place on preserving a viable non-oil tradable sector as well as the relevance of the manufacturing sector in wage formation, and builds on models by Matheson (2010), Pieschacón (2012) and Bergholt et al. (2019). NORA's two-sector model is furthermore 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.[34]

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. With the exception of the final consumption and export 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 the final goods in the economy. Firms in the final consumption and export good sector, however, are assumed to be monopolistically competitive and thus have price-setting power. Exporting firms sell on the world market with a price set in foreign currency, while final consumption good producer sell their goods in the domestic market and choose how quickly to pass through changes in consumption taxes and fees to retail prices.

[32] For modeling purposes we distinguish between the GPFG as it relates to the risk premium on foreign borrowing (OF_t^{RP}) and the GPFG as it relates to the government budget (OF_t), see section 2.7.5 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.

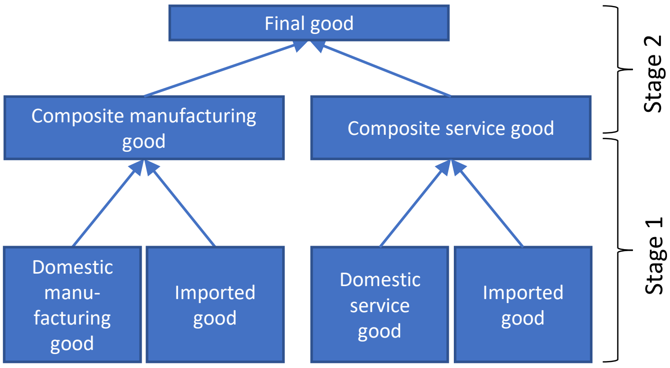
[33] The industries defined as belonging to the manufacturing and service sector, respectively, are listed in appendix C.1. Note, we assume that both sectors have the same capital intensity. Our analysis of the data shows that capital intensity varies significantly at the industry level, but is virtually identical across the composite manufacturing and services sectors that we include in NORA.

[34] 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.

2.6.1 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 form final consumption, investment, export, and government consumption goods. While the first stage is perfecly competitive for all four final goods, the second stage is monopolistically-competitive for the export and consumption good sector.

Figure 3: Final good sector production



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

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

where $\alpha_{M,Z}$ is the parameter governing the import/home bias for the composite manufacturing good employed in the production of the final good Z_t^M and $\eta_{M,Z}$ 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 $P_t^{Nom,M} = P_t^M / P_t$ be the relative price of a domestically-produced manufacturing good, and $P_t^{IM} = P_t^{Nom,IM} / P_t$ the relative price of imported goods. As shown in appendix A.3 this cost minimization problem yields the following final-good-specific demand functions for domestically-produced manufacturing and imported goods:

$$Y_t^{M,Z} = (1-\alpha_{M,Z}) \left(P_t^M / P_t^{M,Z} \right)^{-\eta_{M,Z}} Z_t^M, \tag{21}$$

$$IM_t^{M,Z} = \alpha_{M,Z} \left(P_t^{IM} / P_t^{M,Z} \right)^{-\eta_{M,Z}} Z_t^M, \tag{22}$$

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

$$P_t^{M,Z} = \left((1-\alpha_{M,Z}) \left(P_t^M \right)^{1-\eta_{M,Z}} + \alpha_{M,Z} \left(P_t^{IM} \right)^{1-\eta_M} \right)^{1/(1-\eta_{M,Z})}. \tag{23}$$

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

$$P_t^{M,Z} Z_t^M = P_t^M Y_t^{M,Z} + P_t^{IM} IM_t^{M,Z}.$$

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 $Y_t^{S,Z}$ with imported goods of volume $IM_t^{S,Z}$ with home bias parameter $\alpha_{S,Z}$ and elasticity of substitution $\eta_{S,Z}$. Cost minimization yields demand functions for domestically-produced services and imported goods that are analogous to those in equation (21) and (22). The relative price of the composite service good $P_t^{S,Z}$ is given by an expression equivalent to equation (23). Total value of the composite service good is then given by:

$$P_t^{S,Z} Z_t^S = P_t^S Y_t^{S,Z} + P_t^{IM} IM_t^{S,Z}.$$

Second stage: final good For each final good $Z_t \in \{I_t, G_t^C\}$ (i.e. excluding the export and consumption good), final-good-specific composite manufacturing and service goods are combined to form final goods using the following production function

$$Z_t = \left[(1-\alpha_Z)^{1/\eta_Z} (Z_t^M)^{\frac{\eta_Z - 1}{\eta_Z}} + \alpha_Z^{1/\eta_Z} (Z_t^S)^{\frac{\eta_Z - 1}{\eta_Z}}\right]^{\eta_Z/(\eta_Z - 1)}, \tag{24}$$

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. 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 $P_t^{M,Z}$ and service $P_t^{S,Z}$ good. The solution to this cost-minimization problem, which we relegate to appendix A.3, yields the following final-goods-specific demand functions

$$Z_t^M = (1-\alpha_Z)\left(P_t^{M,Z}/P_t^Z\right)^{-\eta_Z} Z_t, \tag{25}$$

$$Z_t^S = \alpha_Z \left(P_t^{S,Z}/P_t^Z\right)^{-\eta_Z} Z_t. \tag{26}$$

The relative price of final good Z is then given by

$$P_t^Z = \left((1-\alpha_Z)\left(P_t^{M,Z}\right)^{1-\eta_Z} + \alpha_Z \left(P_t^{S,Z}\right)^{1-\eta_Z}\right)^{1/(1-\eta_Z)}.$$

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

$$P_t^I Inv_t = P_t^{M,I} I_t^M + P_t^{S,I} I_t^S, \tag{27}$$

$$P_t^{G^C} G_t^C = P_t^{M,G^C} G_t^{C,M} + P_t^{S,G^C} G_t^{C,S}. \tag{28}$$

Note that as equation (27) makes clear, I_t^M does not capture investments into the manufacturing sector, which is given by Inv_t^M. Instead I_t^M captures the amount of composite manufactured goods used in the production of the final investment good. The same distinction applies to I_t^S and Inv_t^S.

2.6.2 Final consumption and export good sector

In contrast to the final investment and government consumption good we assume that the second stage of the final good sector for consumption and export good is monopolistically-competitive. This allows the second-stage firms to act as price setters. Pricing is subject to price adjustment costs such that export and consumption good prices are sticky.

In the case of the final consumption good sector we impose the value-added (consumption) tax onto firms (as opposed onto households) with firm setting the after-tax price of the final consumption good. Given price adjustment costs, changes in the taxation of consumption then do not have an immediate pass-through to retail prices. This is particularly important for announced consumption tax reforms where forward-looking consumption good price setters give rise to more realistic model results, see Benedek et al. (2015) and Voigts (2016).

The rationale for the export sector's pricing power is unrelated to taxation. Instead it allows local currency price setting, i.e. the setting of prices in the currency of foreign markets to which exporters sell their goods, a practice sometimes called pricing-to-market. This is consistent with the significant amount of evidence of deviations from the law of one price even for traded goods (Betts and Devereux, 2000).

In the following, we will derive the overall second stage production problem for the export sector, and later state the analogous consumption sector problem in a reduced fashion. The final good export consists of a continuum of firms $i \in [0,1]$ that each produce a differentiated export good that are imperfect substitutes. Export firm i produces output of volume $X_t(i)$ and sells it at the relative price $P_t^X(i) = \frac{P_t^{Nom,X}(i)}{P_t^{TP}}$ where $P_t^{Nom,X}(i)$ is the nominal price of a unit of exports in foreign currency and P_t^{TP} 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

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

where ϵ_t^X is the elasticity of substitution across the differentiated export goods.[35] 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

$$X_t(i) = \left(\frac{P_t^X(i)}{P_t^X} \right)^{-\epsilon_t^X} X_t. \tag{29}$$

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 $P_t^X = (\int_0^1 P_t^X(i)^{1-\epsilon_t^X} di)^{\frac{1}{1-\epsilon_t^X}}$ for exports.

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

$$X_t = \left(P_t^X\right)^{-\eta_{TP}} Y_t^{TP}, \tag{30}$$

where Y_t^{TP} denotes output among foreign trading partners which will be discussed in 2.8. The parameter η_{TP} 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.

Equivalently, a continuum of final consumption good firms set the relative price $P_t^C(i) = \frac{P_t^{Nom,C}(i)}{P_t}$ on their output $C_t(i)$. The bundling function is completely analogous to the export sector but subject to the elasticity of substitution given by ϵ_C. This gives rise to equivalent demand functions and aggregate price equations. However, the demand for the aggregate consumption good C_t is, in contrast to the export sector, not given by a reduced-form relationship but endogenously determined by the two household types in the economy.

[35] Retailers are commonly-used modeling devices in DSGE models that serve the purpose of combining the input of competing firms within one sector. NORA features a export and consumption good 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.

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 $P_t^{M,X}$ and service $P_t^{S,X}$ good derived earlier. The derivation of this problem closely follows appendix A.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

$$X_t^M(i) = (1-\alpha_X)\left(P_t^{M,X}/MC_t^X(i)\right)^{-\eta_X} X_t(i), \tag{31}$$

$$X_t^S(i) = \alpha_X \left(P_t^{S,X}/MC_t^X(i)\right)^{-\eta_X} X_t(i), \tag{32}$$

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

$$MC_t^X = \left((1-\alpha_X)\left(P_t^{M,X}\right)^{1-\eta_X} + \alpha_X \left(P_t^{S,X}\right)^{1-\eta_X}\right)^{1/(1-\eta_X)}. \tag{33}$$

Cost minimization in the consumption sector is completely analogous. Note, however, that the consumption sector is subject to a different service good bias parameter, α_C, and elasticity of substitution between the composite manufacturing $C_t^M(i)$ and service $C_t^S(i)$ good, η_C. Moreover, nominal marginal costs in the consumption sector $MC_t^{Nom,C}$ is chosen to be the numeraire in the model, i.e. $P_t = MC_t^{Nom,C}$. In other words, the relative price of marginal costs in the consumption sector is $MC_t^C = MC_t^{Nom,C}/P_t = 1$.

Price setting in the export sector Firms in the final goods export sector set prices to maximize profits

$$\Pi_t^X = [(P_t^X(i) RER_t - MC_t^X) X_t(i) - AC_t^X(i)]. \tag{34}$$

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

$$AC_t^X(i) = \frac{\chi_X}{2}\left(\frac{\frac{P_t^X(i)}{P_{t-1}^X(i)}\pi_t^{TP}}{\left(\frac{P_{t-1}^X}{P_{t-2}^X}\pi_{t-1}^{TP}\right)^{\omega_{Ind}}(\pi_{ss}^{TP})^{1-\omega_{Ind}}} - 1\right)^2 X_t RER_t P_t^X, \tag{35}$$

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 ω_{Ind} is a parameter determining the degree of price indexation.[36]

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 (34) subject to the demand function given by equation (29), is provided in appendix A.4. The solution reveals that all exporting firms set identical prices such that $P_t^X(i) = P_t^X$. Because exporters set identical prices they also have the same output, the same profits, and the same demand for composite manufacturing and service goods, allowing us to drop the i subscript. Export prices in steady state are set at a mark-up over marginal costs:

$$RER_{ss}P_{ss}^X = MC_{ss}^X \frac{\epsilon_{ss}^X}{\epsilon_{ss}^X - 1}.$$

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

The full, dynamic pricing equation is given in the appendix.

Price setting in the consumption sector Since the price-setting problem of consumption firms is quite different we outline it separately here. A consumption sector firm i has the per-period profit given by

$$\Pi_t^C = \left[(P_t^C(i) - (1 + \tau_t^C + \tau_t^{CF})MC_t^C)C_t(i) - AC_t^C(i)\right]. \tag{36}$$

Hence per-period profits of the final consumption good sector are given by the difference in retailer price (i.e. the selling price of the consumption good) and the cost of production of one consumption good plus taxation. Note, since we express profits in real terms, the relative cost of production is given by $MC_t^C = MC_t^{Nom,C}/P_t = 1$. The taxation term τ_t^C is a value-added tax (VAT) on consumption and τ_t^{CF} are volume-based fees on consumption, where $\tau_t^{CF} = F_t^C/P_t$ such that F_t^C is the nominal fee per consumption good.[37] Price adjustment costs are analogously defined (with price adjustment cost parameter χ_C). Maximizing the present discounted value of the consumption good sector profits gives rise to a pricing equation analogous to the export good sector. In particular, in steady state, the price of the consumption good to households is given by $P_t^C = \frac{\epsilon_C}{\epsilon_C - 1}(1 + \tau_t^C + \tau_t^{CF})P_t$, and is thus given as a mark-up over the (after-tax) production cost of a consumption good.

2.6.3 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

$$Y_t^M(i) = Z_t^{Y^M}(K_t^G)^{\kappa_M}(K_t^M(i))^{\alpha_M}(N_t^M(i))^{1-\alpha_M} - FC^M, \tag{37}$$

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 or subsidies. 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.[38]

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 $P_t^M = \frac{P_t^{Nom,M}(i)}{P_t}$ 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 cost of inputs $\int_0^1 P_t^M(i)Y_t^M(i)di$, which yields a set of demand functions given by

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

[38] The parameter κ_M can be freely chosen by the model operator, implying that public investment shocks (see section 2.7.4) can also be assumed to have no effect on total factor productivity.

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

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

$$AC_t^M(i) = \frac{\chi_M}{2}\left(\frac{\frac{P_t^M(i)}{P_{t-1}^M(i)}\pi_t^{ATE}}{\left(\frac{P_{t-1}^M}{P_{t-2}^M}\pi_{t-1}^{ATE}\right)^{\omega_{Ind}}\pi_{ss}^{1-\omega_{Ind}}} - 1\right)^2 Y_t^M P_t^M,$$

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 ω_{Ind} is a parameter determining the degree of price indexation.[39]

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

$$K_{t+1}^M = Inv_t^M + (1-\delta_{KP})K_t^M, \tag{38}$$

where Inv_t^M denotes investments in the manufacturing sector and δ_{KP} is the capital depreciation rate.[40] The firm incurs costs to adjusting the level of investment

$$AC_t^{Inv,M} := \left(\frac{\chi_{Inv}}{2}\left(\frac{Inv_t^M}{Inv_{t-1}^M} - 1\right)^2\right) Inv_t^M,$$

where χ_{Inv} 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

$$P_t B_t^M \quad = \quad P_t BN_t^M + P_{t-1}B_{t-1}^M, \tag{39}$$

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.[41] The cost of borrowing for manufacturing firms is given by $R_{t-1}^L RP_{t-1}^{B,M}$-1, where $RP_t^{B,M}$ captures a risk premium that increases with the amount of borrowing, as captured

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

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

[41] 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.

by the firm's debt-to-capital ratio. In particular, we assume that

$$RP_t^{B,M} = \exp^{\xi_B\left(b_t^M - \beta^M\right)}, \tag{40}$$

where ξ_B captures the responsiveness of the risk premium to the debt-to-capital ratio and β^M is a parameter calibrated to ensure that NORA matches the empirical debt-to-capital ratio in Norwegian firms, see appendix A.10 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.[42] Additionally, firms face costs when adjusting the level of new borrowing.[43] Preserving the symmetry with investment adjustment costs we assume borrowing adjustment costs to be given by

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

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

$$\begin{aligned}\Pi_t^M(i) = \quad & \underbrace{P_t^M(i)Y_t^M(i)}_{\text{sales}} - \underbrace{(1+\tau_t^{SSF})W_t N_t^M(i)}_{\text{labor costs}} - \underbrace{(R_{t-1}^L RP_{t-1}^{B,M} - 1)\frac{B_{t-1}^M(i)}{\pi_t^{ATE}}}_{\text{interest on dom. borrowing}} \\ - \quad & \underbrace{(AC_t^M(i) + AC_t^{Inv,M}(i) + AC_t^{BN,M}(i))}_{\text{Adj. costs}},\end{aligned} \tag{41}$$

where $P_t^M(i)$ is the relative price of the firm's output and τ_t^{SSF} is the social security tax paid by firms.[44] Note that equation (41) represents profits after interest payments, which in accounting is typically referred to as earnings before income taxes (EBT). The tax base for the corporate profit tax is then given by

$$TB_t^{\Pi,M} = \Pi_t^M - \delta_\tau P_t^I K_t^M - TD^{OIF}.$$

Hence, deductable from profits is a depreciation allowance, where the tax depreciation rate is given by δ_τ. Following Sandmo (1974) differences in the true rate of depreciation of the firm's physical capital (δ_{KP}) distort investment decisions. Moreover, the term TD^{OIF} 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

$$\Pi_t^M(i) = \Pi_t^{R,M}(i) + DIV_t^M(i) + TB_t^{\Pi,M}(i)\tau_t^{OIF}. \tag{42}$$

where $\Pi_t^{R,M}$ are retained profits. Investments are financed either by retained profits $\Pi_t^{R,M}$ or new borrowing BN_t^M

$$P_t^I Inv_t^M = \Pi_t^{R,M} + BN_t^M. \tag{43}$$

[42] 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 $R_{t-1}^L(RP_{t-1}^{B,M} - 1)\frac{B_{t-1}^M}{\pi_t^{ATE}} + R_{t-1}^L(RP_{t-1}^{B,S} - 1)\frac{B_{t-1}^S}{\pi_t^{ATE}}$. This monetary stream is redistributed to the Ricardian household in each period in the numerical implementation of the model.

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

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

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.[45]

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 $R_{t+j}^e = \prod_{l=1}^{j} \frac{1-\Delta_{t+l}/\pi_{t+l}^{ATE}\tau_{t+l}^D(1+RRA_{t+l})}{\Delta_{t+l}(1-\tau_{t+l}^D)}$. It will prove useful to write the period-to-period discount factor for dividends as

$$DF_{t+j+1}^{DIV} := \frac{R_{t+j+1}^e}{R_{t+j}^e} = \frac{1 - \Delta_{t+j+1}/\pi_{t+j+1}^{ATE}\tau_{t+j+1}^D(1 + RRA_{t+j+1})}{\Delta_{t+j+1}(1 - \tau_{t+j+1}^D)}. \tag{44}$$

We can now identify

$$R_t^K := \frac{DF_{t+1}^{DIV} - 1}{1 - \tau_{t+1}^{OIF}}$$

as the implied interest rate on equity-financing. To see this note, that shareholders are indifferent between one unit of (pre-tax) dividends in period t and DF_{t+1}^{DIV} many in period t (in real terms) as DF_{t+1}^{DIV} captures the their discount factor on dividends. Hence, for firms to rely on equity financing, i.e. a reduction in dividends payed out, the investment, ignoring corporate taxes for now, needs to earn a gross return of DF_{t+1}^{DIV} and hence a net return of $DF_{t+1}^{DIV} - 1$.[46] Since, however, the return on these equity investments is taxed again at the corporate profit tax rate, the required return and thus cost of equity financing needs to be scaled by the inverse of the tax factor $(1 - \tau_{t+1}^{OIF})$. Finally, note, that the implied interest rate on equity (i.e. its required return) is identical across sectors.

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 $Inv_t^M(i)$ 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 38) and firm debt (see equation (39)) accumulates, and the need to satisfy the demand that materializes at the prevailing wage and price using the production technology in equation (37).

The first-order condition on ***labor*** (further details can be found in appendix A.5) is given by

$$(1 - \tau_t^{OIF})(1 + \tau_t^{SSF})W_t = (1 - \alpha_M)\lambda_t^{Y,M} \frac{Y_t^M(i) + FC^M}{N_t^M}. \tag{45}$$

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.

[45]This becomes evident when rearranging equation (43) to obtain $\Pi_t^{R,M} = P_t^I IN_t^M + (-BN_t^M)$ where the last term captures debt repayment. Hence, any rise in corporate profits can potentially increase investments but also non-investment saving of firms.

[46]The argument in nominal term is as follows: If a firm uses equity in period t to purchase one investment good at price $P_t^{Nom,I}$, it will decrease the level of dividends by that nominal amount in period t. Such an investment will only be in the interest of shareholders (and hence undertaken by firms) if it raises pre-tax firm value by $P_t^{Nom,I}\pi_{t+1}^{ATE}DF_{t+1}^{DIV}$ in the next period. The purchased investment good will, once it is transformed into a physical capital good, be worth $P_t^{Nom,I}\pi_{t+1}^{ATE}$. Hence the required nominal return on the investment is $(P_t^{Nom,I}\pi_{t+1}^{ATE}DF_{t+1}^{DIV} - P_t^{Nom,I}\pi_{t+1}^{ATE})/P_t^{Nom,I}$. The required real return is then $DF_{t+1}^{DIV} - 1$.

The first-order condition on ***investment*** is a complicated and lengthy expression that we relegate to appendix A.5. 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. Under certain simplifying assumptions (no price and investment adjustments costs, constant price of the investment good), the optimality condition on physical capital resembles the well-known expression in Sandmo (1974).[47]

$$\frac{\epsilon_M - 1}{\epsilon_M} P_{t+1}^M \frac{\partial Y_{t+1}^M}{\partial K_{t+1}^M} = P_t^I \left(R_t^K + \delta_{KP} + \frac{\tau_{t+1}^{OIF}(\delta_{KP} - \delta_\tau)}{1 - \tau_{t+1}^{OIF}} \right). \tag{46}$$

The left hand side captures the marginal value of one unit of capital in production in the next period. Note, that the relevant price is the selling price excluding the price mark-up.[48] This, in the optimum, is equated with the right hand side that captures the after-tax equity-financing cost, which is made up by two terms. First, the cost of equity depends on the implied interest rate on equity-financing plus depreciation: $R_t^K + \delta_{KP}$. If real and tax depreciation rates are equal, the cost of equity-financing are completely captured by these terms. If, however, tax depreciation rates are higher than actual depreciation rates (as is the case in the Norwegian tax code), the cost of equity financing is reduced accordingly. The equation, hence, captures the two main channels through which the corporate profit tax rate distorts firm's decision. First, it is directly increasing the required return on equity investments as evident from the definition of R_t^K. Second, the corporate profit tax rate lowers the implied after-tax rental cost of capital if tax depreciation rates exceed actual depreciation rates.

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 (derived in appendix A.5) is more complex 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

$$R_t^K + \frac{\pi_{t+1}^{ATE} - 1}{(1 - \tau_{t+1}^{OIF})\pi_{t+1}^{ATE}} = \frac{R_t^L RP_t^{B,M}(1 + \xi_B b_t^M) - 1}{\pi_{t+1}^{ATE}}. \tag{47}$$

The right-hand side of equation (47) 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 $RP_t^{B,M}$, and the marginal increase in the risk premium $\xi_B b_t^M$ caused by an increase in the debt-to-capital ratio, see equation (40). The left-hand side of equation (47) captures the cost of equity financing.[49] In particular the cost of equity declines with the rate-of-return allowance RRA_t, see definition of R_t^K and DF_t^{DIV}. Hence, a higher rate-of-return allowance will reduce the marginal cost of equity financing and shift financing away from debt to equity.[50]

[47] Note, that we make the assumption of a constant investment good price and the absence of adjustment costs to enable a better comparison with the results from Sandmo (1974) who derived his model under the same simplifying assumptions. See appendix A.5 for the derivation of the full optimality condition on capital as well as the simplified version given here.

[48] In Sandmo (1974) firms are perfectly competitive such that the mark-up term collapses to one.

[49] Note, that the cost of equity-financing, as opposed to equation (46), is increased by the term $\frac{\pi_{t+1}^{ATE}-1}{(1-\tau_{t+1}^{OIF})\pi_{t+1}^{ATE}}$ capturing the fact that debt-financed investments need to earn a higher return since the installed physical capital does not raise the value of the firm as the increase in assets is cancelled by the increase in debt.

[50] In appendix A.6, we show that if the ordinary income tax rate on households τ_t^{OIH} and on firm profits τ_t^{OIF} 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 NORA. 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, the financial fees associated with trading firm stocks in equation (5) imply an equity premium which is taxed and thus 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.

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

$$(1-\tau^{OIF})P^M = \lambda^{Y,M}\frac{\epsilon_M}{\epsilon_M - 1}. \tag{48}$$

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.[51]

2.6.4 Imported goods sector

Individual importing firms sell their output $IM_t(i)$ at a relative price $P_t^{IM}(i)$ 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

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

where ϵ_t^{IM} 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

$$IM_t(i) = \left(\frac{P_t^{IM}(i)}{P_t^{IM}}\right)^{-\epsilon_t^{IM}} IM_t. \tag{49}$$

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

Individual importing firms set prices in order to maximize profits

$$\Pi_{F,t}(i) = (P_t^{IM}(i) - RER_t)IM_t(i) - AC_t^{IM}(i), \tag{50}$$

where the "cost of production" equals the real exchange rate RER_t since this is 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

$$AC_t^{IM}(i) = \frac{\chi_{IM}}{2}\left(\frac{\frac{P_t^{IM}(i)}{P_{t-1}^{IM}(i)}\pi_t^{ATE}}{\left(\frac{P_{t-1}^{IM}}{P_{t-2}^{IM}}\pi_{t-1}^{ATE}\right)^{\omega_{Ind}}\pi_{ss}^{1-\omega_{Ind}}} - 1\right)^2 IM_t P_t^{IM}.$$

The solution to the price-setting problem, which involves maximizing the net present value of profits given by equation (50) subject to the demand function given by equation (49), is given in appendix A.7. The result implies that all import firms set the same price $P_t^{IM}(i) = P_t^{IM}$, and that in steady state the price is set as a markup over the real exchange rate $P^{IM} = RER\frac{\epsilon^{IM}}{\epsilon^{IM}-1}$.

2.7 Monetary and fiscal policy

Monetary policy in NORA 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

[51] 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 (48), 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.

comparable level of fiscal detail include Gadatsch et al. (2016) and Stähler and Thomas (2012).

2.7.1 Central bank

The central bank sets the nominal interest rate according to a rule from the 2019 version of NEMO (Kravik and Mimir, 2019)

$$R_t = \widetilde{R}_t \left(\frac{R_{t-1}}{\widetilde{R}_t}\right)^{\rho_R} \left(\left(\frac{\pi_t^{ATE,Ann}}{\widetilde{\pi}_t^{ATE,Ann}}\right)^{\psi_\pi} \left(\frac{\pi_{t+1}^{ATE,Ann}}{\widetilde{\pi}_t^{ATE,Ann}}\right)^{\psi_{\pi,F}} \left(\frac{\pi_{t+1}^{W,N}}{\widetilde{\pi}_t^{Nom,W}}\right)^{\psi_W} \left(\frac{Y_t}{\widetilde{Y}_t}\right)^{\psi_Y} \left(\frac{RER_t}{\widetilde{RER}_t}\right)^{\psi_{RER}} \right)^{1-\rho_R} \exp(Z_t^R), \tag{51}$$

where $\widetilde{X}_t \in \{\widetilde{R}_t, \widetilde{\pi}_t^{ATE,Ann}, \widetilde{\pi}_t^{Nom,W}, \widetilde{Y}_t, \widetilde{RER}_t\}$ denotes the (potentially time-varying) "target" value of X_t, which we discuss further below, $\pi_t^{ATE,Ann}$ is annualized quarterly inflation, and $\pi^{Nom,W}$ is nominal wage inflation. The parameters $\rho_R, \psi_\pi, \psi_{\pi,F}, \psi_W, \psi_Y$ and ψ_{RER} 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.[52] 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

$$\widetilde{X}_t = \left(X_T \left(\widetilde{X}_{t-1}\right)^{\rho_X}\right)^{\frac{1}{\rho_X+1}}$$

for the variables $X_t \in \{R_t, \pi_t^{ATE,Ann}, \pi_t^{Nom,W}, Y_t, RER_t\}$. 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.

2.7.2 Government budget

The government finances its expenditures, which consist of purchases of goods and services, 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
τ_t^{OIH}	Household ordinary income tax	Households
α_t^{OIH}	Scale-up factor for dividend taxation	Households
RRA_t	Allowance on return on shares	Households
τ_t^{OIF}	Firm ordinary income tax	Firms
τ_t^{LS}	labor surtax	Households
τ_t^{SSH}	Household social security contribution	Households
τ_t^{SSF}	Firm social security contribution	Firms
T_t^L	Lump-sum tax	Households

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

Total government revenue is thus given by

$$
\begin{aligned}
T_t = & \underbrace{T_t^L}_{\text{Lump-sum tax}} + \underbrace{C_t(\tau_t^C + F_t^C/P_t)}_{\text{Consumption taxes and fees}} + \underbrace{(W_t N_t^P + W_t^G N_t^G)\tau_t^{SSF}}_{\text{Social security contributions of employers}} \\
& + \underbrace{(W_t N_t^P + W_t^G N_t^G + UB_t(L_t - E_t) + TR_t + \frac{DP_{t-1}}{\pi_t^{ATE}}(R_{t-1} - 1) - TD^{OIH})\tau_t^{OIH}}_{\text{Ordinary income tax on personal income}} \\
& + \underbrace{(W_t N_t^P + W_t^G N_t^G + UB_t(L_t - E_t) + TR_t - TD^{LS})(\tau_t^{LS} + \tau_t^{SSH})}_{\text{Additional taxes on Labor income and transfers}} \\
& + \underbrace{(\Pi^{M,TB} + \Pi^{S,TB})\tau_t^{OIF}}_{\text{Corporate income taxation}} + \underbrace{\left(DIV_t + AV_t - RRA_t P_{t-1}^E\right)\alpha_t^{OIH}\tau_t^{OIH}}_{\text{Dividend and capital gains tax}},
\end{aligned}
\tag{52}
$$

where we exploit the fact that number of stocks are normalized to one, and sum up total dividends $DIV_t = DIV_t^M + DIV_t^S$, total 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

$$
\begin{aligned}
G_t = & \underbrace{P_t^{G^C} G_t^C}_{\text{Government purchases}} + \underbrace{P_t^I G_t^I}_{\text{Government investment}} + \underbrace{UB_t(L_t - E_t)}_{\text{Unemployment benefits}} \\
& + \underbrace{TR_t + AVT_t}_{\text{Lump-sum transfers}} + \underbrace{W_t^G N_t^G (1 + \tau_t^{SSF})}_{\text{Government wage bill}}.
\end{aligned}
\tag{53}
$$

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

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

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

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

where OFW_t denotes withdrawals from the Government Pension Fund Global (GPFG), that will be discussed in section 2.7.5.

The government budget constraint is then given by

$$\underbrace{D_{t-1}/\pi_t^{ATE} - D_t}_{\text{Net change in government debt}} = GS_t^{Adj} = OFW_t + T_t - G_t - DI_t. \tag{54}$$

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 (54) simplifies to

$$\underbrace{T_t}_{\text{Revenue}} + \underbrace{OFW_t}_{\text{Withdrawals from GPFG}} = \underbrace{G_t}_{\text{Government spending}} + \underbrace{DI_t}_{\text{Debt interest payments}} . \tag{55}$$

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 (55) always holds.

2.7.3 Government revenue and current spending

Unless they are "fiscal instruments" used to balance the budget in equation (55), 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

$$X_t = X_{ss} + \rho_X (X_{t-1} - X_{ss}) + Z_t^X, \tag{56}$$

where $X_t \in \{\tau_t^C, \tau_t^{OIH}, \tau_t^{OIF}, \tau_t^{LS}, \tau_t^{SSH}, \tau_t^{SSF}\}$ and X_{ss} denotes the steady state of X_t. Spending components (except public investment which is discussed in section 2.7.4) and non-tax-rate revenue instruments are assumed to follow the following multiplicative process

$$X_t = X_{ss} \left(\frac{X_{t-1}}{X_{ss}}\right)^{\rho_X} \exp(Z_t^X), \tag{57}$$

where $X_t \in \{G_t^C, T_t^L, OFW_t, TR_t^L, TR_t^R, UB_t, N_t^G, \alpha_t^{OIH}\}$. Hence, instrument X_t remains constant at its steady-state level X_{ss} 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 (56) and (57), 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.[53] 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.[54]

[53]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 (56) would take the form

$$X_t = X_{ss} + \rho_X (X_{t-1} - X_{ss}) + (1 - \rho_X)\phi_X \left(\frac{D_{t-1}}{Y_{t-1}} - \frac{D_{ss}}{Y_{ss}}\right) + Z_t^X,$$

while the process for current spending components and non-tax-rate revenue in equation (57) would follow

$$X_t = X_{ss} \left(\frac{X_{t-1}}{X_{ss}}\right)^{\rho_X} \left(\frac{D_{t-1}/Y_{t-1}}{D_{ss}/Y_{ss}}\right)^{(1-\rho_X)\phi_X} \exp(Z_t^X),$$

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.

[54]Nominal consumption fees F_t^C are adjusted by inflation every year, and thus have exactly the same effect in NORA 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 A.6 this implies that the RRA_t depends on the prevailing interest rate and the household's ordinary income tax rate

$$RRA_t = (R_t - 1)(1 - \tau_t^{OIH}).$$

It is currently not possible to independently shock the RRA_t.

2.7.4 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.

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

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

where $G^{I,Auth}_{t=1}$ 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 $G^I_{t=1} = \phi_1 G^{I,Auth}_{t=1}$ and in the second period to $G^I_{t=2} = \phi_2 G^{I,Auth}_{t=1}$, 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.

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 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

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

where δ_{KG} is the depreciation rate of public capital and $G^{I,Auth}_{t-N+1}$ is the authorized amount of public investment $N-1$ 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 ω_n. Hence, ω_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 G^I_t is then given by

$$G^I_t = \sum_{n=0}^{N-1} \omega_n G^{I,Auth}_{t-n}. \tag{58}$$

Equation (58) 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, $\sum_{n=0}^{N-1} \omega_n = 1$ holds.

The amount of authorized public investments follows the autoregressive process

$$G^{I,Auth}_t = G^{I,Auth}_{ss} \left(\frac{G^{I,Auth}_{t-1}}{G^{I,Auth}_{ss}} \right)^{\rho_A} \exp(Z^{G^{I,Auth}}_t),$$

where $G^{I,Auth}_{ss}$ is the steady-state level of authorized investment, $Z^{G^{I,Auth}}_t$ is a shock to authorized public investment, and ρ_A is an autoregressive parameter that determines the speed at which a shock $Z^{G^{I,Auth}}_t$ translates into higher authorized public investment.

2.7.5 Government pension fund global

NORA 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.[55] 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 NORA, 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 OF_t (for "oil fund") is assumed to evolve according to the following process:

$$OF_t = (1 + R^{OF})OF_{t-1} - \frac{OFW_t}{RER_{ss}}, \tag{59}$$

where R^{OF} is the constant real rate of return of the fund, RER_{ss} is the steady-state exchange rate, and OFW_t denotes the domestic-currency value of withdrawals from the GPFG. Hence, $\frac{OFW_t}{RER_{ss}}$ captures the value of oil fund withdrawals in foreign currency.

During simulations it is possible to use oil fund withdrawals OFW_t as a financing instrument. This can be done in two ways. In the first case, equation (59) 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.[56]

In the second case, equation (59) is active and changes in OFW_t will affect the value of the GPFG. In order to avoid an imploding (or exploding) value of the fund, the take-out rate $TOR_t := \frac{OFW_t}{RER_{ss} \cdot OF_t}$ has to return to the real rate of return of the GPFG in the long run

$$TOR_{ss} = R^{OF}.$$

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.

2.8 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^{TP}, foreign output by trading Y_t^{TP} and non-trading Y_t^{NTP} partners, the foreign interest rate R_t^{TP} 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 Inv_t^{Oil} in a reduced-form fashion depending on the oil price.

[55] 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.

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

The output of trading partners Y_t^{TP} is given by the following system of equations

$$
\begin{aligned}
Y_t^{TP} &= Y_{ss}^{TP}\left(\frac{Y_{t-1}^{TP}}{Y_{ss}^{TP}}\right)^{\rho_{Y^{TP}}}\left(\frac{Y_t^{F,TP}}{Y_{ss}^{F,TP}}\right)^{1-\rho_{Y^{TP}}}\left(\frac{P_t^{Oil}}{P_{ss}^{Oil}}\right)^{-\psi_{Y^{TP},P^{Oil}}}\left(\frac{Y_t^{NTP}}{Y_{ss}^{NTP}}\right)^{\psi_{Y^{TP},Y^{NTP}}}\exp(Z_t^{Y^{TP}}),\\
Y_t^{F,TP} &= Y_{ss}^{F,TP}\left(\frac{Y_{t+1}^{F,TP}}{Y_{ss}^{F,TP}}\right)^{\psi_{Y^{F,TP},Y^{F,TP}}}\left(\frac{R_t^{TP}}{\pi_{t+1}^{TP}}/\frac{R_{ss}^{TP}}{\pi_{ss}^{TP}}\right)^{-\psi_{Y^{F,TP},R^{TP}}}.
\end{aligned}
$$

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 $Y_t^{F,TP}$, 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 $Z_t^{Y^{TP}}$ denotes a shock to the output of trading partners.

The output of non-trading partners Y_t^{NTP} is given by

$$
Y_t^{NTP} = Y_{ss}^{NTP}\left(\frac{Y_{t-1}^{*,NTP}}{Y_{ss}^{NTP}}\right)^{\rho_{Y^{NTP}}}\left(\frac{P_t^{Oil}}{P_{ss}^{Oil}}\right)^{-\psi_{Y^{NTP},P^{Oil}}}\left(\frac{Y_t^{TP}}{Y_{ss}^{TP}}\right)^{\psi_{Y^{NTP},Y^{TP}}}\exp(Z_t^{Y^{NTP}}).
$$

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:

$$
\frac{Y_t^{Glob}}{Y_{ss}^{Glob}} = \omega_{Y,TP}\frac{Y_t^{TP}}{Y_{ss}^{TP}} + (1-\omega_{Y,TP})\frac{Y_t^{NTP}}{Y_{ss}^{NTP}},
$$

where $\omega_{Y,TP}$ 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

$$
\begin{aligned}
\pi_t^{TP} &= \pi_{ss}^{TP}\left(\frac{\pi_{t-1}^{TP}}{\pi_{ss}^{TP}}\right)^{\rho_{\pi^{TP}}}\left(\frac{\pi_t^{F,TP}}{\pi_{ss}^{F,TP}}\right)^{1-\rho_{\pi^{TP}}}\left(\frac{P_t^{Oil}}{P_{ss}^{Oil}}\right)^{\psi_{\pi^{TP},P^{Oil}}},\\
\pi_t^{F,TP} &= \pi_{ss}^{F,TP}\left(\frac{\pi_{t+1}^{F,TP}}{\pi_{ss}^{F,TP}}\right)^{\psi_{\pi^{F,TP},\pi^{F,TP}}}\left(\frac{Y_t^{TP}}{Y_{ss}^{TP}}\right)^{\psi_{\pi^{F,TP},Y^{TP}}}\exp(Z_t^{\pi^{TP}}).
\end{aligned}
$$

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 $\pi_t^{F,TP}$. The shock $Z_t^{\pi^{TP}}$ 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

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

The parameters $\psi_{\pi^{TP}}$ and $\psi_{Y^{TP}}$ capture the weights placed by the foreign trading partner central bank on preventing deviations of inflation from target and keeping output at potential, while $\rho_{R^{TP}}$ captures the weight placed on interest rate smoothing. The shock $Z_t^{R^{TP}}$ 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

$$P_t^{Oil} = P_{ss}^{Oil} \left(\frac{P_{t+1}^{Oil}}{P_{ss}^{Oil}} \right)^{\psi_{POil}} \left(\frac{Y_t^{Glob}}{Y_{ss}^{Glob}} \right)^{\psi_{Poil,YGlob}} \exp(Z_t^{P^{OIL}}),$$

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

$$Inv_t^{Oil} = Inv_{ss}^{OIL} \left(\frac{Inv_{t-1}^{Oil}}{Inv_{ss}^{OIL}} \right)^{\rho_{InvOil}} \left(\frac{P_t^{Oil}}{P_{ss}^{Oil}} \right)^{\psi_{InvOil,POil}} \exp(Z_t^{Inv^{OIL}}),$$

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

2.9 Aggregation and market clearing

To complete the technical description of NORA 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.

2.9.1 Total investment demand

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

$$I_t = Inv_t^M + Inv_t^S + Inv_t^H + Inv_t^{Oil} + G_t^I.$$

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

2.9.2 Housing

We differentiate between housing investment and investment in physical capital in the corporate sector. The accumulation of physical capital is described in section 2.6.3. Housing investment is modeled as a reduced-form process.[57] Housing investments are assumed to evolve in line with long-run changes in GDP

$$Inv_t^H = Inv_{ss}^H \frac{\widetilde{Y}_t}{Y_{ss}}.$$

The moving-average process for GDP ensures housing investment will gradually converge to a new level following permanent changes in GDP. Housing capital evolves according to

$$K_{t+1}^H = (1 - \delta_H) K_t^H + Inv_t^H,$$

where δ_H is the depreciation rate on housing capital. Consumption of housing services, a component of GDP, is defined as $C_t^H = R^H K_t^H$ where R^H is the return on housing capital. We are agnostic about who owns the

[57]This approach avoids having to calibrate corporate investments to a empirical target that includes housing investments, which would alter the transmission mechanism of corporate taxation. For example the tax on corporate profits would then implicitly be applied not only to the returns to corporate capital but also to housing capital.

housing capital and consumes the associated housing services and do therefore not take these into account when we model the household sector.

2.9.3 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 $Z_t \in \{C_t, I_t, X_t, G_t^C\}$ in the economy

$$
\begin{aligned}
Y_t^M &= Y_t^{M,C} + Y_t^{M,I} + Y_t^{M,G^C} + Y_t^{M,X}, \\
Y_t^S &= Y_t^{S,C} + Y_t^{S,I} + Y_t^{S,G^C} + Y_t^{S,X}, \\
IM_t &= IM_t^{M,C} + IM_t^{M,I} + IM_t^{M,G^C} + IM_t^{M,X} + IM_t^{S,C} + IM_t^{S,I} + IM_t^{S,G^C} + IM_t^{S,X}.
\end{aligned}
\tag{60}
$$

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 intermediate manufacturing good and the intermediate service good in the production of the four final goods, the expression for total production in the import sector in equation (60) consists of a total of eight terms.[58]

2.9.4 Domestic output

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

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

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

$$
P_t^Y Y_t^D = \underbrace{P_t^M Y_t^{D,M} + P_t^S Y_t^{D,S}}_{\text{Value of domestically-sold output}} + \underbrace{RER_t P_t^X X_t - P_t^{IM}(IM_t^{M,X} + IM_t^{S,X})}_{\text{Value added in the export sector}},
$$

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 2.6.2 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

$$
P_t^Y Y_t^D = P_t^M Y_t^M + P_t^S Y_t^S + VA_t^X X_t, \tag{61}
$$

where $VA_t^X = RER_t P_t^X - MC_t^X$ is the value added per unit in the export sector. Marginal costs in the final export sector MC_t^X are given in equation (33). Profits in the export sector are then given by $\Pi_t^X = VA_t^X X_t - AC_t^X$. Adjustment costs in the final export sector AC_t^X are defined in equation (35).

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

[58] 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 A.8 for further details. GDP is then defined as the sum of domestic output, the return to housing (which equals housing services consumption), the government wage bill, public capital depreciation and inventory changes

$$Y_t = Y_t^D + R^H K_t^H + \frac{(1+\tau_{ss}^{SSF})W_{ss}^G}{P_{ss}^Y} N_t^G + \frac{P_{ss}^I \delta_{KG}}{P_{ss}^Y} K_t^G + \Delta INV_t. \tag{62}$$

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 (62) 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 components in the GDP definition. Inventory changes ΔINV_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

$$\begin{aligned} Y_t^{CPI} &= P_t^Y Y_t \\ &= P_t^Y Y_t^D + P_t^Y R^H K_t^H + (1+\tau_{ss}^{SSF})W_{ss}^G N_t^G + P_{ss}^I \delta_{KG} K_t^G + P_t^Y \Delta INV_t. \end{aligned}$$

2.9.5 Balance of payments

Before deriving the balance of payments we introduce "residual" imports IM_t^{Res} that are necessary for NORA 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 NORA 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.

$$IM_t^{Res} = IM_{ss}^{Res} \frac{IM_t}{IM_{ss}},$$

where IM_{ss}^{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

$$NX_t = RER_t P_t^X X_t - P_t^{IM}(IM_t + IM_t^{Res}),$$

where $RER_t P_t^X$ is the relative domestic-currency price of exports and P_t^{IM} is the relative price of imports.

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

$$NX_t + OFW_t + P_t^I Inv_t^{Oil} = \frac{EX_t P_t^{TP}}{P_t}(-B_t^F) - \frac{EX_t P_{t-1}^{TP}}{P_t}(-B_{t-1}^F) R_{t-1}^{TP} RP_{t-1}(A_{t-1}). \tag{63}$$

The left hand side of equation (63) 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 mainland economy) and a non-resident.[59] The right hand side of equation (63) captures the net change in in foreign assets (excluding the GPFG) including interest income.[60]

2.9.6 Aggregate market clearing

We obtain the aggregate market clearing condition by inserting the balance of payments in equation (63), the government budget constraint in equation (54), the budget constraint for liquidity-constrained households in equation (9), the profit functions of intermediate goods firms in the manufacturing and service sector in (41), and the bank balance sheet in equation (17) into the budget constraint of Ricardian households in equation (5), yielding

$$P_t^Y Y_t^D = C_t + NX_t + P_t^I I_t + P_t^{G^C} G_t^C + AC_t, \tag{64}$$

where AC_t are total adjustment costs in the economy.[61]. The aggregate market clearing condition in equation (64) differs from the definition of output in (61) in that the latter expresses total output as the sum of domestic production, i.e. from the supply side of the economy, whereas equation (64) expresses GDP as the sum of total demand. Together equations (61) and (64) shows that supply equals demand in our model economy.

2.10 Shocks

The shocks in NORA 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 θ_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 occurring in NORA.

Manufacturing sector technology shock

$$Z_t^{Y^M} = \theta_{Y^M} Z_{t-1}^{Y^M} + \sigma_{Y^M} E_t^{Y^M}$$

Service sector technology shock

$$Z_t^{Y^S} = \theta_{Y^S} Z_{t-1}^{Y^S} + \sigma_{Y^S} E_t^{Y^S}$$

Consumption preferences shock

$$Z_t^{U} = \theta_{U} Z_{t-1}^{U} + \sigma_{U} E_t^{U}$$

Risk premium shock

$$Z_t^{RP} = \theta_{RP} Z_{t-1}^{RP} + \sigma_{RP} E_t^{RP}$$

Monetary policy shock

$$Z_t^{R} = \theta_{R} Z_{t-1}^{R} + \sigma_{R} E_t^{R}$$

Trading partners' output shock

$$Z_t^{Y^{TP}} = \theta_{Y^{TP}} Z_{t-1}^{Y^{TP}} + \sigma_{Y^{TP}} E_t^{Y^{TP}}$$

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

[60] 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.

[61] Further details on the derivation of the aggregate market clearing condition can be found in the appendix A.9

Non-trading partners' output shock

$$Z_t^{Y^{NTP}} = \theta_{Y^{NTP}} Z_{t-1}^{Y^{NTP}} + \sigma_{Y^{NTP}} E_t^{Y^{NTP}}$$

Foreign inflation shock

$$Z_t^{\pi^{TP}} = \theta_{\pi^{TP}} Z_{t-1}^{\pi^{TP}} + \sigma_{\pi^{TP}} E_t^{\pi^{TP}}$$

Foreign monetary policy shock

$$Z_t^{R^{TP}} = \theta_{R^{TP}} Z_{t-1}^{R^{TP}} + \sigma_{R^{TP}} E_t^{R^{TP}}$$

Government purchases shock

$$Z_t^{G^C} = \theta_{G^C} Z_{t-1}^{G^C} + \sigma_{G^C} E_t^{G^C}$$

Lump-sum tax shock

$$Z_t^{T^L} = \theta_{T^L} Z_{t-1}^{T^L} + \sigma_{T^L} E_t^{T^L}$$

Consumption tax shock

$$Z_t^{\tau^C} = \theta_{\tau^C} Z_{t-1}^{\tau^C} + \sigma_{\tau^C} E_t^{\tau^C}$$

Household ordinary income tax shock

$$Z_t^{\tau^{OIH}} = \theta_{\tau^{OIH}} Z_{t-1}^{\tau^{OIH}} + \sigma_{\tau^{OIH}} E_t^{\tau^{OIH}}$$

Firm ordinary income tax shock

$$Z_t^{\tau^{OIF}} = \theta_{\tau^{OIF}} Z_{t-1}^{\tau^{OIF}} + \sigma_{\tau^{OIF}} E_t^{\tau^{OIF}}$$

labor surtax shock

$$Z_t^{\tau^{LS}} = \theta_{\tau^{LS}} Z_{t-1}^{\tau^{LS}} + \sigma_{\tau^{LS}} E_t^{\tau^{LS}}$$

Household social security contributions shock

$$Z_t^{\tau^{SSH}} = \theta_{\tau^{SSH}} Z_{t-1}^{\tau^{SSH}} + \sigma_{\tau^{SSH}} E_t^{\tau^{SSH}}$$

Firm social security contributions shock

$$Z_t^{\tau^{SSF}} = \theta_{\tau^{SSF}} Z_{t-1}^{\tau^{SSF}} + \sigma_{\tau^{SSF}} E_t^{\tau^{SSF}}$$

Oil fund withdrawals shock

$$Z_t^{OFW} = \theta_{OFW} Z_{t-1}^{OFW} + \sigma_{OFW} E_t^{OFW}$$

Government employment shock

$$Z_t^{NG} = \theta_{NG} Z_{t-1}^{NG} + \sigma_{NG} E_t^{NG}$$

Government authorized investment shock

$$Z_t^{G^{I,Auth}} = \theta_{G^{I,Auth}} Z_{t-1}^{G^{I,Auth}} + \sigma_{G^{I,Auth}} E_t^{G^{I,Auth}}$$

Oil sector investment shock

$$Z_t^{Inv^{OIL}} = \theta_{Inv^{OIL}} Z_{t-1}^{Inv^{OIL}} + \sigma_{Inv^{OIL}} E_t^{Inv^{OIL}}$$

Transfers to liquidity-constrained households shock

$$Z_t^{TR^L} = \theta_{TR^L} Z_{t-1}^{TR^L} + \sigma_{TR^L} E_t^{TR^L}$$

Transfers to Ricardian households shock

$$Z_t^{TR^R} = \theta_{TR^R} Z_{t-1}^{TR^R} + \sigma_{TR^R} E_t^{TR^R}$$

Oil price shock

$$Z_t^{POIL} = \theta_{POIL} Z_{t-1}^{POIL} + \sigma_{POIL} E_t^{POIL}$$

Labor force participation shock

$$Z_t^{L} = \theta_L Z_{t-1}^{L} + \sigma_L E_t^{L}$$

Nash reference utility shock

$$Z_t^{V} = \theta_V Z_{t-1}^{V} + \sigma_V E_t^{V}$$

3 Calibration

The current version of NORA is calibrated to the Norwegian mainland economy following a two-step strategy. In a first step the parameters that determine the steady state of NORA 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.[62] In a second step parameters that only affect the dynamic properties of NORA 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).[63] 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 NORA are reported in table 2.

We first discuss the steady-state parameters that are chosen such that the deterministic steady-state of NORA replicates long-run targets in the data.[64] 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 A.10. In what follows we provide a brief summary.

The steady-state gross inflation rate in Norway π_{ss}^{ATE} is set to two percent annually, consistent with Norges Banks new inflation target. The inflation rate including consumption taxes and fees is identical in steady state ($\pi_{ss} = \pi_{ss}^{ATE}$). The steady-state rate of inflation in Norway's trading partners π_{ss}^{TP} 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 (20) then implies a steady-state nominal interest rate abroad of the same value as in Norway.

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

[63] 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).

[64] 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.

Table 2: Steady-state parameters

Parameter	Description	Value
σ	Intertemporal elasticity of substitution	1.01
$\eta_{M,C}$, $\eta_{S,C}$	Elasticity of substitution across imports and domestic goods for consumption	0.5
$\eta_{M,I}$, $\eta_{S,I}$	Elasticity of substitution across imports and domestic goods for investment	0.5
η_{M,G^C}, η_{S,G^C}	Elasticity of substitution across imports and domestic goods for government purchases	0.5
η_X^M, $\eta_{S,X}$	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_{G^C}	Elasticity of substitution across sectors for government purchases	1.01
η_X	Elasticity of substitution across sectors for exports	1.01
η_{TP}	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^{IM}	Elasticity of substitution across differentiated imported goods	6
ϵ^X	Elasticity of substitution across differentiated export goods	6
ϵ_C	Elasticity of substitution across differentiated consumption goods	21
ω	Share of liquidity-constrained households	0.3
β	Discount factor	0.9973
δ_{KP}	Private capital depreciation (quarterly)	0.0217
δ_{KG}	Public capital depreciation (quarterly)	0.0201
δ_H	Housing capital depreciation (quarterly)	0.0121
δ_τ	Tax depreciation rate (quarterly)	0.0330
$\alpha_{M,C}, \alpha_{S,C}$	Import content of composite consumption good	0.54, 0.25
$\alpha_{M,I}, \alpha_{S,I}$	Import content of composite investment good	0.68, 0.28
$\alpha_{M,G^C}, \alpha_{S,G^C}$	Import content of composite government purchases good	0.87, 0.15
$\alpha_{M,X}, \alpha_{S,X}$	Import content of composite export good	0.33, 0.20
α_C	Service sector bias of final consumption good	0.65
α_I	Service sector bias of final investment good	0.84
α_{G^C}	Service sector bias of final government purchases good	0.83
α_X	Service sector bias of final export good	0.55
α_M, α_S	Capital elasticity in production function	0.32
F^S	Financial fees on stocks (quarterly)	0.0074
c_N	Constant in union's utility function	103.3
R^H	Return on housing capital (quarterly)	0.0169
TD^{OIH}	Tax deduction, ordinary income tax on households	0.5585
$TD^{OIF,M}$	Tax deduction, ordinary income tax on manufacturing sector firms	0.0316
$TD^{OIF,S}$	Tax deduction, ordinary income tax on service sector firms	0.1136
TD^{LS}	Tax deduction parameter, labor surtax and social security contribution	-0.1163
σ_N	Curvature of wage utility	1.01
γ	Bargaining power parameter	0.5
ν_U	Weight of unemployment in reference utility	0.8

In line with the assumptions in NOU (2016) we assume that the steady-state equity premium ("aksjepremie") is 3 percent per year. Given the derived relationship between financial fees and the equity premium in NORA, see appendix A.1, we set financial fees $F^S = 0.0074$ to obtain the empirical value for the equity premium. We furthermore assume that $F_t^S = F^S$, in other words financial fees are constant over time.

We set the service sector bias of the final consumption good α_C, investment good α_I, government consumption good α_{G^C} and export good α_X to the values reported in the table to match the values in the input-output tables underlying the national accounts.[65] National account input-output table also allow us to determine the import content of the composite manufacturing and service good used in the production of all four final goods.

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

Taken together these parameters yield GDP shares of the four final goods C_t, I_t, G_t^C, 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 NORA 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 tax depreciation rate is set to $\delta_\tau = 0.033$ corresponding to the average tax depreciation rate in the data, see appendix C.2 for more details. The government wage bill as a share of GDP is calibrated to its empirical counterpart by setting the wage mark-up $MARKUP^{GW}$ to 1.41. As noted in section 2.9.5 the combined import-content of the four final goods in NORA does not match the aggregate import share in the national accounts. We overcome this discrepancy by setting steady-state residual imports IM_{ss}^{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_{ss}^{TP} 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 0.32. We set the deprecation rate of private capital δ_{KP} to 0.0217 (approximately 9.0 percent per annum) to be consistent with the calibrated values of private investment and capital to GDP ratios. Analogously we set the depreciation rate for housing $\delta_H = 0.0121$ (approximately 4.9 percent per annum) to match the ratio of housing investment to housing capital in the steady state. The return on housing is set to $R^H = 0.0169$ in order to match the empirically determined housing consumption to GDP ratio. 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 NORA.[66] We set the tax deduction parameters according to the values in table 2 such that the tax base to GDP ratio is in line with the data. 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.[67] 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, see the appendix for more details. We are not able to calibrate the amount of oil fund withdrawals OFW directly. This is because OFW is used as balancing item to make sure the balance of payments holds. As shown in table 3 NORA 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 NE 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 0.49 and 0.19 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 4.4 percent. The labor income share is matched exactly by setting fixed costs in manufacturing and service sector to the appro-

[66] Further details on our methodology for calculating effective tax rate can be found in appendix C.
[67] No such deduction exists in the Norwegian tax code.

priate value, see appendix A.10 for details. The constant in the union utility function c_N is set to 103.3 to ensure that the wage setting equation holds in steady state.

The remaining 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 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 (Konjunkturinstitutet, 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 ($\eta_{M,Z}$) and service ($\eta_{S,Z}$) sector for each of the four final goods $Z \in \{C, I, X, G^C\}$. 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_{TP} 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 (Konjunkturinstitutet, 2019) and the RAMSES model at the Swedish Riksbank (Adolfson et al., 2013).

The elasticity of substitution across sectors η_Z is set close to 1 for each of the four final goods $Z \in \{C, I, X, G^C\}$. 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_t^{IM}), and exported goods (ϵ_t^X), which implies a markup of 20 percent. Following Voigts (2016) we set the elasticity of substitution across final consumption good firms to $\epsilon_C = 30$.

The remaining parameters describing wage setting are set to obtain realistic fiscal multipliers in NORA. The curvature of the union's utility function σ_N over wages is set to 1.01, approximating logarithmic utility. We follow Gertler and Trigari (2009) and set the bargaining parameter γ to 0.5, implying equal weight on the payoff function of firms and the union in the Nash product in equation (13). The weight of unemployment in the reference utility ν_U is set to a 0.8 in order to obtain higher real wages in tighter labor market conditions as predicted by the wage curve.

3.2 Dynamic parameters

Most of the dynamic parameters in the domestic economy block of NORA 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. parameters in the labor market block) or need to be fixed to ensure reasonable model dynamics following permanent shocks. As there is an exact correspondence between the foreign economy block in NORA 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 13 dynamic parameters in order to minimize the distance between the response of 10 macroeconomic variables to 5 macroeconomic shocks in NORA and the most recently-estimated version of NEMO (Kravik and Mimir, 2019). The five shocks included in the impulse

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	0.431	0.431	Yes
Housing consumption	0.086	0.086	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
Housing investment	0.062	0.062	Yes
Private investment	0.090	0.090	Yes
Oil sector investment	0.073	0.073	Yes
Total imports	0.348	0.348	Yes
Imports by importing firms	0.315	0.315	Yes
Residual imports	0.033		No
Exports	0.224	0.224	Yes
Changes in inventory	0.001	0.052	No
Stocks (ratio to mainland yearly GDP)			
Private capital stock	1.036	1.036	Yes
Housing capital stock	1.266	1.266	Yes
Public capital stock	0.694	0.694	Yes
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	0.192	0.192	Yes
Transfers to liquidity-constrained household	0.101		No
Transfers to Ricardian household	0.091		No
Oil fund withdrawals	0.06	0.058	No
Lump-sum taxation	0.054		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	0.413	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
Labor surtax 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	0.682	0.682	Yes
Public sector employment rate	0.191	0.191	Yes
Private sector employment rate	0.490	0.490	Yes
Unemployment rate (percent of labor force)	0.044	0.044	Yes
Labor force participation rate	0.713	0.713	Yes
Labor income share	0.471	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.

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 NORA does a reasonably job at matching the impulse

Table 4: Overview on dynamic parameters

Parameter	Description	Value	Source
Labor market			
ρ_E	Persistence in employment	0.72	Authors' choice
ρ^W	Persistence in wages	0.05	Authors' choice
Risk premia			
ξ_{NFA}	Risk premium parameter for net foreign assets	0.001	IRF matching
ξ_{EX}	Risk premium parameter for nominal exchange rate	0.00	IRF matching
ξ_{OF}	Risk premium parameter for sovereign wealth fund proxy	0.017	IRF matching
$\rho_{OF,RP}$	Persistence in wealth fund proxy	0.81	IRF matching
ξ_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	1000	IRF matching
χ_S	Adjustment cost parameter for service sector	1000	IRF matching
χ_{IM}	Adjustment cost parameter for imports	1000	IRF matching
χ_X	Adjustment cost parameter for exports	864.7	IRF matching
χ_C	Adjustment cost parameter for consumption goods	21	Author's choice
ω_{Ind}	Degree of indexation in price adjustments	0.62	IRF matching
χ_{Inv}	Adjustment cost parameter for investments	13.0	IRF matching
χ_{BN}	Adjustment cost parameter for new debt	0.025	Author's choice
Monetary policy			
ρ_R	Persistence in interest rate	0.67	NEMO 2019
ψ_π	Interest rate response to annual inflation	0	NEMO 2019
$\psi_{\pi,F}$	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_{RER}	Interest rate response to real exchange rate	0.02	NEMO 2019
ρ_X	Persistence in target	10	Authors' choice
Shock processes			
θ_Y	Persistence in technology shock	0.804	NEMO 2019
θ_{RP}	Persistence in risk premium shock	0.737	NEMO 2019
θ_{POil}	Persistence in oil price shock	0.874	NEMO 2019
θ_{YNTP}	Persistence in global demand shock	0	NEMO 2019
Foreign sector			
$\omega_{Y,TP}$	Weight of trading partner output in global output	0.1	NEMO 2019
ρ_{YTP}	Persistence in trading partners' output	0.615	NEMO 2019
ρ_{YNTP}	Persistence in non-trading partners' output	0.926	NEMO 2019
$\rho_{\pi TP}$	Persistence in foreign inflation	0.886	NEMO 2019
ρ_{RTP}	Persistence in foreign interest rate	0.841	NEMO 2019
$\psi_{Y^{F,TP},Y^{F,TP}}$	Persistence in forward-looking foreign output	1	NEMO 2019
$\psi_{Y^{F,TP},R^{TP}}$	Effect of real interest rate on foreign IS curve	0.757	NEMO 2019
$\psi_{Y^{TP},P^{Oil}}$	Effect of oil price on trading partners output	0.0048	NEMO 2019
$\psi_{Y^{NTP},P^{Oil}}$	Effect of oil price on non-trading partners output	0.0012	NEMO 2019
$\psi_{Y^{TP},Y^{NTP}}$	Effect of non-trading partner on trading partner output	1.0994	NEMO 2019
$\psi_{Y^{NTP},Y^{TP}}$	Effect of trading partner on non-trading partner output	0.0114	NEMO 2019
$\psi_{\pi^{F,TP},\pi^{F,TP}}$	Effect of inflation in foreign forward-looking Philips curve	0.1497	NEMO 2019
$\psi_{\pi^{F,TP},Y^{TP}}$	Effect of output in foreign forward-looking Philips curve	0.0462	NEMO 2019
$\psi_{\pi^{TP},P^{Oil}}$	Effect of oil price on foreign price level	0.0006	NEMO 2019
$\psi_{\pi^{TP}}$	Responsiveness to inflation in foreign Taylor rule	1.4606	NEMO 2019
$\psi_{Y^{TP}}$	Responsiveness to output in foreign Taylor rule	0.04	NEMO 2019
$\psi_{P^{Oil}}$	Persistence in oil price	0.2026	NEMO 2019
$\psi_{Poil,YGlob}$	Effect of global output on oil price	4.0027	NEMO 2019
$\psi_{InvOil,POil}$	Effect of oil price on oil sector investment	0.0929	IRF matching
$\rho_{Inv^{Oil}}$	Persistence in oil sector investment	0.7428	IRF matching

responses from NEMO (see appendix B). In the remainder of this section we discuss the parameter estimates resulting from the impulse response matching procedure.

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.[68]

Given that NEMO only includes one non-oil production sector, the impulse responses from that model are not informative about the relative size of price adjustment costs in the domestic manufacturing (χ_M) and service sectors (χ_S) in NORA. As a result, the parameters capturing the cost of changing prices in these sectors are assumed to be identical during the matching procedure. The estimate of 1000 (upper bound) 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 NORA compared to NEMO.[69]

The upper bound of 1000 imposed during the matching procedure is binding for the parameter governing the cost of changing import prices (χ_{IM}), which is slightly higher than the NEMO estimate of 830.1. The parameter for the cost of adjusting exp export prices in foreign currency (χ_X) is estimated at 864.7. 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 adjustment cost parameter in the final good consumption sector, $\chi_C = 21$, is calibrated to match the results from Benedek et al. (2015), who measure the total pass-through of a standard VAT reform, announced 1 year ahead. They found that approximately 70 % of the total pass-through is completed by the time of the VAT reform due to anticipation effects. In NORA, we obtain this amount of anticipated pass-through in an announced VAT reform by setting $\chi_C = 21$.

The parameter determining the degree of backward indexation of prices (ω_{Ind}) is important for generating the hump-shaped response of inflation and wages to shocks that is typically observed in empirical models. The point estimate for (ω_{Ind}) is 0.63 compared to a value of 1 in NEMO.[70]

The parameters in the labor market block, including parameters related to the behaviour of labor force participation, unemployment, and wage bargaining, are calibrated directly rather than estimated using impulse response matching. This is because NEMO does not provide information on many of these variables and because wages in NEMO are determined in a setting that is not comparable to that in NORA. 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). The parameter governing the rate of adjustment of wages α^N is set to 0.05 to generate a sluggish wage response in NORA. No comparable parameter exists in NEMO.

The point estimate of the adjustment cost parameter for investment (χ_{Inv}) in the services and manufacturing sectors is 13.0. 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 ($\psi_{InvOil,POil}$) is 0.092. We further estimate the persistence parameter of oil sector investments ($\rho_{Inv^{Oil}}$) to be 0.7428. 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.

[68]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 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).

[69]Note, that even higher values of price adjustment costs give negligibly small increases in internal persistency in the model, such that the upper bound of 1000 does not impact simulation results in a significant way.

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

The risk premium parameters have a significant bearing on the response of the exchange rate, interest rates, and inflation in NORA. The point estimate for the elasticity of the risk premium to net foreign assets (ξ_{NFA}) is at the lower bound of 0.001 imposed during the matching procedure. This is 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 0.00. This is line with NEMO where this parameter is also set to zero. 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 ($\rho_{OF,RP}$) to be 0.81 and the elasticity of the risk premium to changes in the wealth fund (ξ_{OF}) to be 0.017. The parameter governing the risk premium for firm borrowing (ξ_B) is set to 0.025, which gives rise to realistic movements in firm borrowing.

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 2.7.1, 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 $\rho_{\widetilde{Y}}$ 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.

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 (θ_Y for a technology shock, θ_{RP} for a risk premium shock, θ_{POil} for an oil-price shock and $\theta_{Y^{NTP}}$ 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 NORA, 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

NORA contains a number of dynamic parameters that relate to the tax and spending rules introduced in section 2.7.3 and 2.7.4. The autoregressive parameters ρ_X capture the persistence of the tax rates (equation 56) and various spending components (equation 57) and can be freely chosen by the model user depending on the desired smoothness of these variables.[71] 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 ω_n in equation (58) 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, α_{ss}^{OIH} 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 R_{ss}^{TP}.

4 Simulations

In this section we will present some simulation results to illustrate the properties of NORA. Section 4.1 will examine the impulse responses of the main macroeconomic variables in NORA to selected macroeconomic shocks. In section 4.2 we conduct a number of fiscal policy experiments, including simulations to illustrate the fiscal multipliers in NORA and simulations that illustrate the effect of permanent changes to fiscal policy, for

[71] 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.

example a permanent increase in government spending or public employment. The simulations demonstrate possible ways NORA 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.

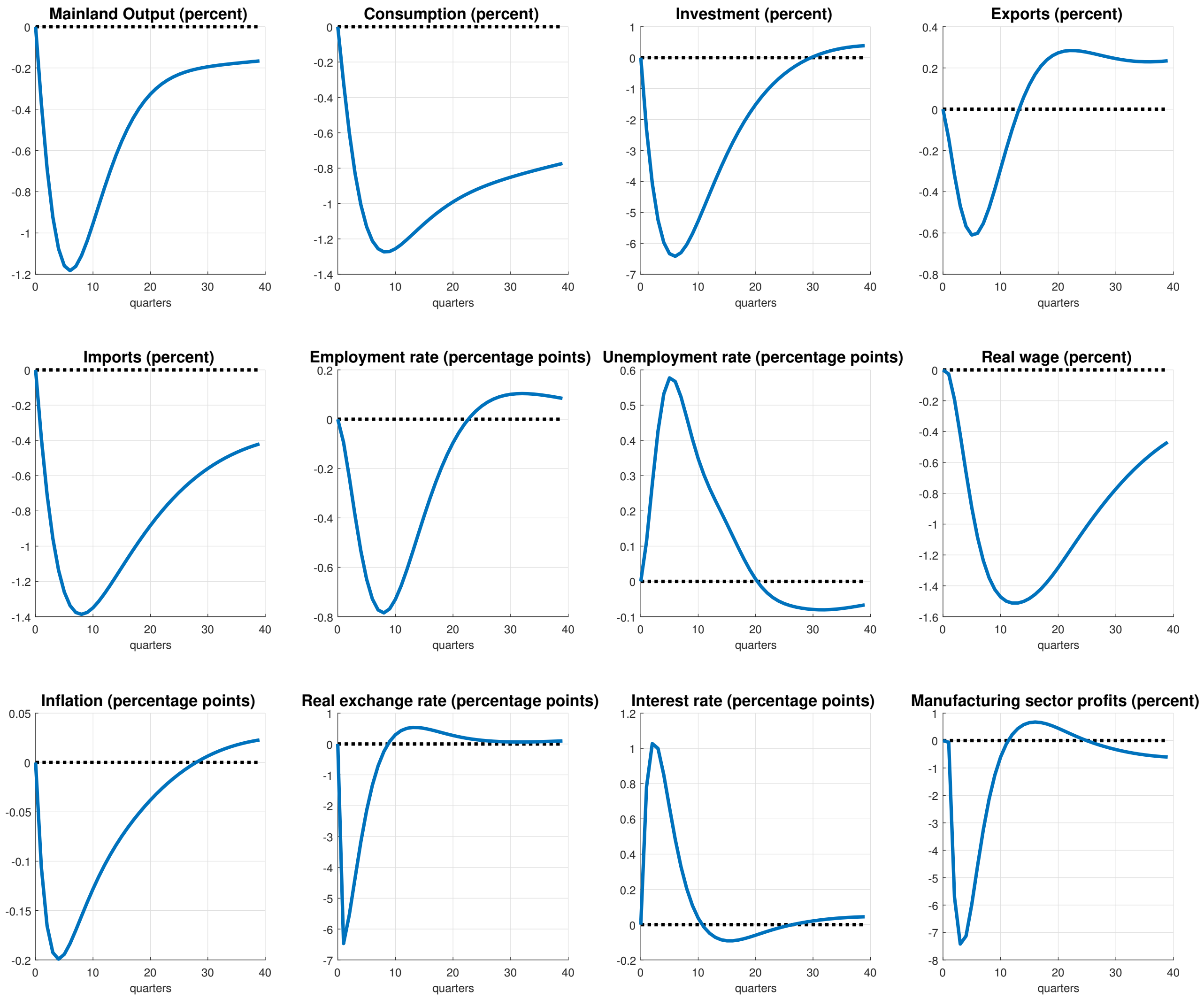
Higher interest rates increase capital inflows, putting upwards pressure on the nominal and (because of price stickiness) real exchange rate. The stronger real exchange rate undermines competitiveness by pushing up the foreign-currency price of exports, leading to a decline in export demand. The fall in both domestic and external demand results in a 1.2 percent decline in mainland output which reaches its trough after 7 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.[72]

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.

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 0.20 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.

[72] 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 13 where, for calibration purposes, we impose that the magnitude of the monetary policy shock is the same as in the NEMO.

Figure 4: Impulse responses to a monetary policy shock



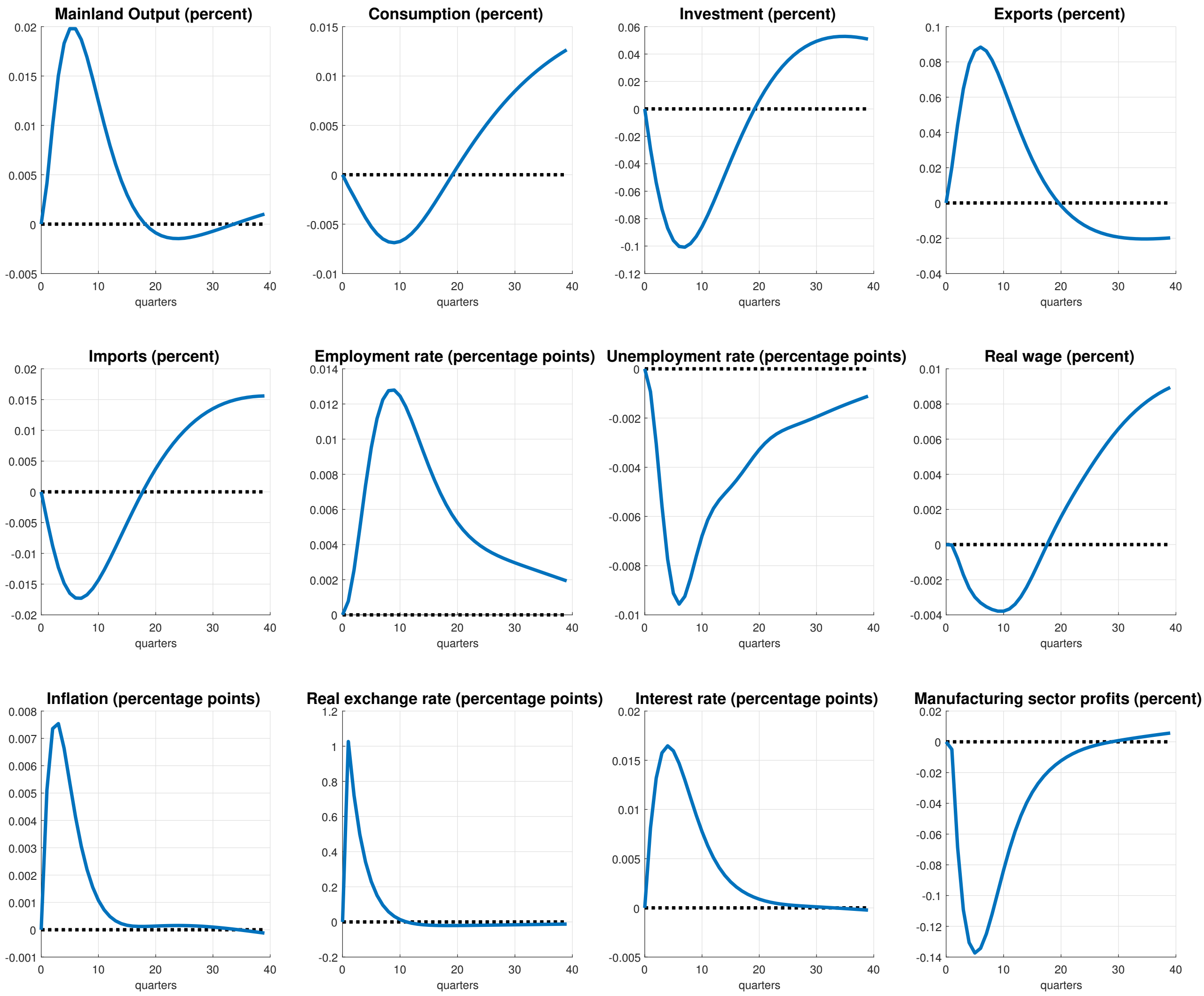
4.1.2 Shock to the external risk premium

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 import prices, helps ensure that mainland output increases.

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

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



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.[73]

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).[74]

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 nominal wages, with the result that the real exchange rate appreciates in the short-run.

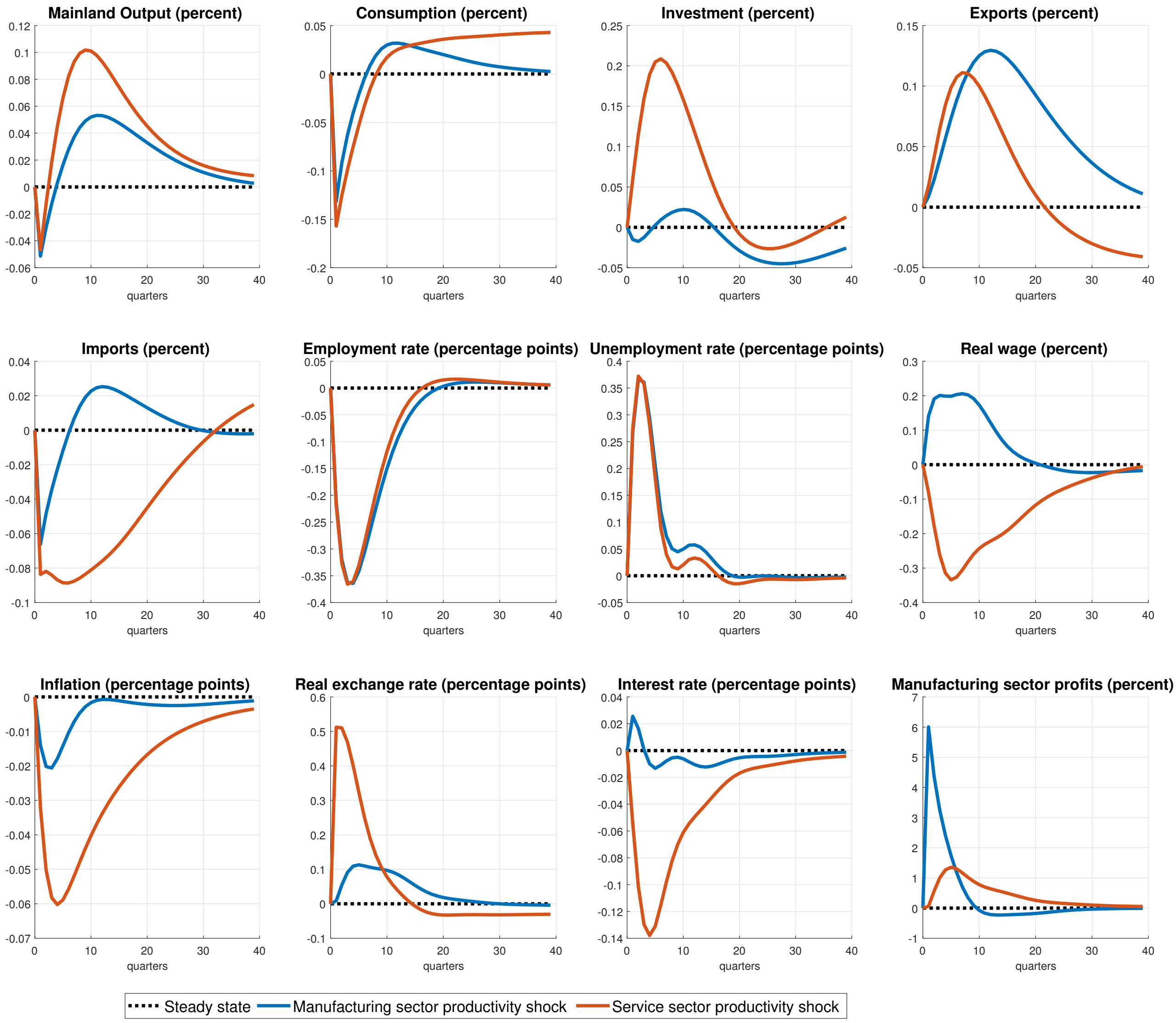
In the case where the increase in total factor productivity originates in the service sector, declining real interest rates put upward pressure on private investment. Investment oscillates around zero, however, in the case where the technology shock originates in the manufacturing sector due to the lack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

[73] Economy-wide 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.

[74] 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



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.[75] 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

[75] 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.

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.[76]

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.[77]

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 crowds out 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.[78]

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 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.

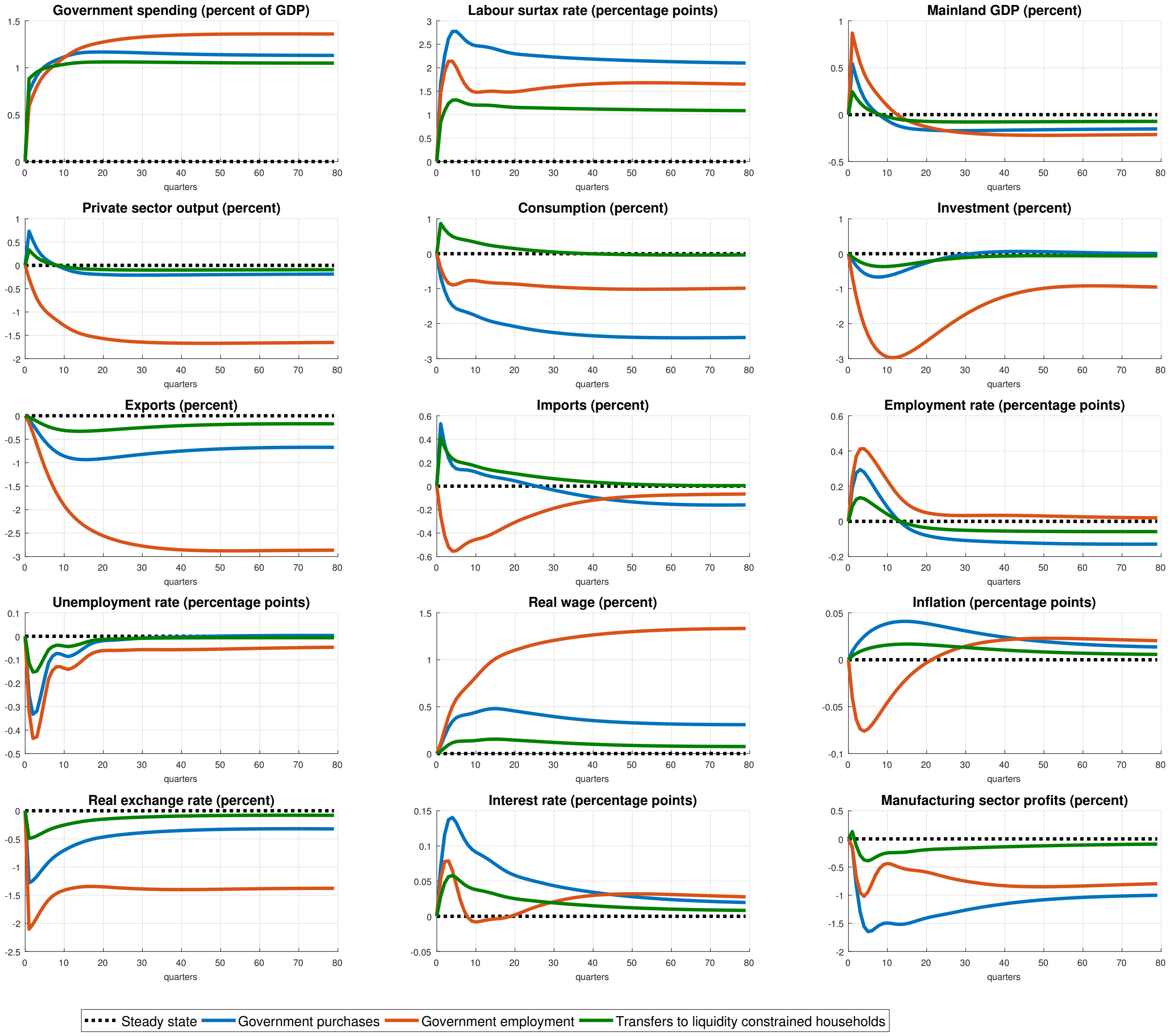
Private investment falls initially in all three scenarios due to higher interest rates. The decline in private sector employment following an expansion in public employment reduces the marginal productivity of capital, putting additional downward pressure on investment in this scenario. In the medium-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

[76] 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.

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

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

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



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 NORA.

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.

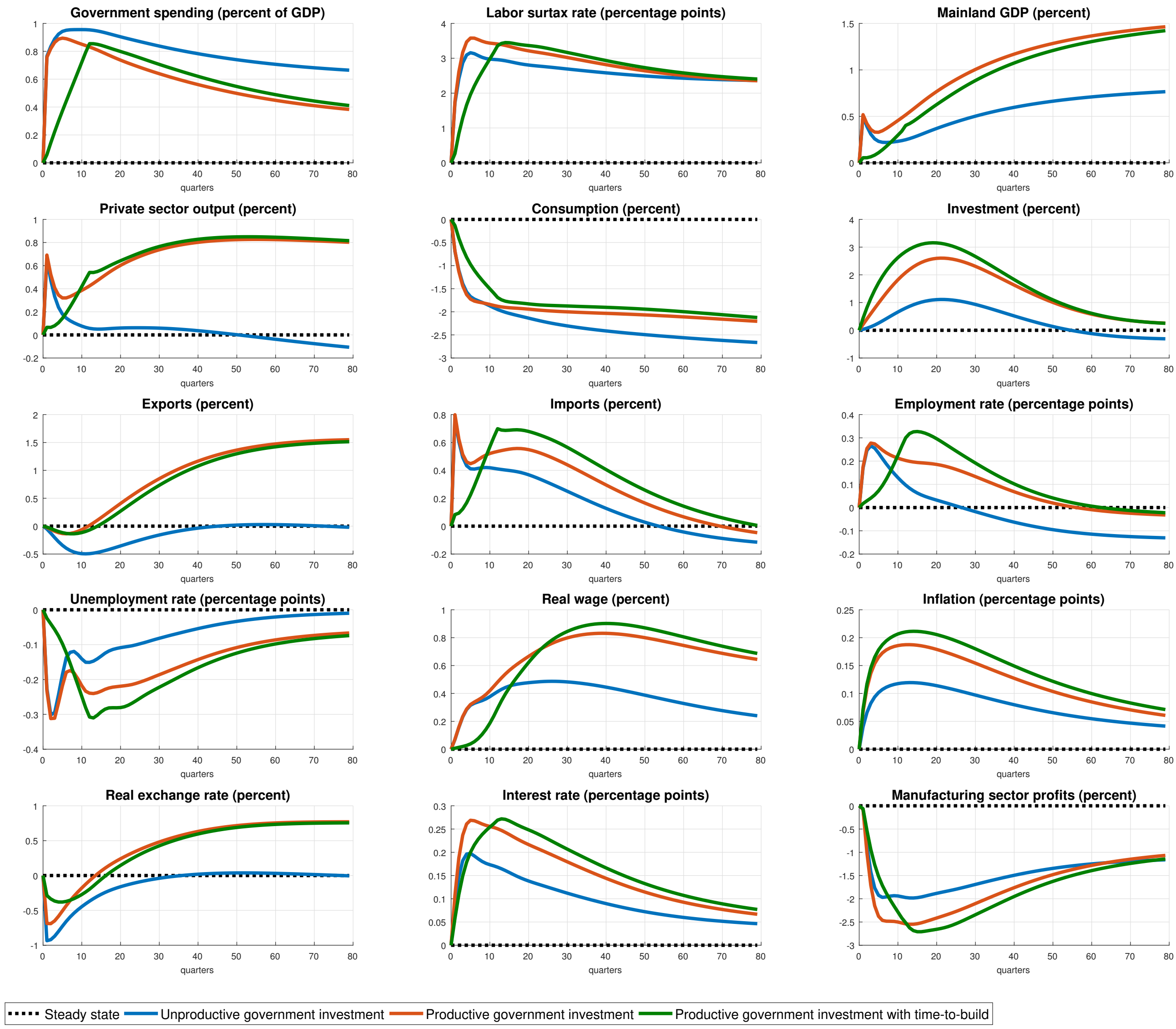
Figure 8 simulates the impact of a permanent one percent of GDP increase in government authorized investment financed by an increase in labor surtaxes. The first simulation (blue line) assumes that the additional public capital is unproductive in the sense that it does not increase firms' total factor 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.[79]

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 (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.

[79] 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 0.005 in the simulations with productive public capital (red and green lines).

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



Over time the initial shock to aggregate demand 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.[80]

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 pro-

[80] 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.

ductivity 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 appreciation 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.

4.2.2 Permanent decrease in taxes

Reduction in household taxation Figure 9 simulates the impact of a decrease in the consumption tax rate (blue line), the ordinary income tax rate on households (red line), and the labor surtax, financed in each case by a decrease in transfers to Ricardian households.[81] The decrease in taxes is scaled in such a way that tax revenue on impact falls by 0.5 percent of the initial steady-state value of mainland GDP. The decline in the consumption tax base is the smallest and thus requires the largest drop in tax rate to achieve this drop in tax revenue. The tax rate on household ordinary income falls by approximately 1 percentage point due to a slightly larger tax base, see table 3. The labor surtax has to decline by even less (approximately 0.8 percentage points) to generate the same amount of revenue given the even broader tax base. Total tax revenue decreases by more than 0.5 percent of GDP in each case as a result of movements in the tax base. In the case of the consumption tax (blue line) and the labor surtax (green line) this is nearly entirely due to the fact that transfers to Ricardians (the financing instrument) are taxed as ordinary income. This effect is also present when we simulate a decline in the ordinary income tax rate on households (red line), but in this scenario the decline in tax revenue is amplified by a decline in dividends (not shown), which are also taxed as ordinary income.

A cut in the consumption tax rate (blue line) increases aggregate consumption on impact due to a permanent increase in the purchasing power of liquidity-constrained households. However, this is gradually (due to consumption habits) offset by a decline in consumption by Ricardian households, triggered by a negative wealth effect caused by the decrease in transfers necessary to finance the tax cut.[82] The initial increase in consumption boosts aggregate demand, private sector output, and mainland GDP. The effect is short-lived, however, with mainland GDP returning to trend after 10 quarters due to the decline in consumption and temporarily lower investment. In the long-run, mainland GDP is exactly zero indicating that the only impact of the reduction in consumption taxes financed by lower transfers to Ricardian households is to shift consumption from Ricardian to liquidity-constrained households. Hence the consumption tax rate in NORA does not distort households' labor supply decisions. This is at odds with traditional fiscal policy DSGE models where the consumption tax rate affects the marginal rate of substitution between consumption and leisure, and hence the real wage, and is a result of our novel approach to modeling wage formation in Norway.[83]

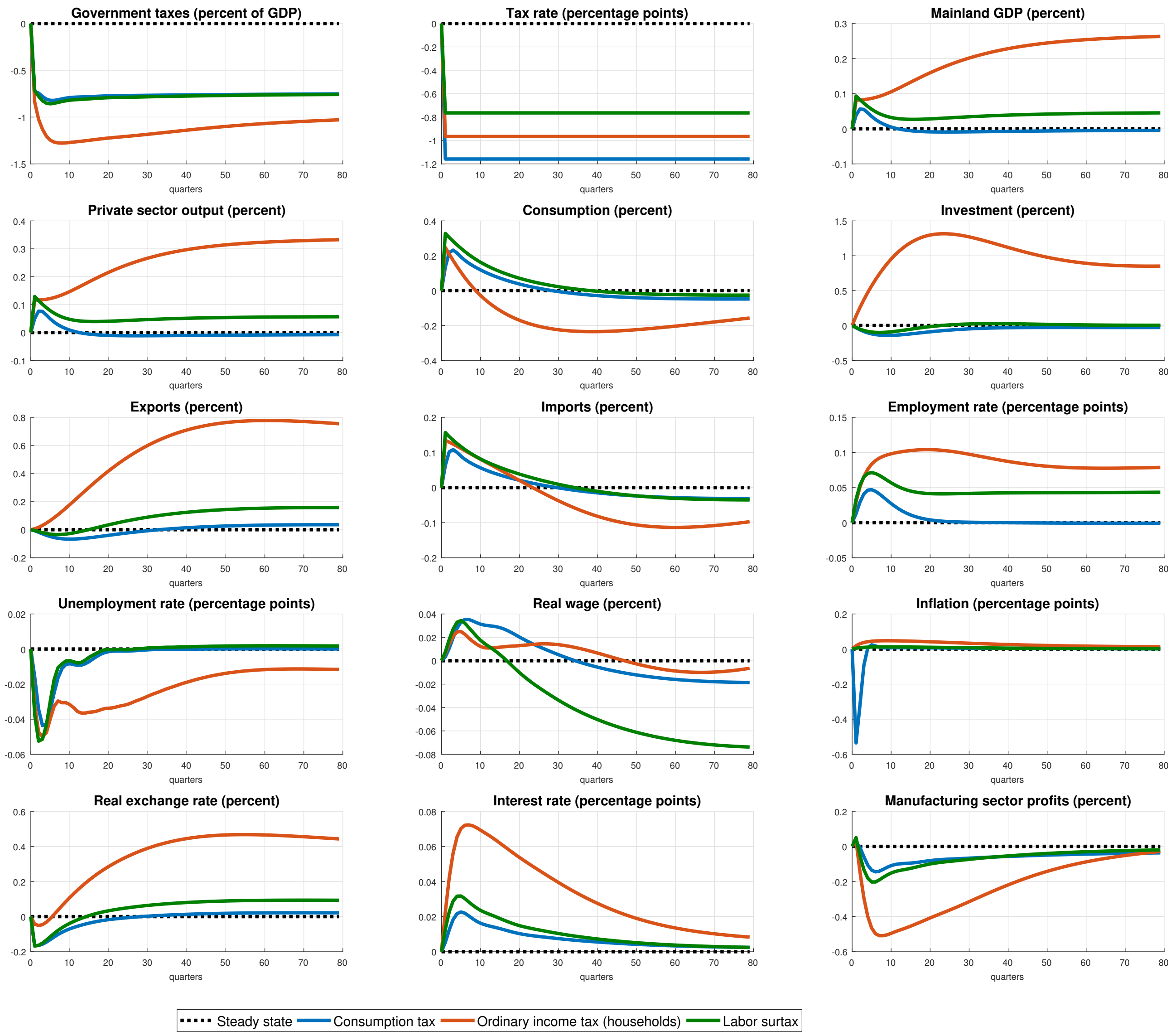
Forward-looking firms internalize the fact that the effect of the consumption tax cut is short-lived and will have no effect in the long-run. Hence, pre-tax inflation is broadly unchanged and there is only small increase in interest rates. The pre-tax real exchange rate does appreciate somewhat in the short-run due to an increase in foreign borrowing by banks, which is equivalent to a decline in the demand for foreign assets. The increase

[81] We choose transfers to Ricardian households as the financing instrument in our tax policy simulations as these transfers are non-distortionary, thus allowing us to focus exclusively on the effects of the decline in taxes.

[82] Recall that transfers to Ricardian households fall by an amount sufficient to cover the total cost of the tax cut. Hence, the benefits of the tax cuts are shared between all households, but entirely paid for by the Ricardian household.

[83] The result that the consumption tax rate does not distort labor supply decisions no longer holds if we set I^{τ} in equation (14) to 1 so that unions payoff function depends on after-tax rather than pre-tax real wages.

Figure 9: Permanent decrease in household taxes financed by lower transfer to Ricardian households



in foreign borrowing is a result of a decline in savings by Ricardian households who use financial markets to help smooth the decline in consumption. As a result, there is a modest decline in exports. Imports increase temporarily in line with the increase in consumption.

Because the effect of the tax cut is short-lived, employment increases only modestly and workers are instead asked to work additional hours to meet the short-run increase in aggregate demand. As a result, there is only a small decline in unemployment and the pre-tax real wage remains broadly unchanged.

The response to a cut in the labor surtax (green line) is very similar to that of a consumption tax cut. The main transmission channel is a temporary increase in consumption that results in a short-lived boost to aggregate demand, output, and employment. However, unlike the consumption tax cut, a cut in the labor surtax boosts labor force participation permanently (not shown). This increase in the labor force puts upwards pressure on unemployment once the initial boost in employment has died out, leading to lower wage claims by unions. The decline in the (pre-tax) real wage in turns allows employment and output to settle at a higher level, and dampens the long-run increase in unemployment.

A cut in the ordinary income tax rate affects the economy through numerous channels, including aggregate demand, labor supply, and domestic savings. Similar to the consumption and labor tax, a cut in the ordinary income tax leads to a short-run boost to consumption due to the increase in the purchasing power of liquidity-constrained households. Over time this increase in consumption is offset by a decline in consumption by Ricardian households which in this scenario is magnified by the lower tax rate on financial assets, which induces Ricardian households to save more in both stocks and bank deposits.

The increase in domestic savings reduces the cost of capital through two channels. First, as the demand for stocks increases the cost of equity-financing falls. Second, the increase in deposits by households reduces banks' reliance on international funding, decreasing the external risk-premium and thus the interest rate at which it lends to firms. As the cost of capital falls firms start investing to reach the now higher optimal level of capital. This increase in investments generates an increase in aggregate demand which is considerably larger than the increase resulting from a cut in the consumption tax rate and the labor surtax. As a result there is a noticeable increase in inflation that forces the central bank to raises interest rates and thus triggers an appreciation of the real exchange rate.

Over time, however, the decline in the cost of capital reduces the marginal cost of firms, allowing them to cut the price of domestic goods relative to imported goods. This in turn leads to a permanently weaker real exchange rate.[84] The decline in domestic prices reduces marginal costs for exporters. This, coupled with the weaker real exchange rate, make it possible for exporters to cut prices, thus triggering a sizeable increase in exports. The weaker real exchange rate in turn triggers a long-run substitution away from imports after the initial investment-led increase.

The higher capital stock increases the marginal productivity of labor, encouraging firms to increase employment. Real wages remain broadly unchanged despite the ensuing decline in unemployment due to a drop in manufacturing sector profits. The latter is a consequence of the increased borrowing costs faced by firms as they expand investment to boost their productive capacity. In the long-run, higher output boosts profits in both the manufacturing and service sector, allowing firms to agree to higher wages during wage negotiations and pay out higher dividends which in turn boosts consumption (not shown). Overall, a 0.5 percent of GDP cut in the ordinary tax rate for household boosts mainland GDP by 0.3 percent in the long-run (not shown).

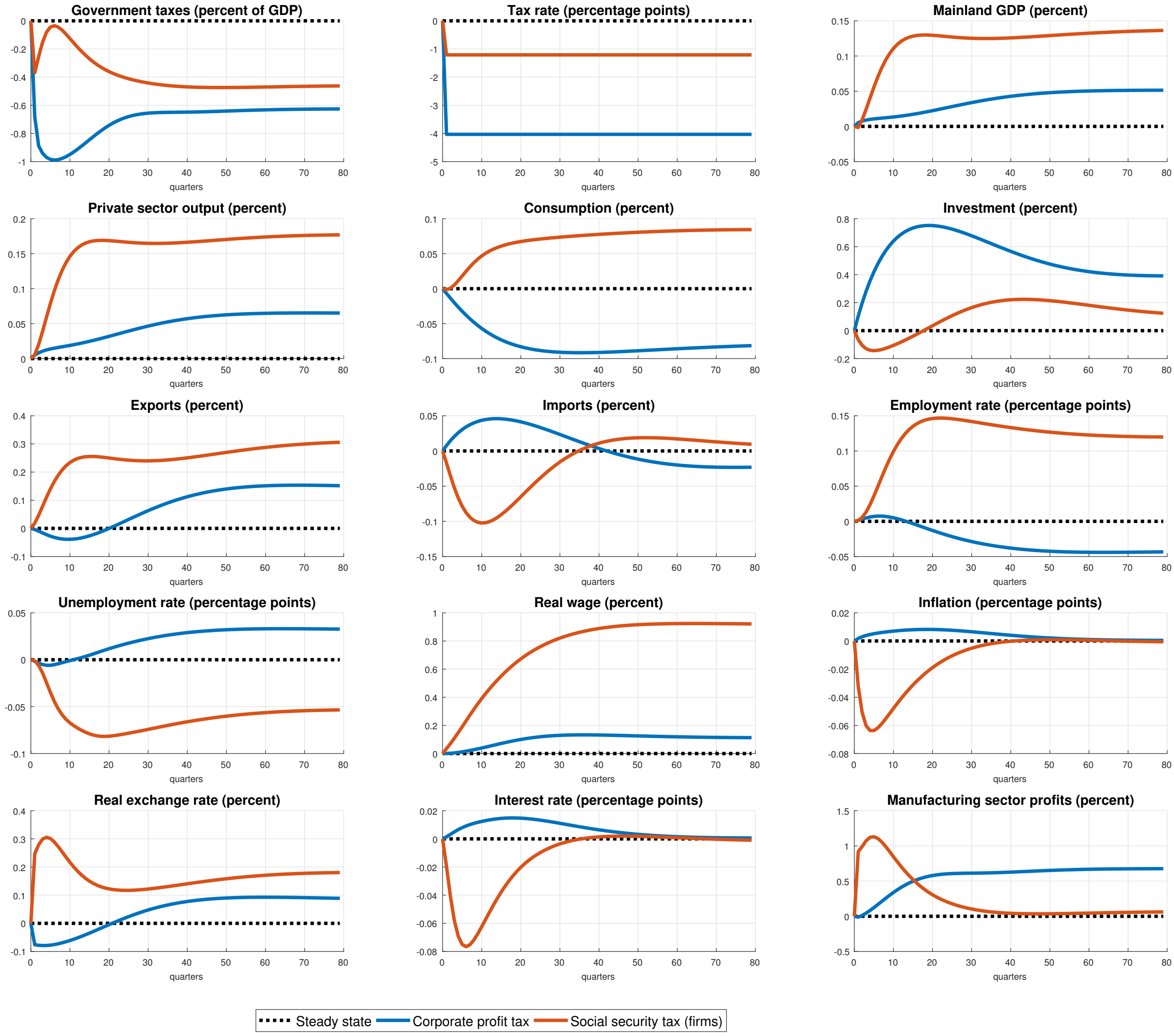
Reduction in corporate taxation In figure 10 we simulate a decrease in the corporate profit tax rate (blue) and the social security tax rate for firms (red). As in figure 9 the tax cut is financed by a reduction in transfers to Ricardian households and scaled in such a way that the ex-ante decrease in tax revenue amounts to 0.5 percent of GDP. Due to differences in the size of the relevant tax bases, see table 3, the corporate profit tax rate has to decline by 4 percentage points, while the social security rate for firms has to decline by approximately 1 percentage point. Actual tax revenue decreases by more than 0.5 percent of GDP in the event of a cut to the corporate profit tax (blue line), partly due the cut in the transfers to Ricardians and partly due to the short-term decline in dividends (see below), both of which are taxed as household ordinary income. Total tax

[84] To see this, consider a decomposition of the real exchange rate RER_t along the lines of Monacelli (2005):

$$RER_t = \frac{EX_t P_t^{TP}}{P_t} = \frac{EX_t P_t^{TP}}{P_t^{Nom,IM}} \frac{P_t^{Nom,IM}}{P_t}$$

where $P_t^{Nom,IM}$ is the nominal price of the imported good. The first term in this decomposition captures the ratio of the domestic-currency price of the foreign good and the price of the foreign good when it is imported and sold in domestic markets. If the law of one price holds this ratio is equal to one. It is not equal to one in NORA due to local currency pricing by importers and in the long-run is simply a function of market power of importers (and is thus not affected by the cut in the ordinary income tax rate). The second term captures the price of the imported good relative to the price of the domestic consumption good. As the price of domestically-produced goods fall, the price of the imported good relative to the domestic good increases. As evident from the above decomposition this implies a real exchange rate depreciation in the long-run.

Figure 10: Permanent decrease in firm tax rates financed by lower transfers to Ricardian households



revenue decreases initially by less than 0.5 percent of GDP following a cut in the social security tax rate for firms (red line), as the effect of lower transfers is more than offset by an increase in tax receipts due to higher corporate profits (see below).

A cut in the corporate profit tax rate (blue line) raises the marginal return on capital above the marginal cost of financing, and makes it optimal for firms to increase their capital stock. The transition to this higher level of capital is made possible by the increase in after-tax profits. In principle, higher after-tax profits could also be used to increase dividends. However, the objective of the firm is to maximize firm value which is given by the present discounted value of future after-tax dividends. This is consistent with a decline in dividends and an increase in retained earnings in the short to medium term, in order to finance the increase in investments necessary to transition to a permanently higher capital stock that will produce higher dividends in the future. This short-term decline in dividends also facilitates a decline in firm borrowing, which is no longer as attractive given the decreased benefit of the deduction of debt interest costs from the corporate profit tax base.

The large increase in investment boosts aggregate demand and encourages firms to increase employment. This leads to a decline in unemployment which encourages unions to increase their wage claims. The increase in real wages unwinds some of the initial increase in labor demand, though employment remains above its initial level in the long-run as the increase in firms' capital stock permanently raises the marginal productivity of labor. The unwinding of the initial increase in employment combined with entry into the labor market by workers attracted by the increase in wages, helps bring unemployment back towards its initial level. Real wages remain higher, however, due to a long-run increase in manufacturing sector profits. The combination of more employment and a higher capital stock results in a sizeable increase in private sector output and mainland GDP in the long-run.

The increase in aggregate demand triggered by the increase in investment pushes up inflation and encourages the central bank to raise interest rates. This encourages Ricardian households to increase their savings rate and postpone spending. This effect more than outweighs the increase in consumption among liquidity-constrained households due to higher labor income, with the result that overall consumption initially falls. Consumption gradually recovers as the interest rate normalizes and is higher in the long-run due to the permanent increase in dividends and higher labor income of Ricardian households.

This increase in the interest rates results in an initial appreciation of the real exchange rate. Over time, however, the real exchange depreciates due to a fall in the price of domestically-produced goods made possible by the decline in the cost of capital.[85] This, combined with a gradual decline in the marginal cost of exporting firms (due to lower domestic prices) leads to a sizeable increase in exports over time. Imports increase initially due to the increase in investment, but declines over time as the depreciation of the real exchange encourages agents to substitute away from imports towards domestically-produced goods.

The reduction in social security contributions by firms (red line) lower the price of labor inputs for firms, which results in an immediate increase in profits and triggers an increase in labor demand. The resulting increase in employment leads to a decline in unemployment which, together with the increase in manufacturing sector profitability, leads to a sizeable increase in real wages. The reduction in the price of labor inputs reduces marginal costs and allows firms to lower prices. Hence, inflation falls, which triggers a decline in nominal interest rates and a depreciation of the real exchange rate.

Overall consumption increases as the positive effect of higher labor income outweighs the negative effect associated with the reduction in transfers to Ricardian households. Despite the cut in interest rates, investment is broadly unaffected. This is because the effect of lower interest rates is offset by a desire by firms to become less capital intensive given the decline in the price of labor inputs. Exports increase modestly due to a combination of a depreciated exchange rate and lower marginal costs. Overall, the cut in social security contributions by firms result in a higher level of output as firms find it optimal to expand employment and therefore production. The magnitude of these effects are, however, smaller relative to the impact of a cut in the corporate profit tax.

4.2.3 Fiscal multipliers

In this section we discuss the fiscal multiplier in NORA following a permanent increase in government purchases of goods and services. We compare the results to the equivalent multiplier in KVARTS (Boug and Dyvi, 2008) and assess the sensitivity of the multiplier to different modeling assumptions and changes in key parameter values. More specifically, we simulate a permanent increase in government purchases by 1 percent of pre-stimulus GDP. We assume that the increase in government spending is completely financed in every period by labor surtax. We measure the multiplier as the percentage deviation of real GDP from baseline GDP as a result of the 1 percent of GDP increase in government purchases. This is consistent with the definition of the fiscal multiplier in Coenen et al. (2012a).

[85] See footnote 84 for an explanation for why the real exchange rate depreciates after a fall in the relative price of domestically-produced goods.

Figure 11a shows the fiscal multiplier in NORA following an unanticipated permanent increase in government purchases in period 5. The impact multiplier of 0.55 in NORA (blue line) is similar to the value in KVARTS (red line), but below the values of 0.7-1.0 found in Coenen et al. (2012a) for the US and Europe, and the value of 0.8 found in Stähler and Thomas (2012) for Spain. The fact that the multiplier in a small open economy like Norway is smaller than in the US and Europe conforms with the findings in Ilzetzki et al. (2013) that fiscal multipliers are larger in economies that are less industrialized and less dependent on international trade. The higher impact multiplier in Stähler and Thomas (2012) is likely due to their assumption of full home bias in public consumption. By contrast the national account input-output tables used to calibrate NORA indicate that imported inputs make up as much as 27 percent of government purchases of goods and services. Figure 12f illustrates that reducing the import share of government purchases in NORA also leads to higher impact multipliers.

In both NORA and KVARTS the fiscal multiplier gradually falls as the increase in government spending crowds-out private spending. Crowding-out occurs much more gradually in KVARTS than in NORA, however, with the positive effect on GDP in KVARTS lasting between 5-6 years compared to approximately 3 years in NORA. Coenen et al. (2012a) also find more long-lasting effects on GDP following a permanent increase in government purchases in the sample of policy models they review, a fact they attribute to the use of lump-sum taxes as financing instrument. This is consistent with the findings in figure 11b where the effect on output is both larger on impact and longer in duration when transfers to Ricardian households (equivalent to lump-sum taxes in NORA) are used as the financing instrument.

Figure 11b displays the sensitivity of the fiscal multiplier to alternative financing instruments. The impact multiplier is largest (close to 0.8) if the increase in government spending if financed by an increase in firms' social security tax (green line). This is because capital is fixed in the short run, and hence firms have no choice but to increase labor demand to meet the increase in demand despite the increase in the cost of labor inputs. Hence, while this tax rate acts to distort away from the use of labor as an input, the firms are forced to uphold high employment to satisfy the high aggregate demand and the multiplier is thus not dampened. The pace of crowding out is relatively rapid, however, with the positive impact on GDP only lasting for 2 years. The impact multiplier is approximately 0.75 if the increase in government spending is financed by lower transfers to Ricardian households (purple line). This is due to consumption habits, which lead Ricardian households to only gradually adjust consumption to a level commensurate with their reduced lifetime income. This simulation is the one that most closely corresponds to the empirical analysis in Ilzetzki et al. (2013) as well as Holden and Sparrman (2018), where the peak spending multiplier is assessed to be 0.8.[86] The impact multiplier when consumption taxes are used to finance the increase in government spending (orange line) is similar to when labor taxes are used as the financing instrument (blue line).

Figure 11c investigates the sensitivity of the multiplier to changes in the duration of the increase in government spending. The impact multiplier is largely determined by the size of the demand impulse resulting from the increase in government spending, and thus unaffected by changes in the duration of the fiscal stimulus. However, the pace of crowding-out is significantly slower if the fiscal stimulus only lasts for 2 years (green line), due to more modest negative wealth effects on Ricardian households. The sharp decline in output at the end of the stimulus period is due to the sudden reduction in aggregate demand.

Figure 11d looks at how the fiscal multiplier is affected by the behaviour of the central bank. Not surprisingly, the fiscal multiplier increases with the degree of monetary accommodation. As noted by Coenen et al.

[86] Holden and Sparrman (2018) find that approximately three-quarters of the changes in government spending in their cross-country sample are debt financed. Consistent with the Ricardian equivalence theorem, Ricardian households in NORA treat debt issuance and (non-distortionary) taxation as equivalent. Because transfers are non-distortionary this simulation is therefore equivalent to a debt-financed increase in government spending and therefore resembles the analysis in Holden and Sparrman (2018).

(2012a) this is because, in the absence of monetary accommodation (blue line), the central bank will react to the increase in aggregate demand and inflation resulting from an increase in government spending by tightening monetary policy sufficient to increase the real interest rate. This will offset a part of the positive impact on GDP. By contrast, if nominal interest rates are held constant for a period of time (red and green lines), real interest rates will fall, reinforcing the positive effects on GDP resulting from the increase in government spending.

Figure 11e investigates how the fiscal multiplier is affected if the increase in government spending is, for a period of time, financed by larger withdrawals from the oil fund instead of by an increase in the labor surtax (red and green lines). After the temporary increase in oil fund withdrawals the value of the fund is permanently lower, which permanently lowers the sustainable amount of withdrawals. The resulting gap is filled by an increase in the labor surtax. Unsurprisingly, the use of oil money increases the multiplier during the periods where oil fund resources are used as a financing instrument due to the now absent negative effects of labor taxation. However, once the increase in government purchases is no longer financed by oil fund withdrawals, the multiplier drops again. In the long-run (not shown), GDP will be lower the longer additional oil fund withdrawals have been used as a financing instrument. This is because a more protracted use of oil money leads to a more depleted oil fund and thus a lower sustainable level of oil fund withdrawals that has to be met by higher (distortionary) labor taxes.

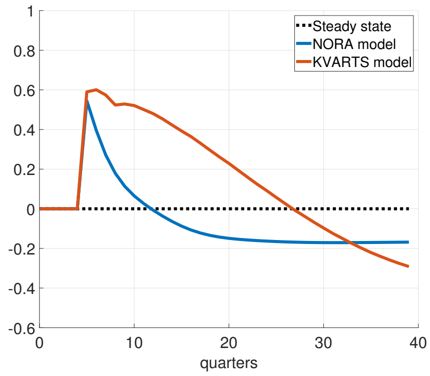
Figure 11f shows how the fiscal multiplier is affected by a 4-quarter preannouncement of the increase in government spending (red line). Preannouncing the increase in government spending (red line) reduces output in the period leading up to the actual increase in spending. This is primarily due the immediate appreciation of the real exchange rate, which forces exporters to increase the foreign-currency price of exports and thus reduces export demand. This is amplified by the behaviour of forward-looking Ricardian households, who immediately start reducing their consumption because of the future increase in taxation. The boost to GDP when government spending actually increases is determined by the behaviour of liquidity-constrained households and thus broadly similar. However, because of the lower starting point, the increase in GDP relative to its initial starting point is smaller.

Figure 11g investigates how the multiplier changes if we assume that labor unions payoff function in equation (14) depends the level of labor and consumption taxes, i.e. if $I^{\tau} = 1$ (red line). As noted in section 2.4, such an assumption may be warranted if the increase in labor tax is not perceived to be used to finance spending that provides additional public services that compensate workers for their lower after-tax wage. This assumption is also more in line with traditional fiscal policy DSGE model where workers would demand to be partly compensated for higher labor taxes by an increase in their pre-tax wage. As before, the impact multiplier is determined by the size of the demand impulse, and thus largely unaffected. However, the pace and strength of crowding-out is significant higher because pre-tax real wages now increase to partly compensate for workers for the increased labor taxes. This in turn reduces labor demand and employment, which results in a permanently lower level of output in the long-run. The long-run fiscal multiplier in this scenario is approximately -0.45, significantly lower than the value of -0.2 when the labor unions payoff function depends on pre-tax real wages.

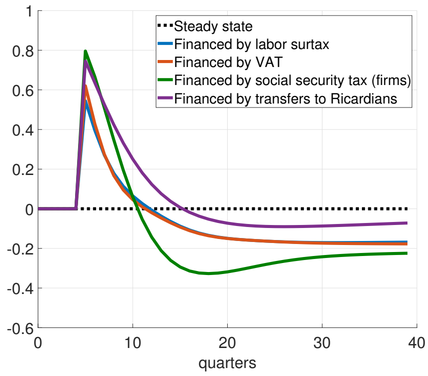
Figure 11h looks at how the multiplier varies across different spending components. An permanent increase in government employment results in the highest multiplier. This reflects the fact that government employment is a direct component of GDP. The strength of crowding-out is relatively high, however, given the impact of higher government employment on unemployment and labor union's wage demands. Government purchases and investment also result in sizeable increase in real GDP given that these spending categories are also direct components of GDP. However, unlike with government employment, part of the increase in government purchases and investment immediately leaks out through higher imports, limiting the increase in domestic demand. In the case of government investment, GDP is increased permanently as public capital depreciation is a component of GDP. Targeted transfers to liquidity-constrained households yield a relatively modest impact multiplier of approximately 0.2. This is because transfers are taxed as ordinary income, and hence part of the increase in transfer is immediately returned to the government in the form of higher taxes, limiting the overall increase in the disposable income of liquidity-constrained households.

Figure 11: Sensitivity of the fiscal multiplier

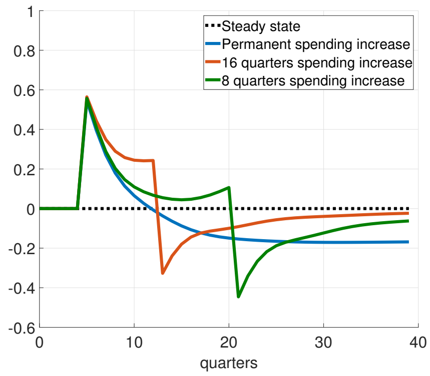
(a) Comparison with KVARTS



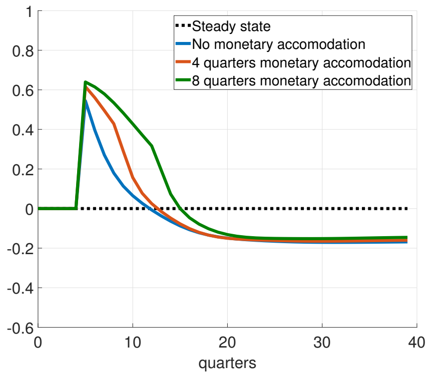
(b) Comparison across different financing instruments



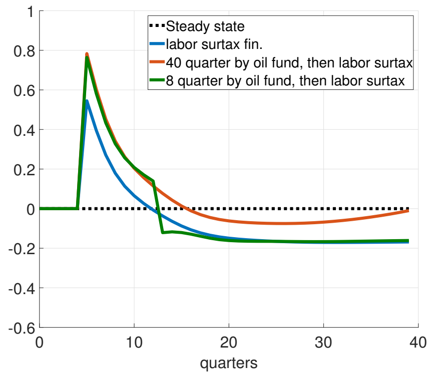
(c) Comparison with temporary spending increase



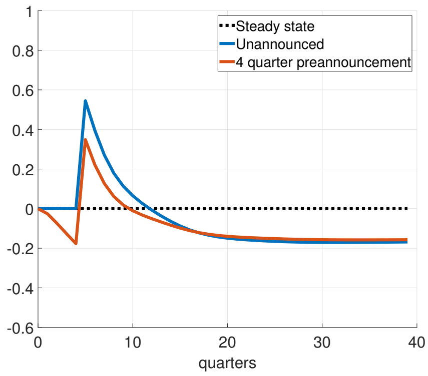
(d) Comparison with monetary accommodation



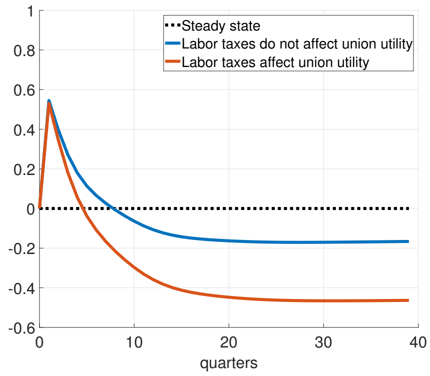
(e) Comparison with temporary oil financing



(f) Comparison with preannouncement



(g) Comparison with labor taxes affecting wage barg.



(h) Comparison with other spending components

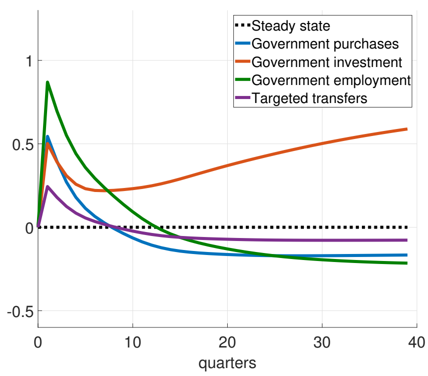


Figure 12a investigates how the multiplier depends on the share of liquidity-constrained households in the economy. In this and subsequent simulations "baseline" (blue line) refers to the benchmark calibration of NORA. In this simulation the multiplier falls with the share of liquidity-constrained households. This is because of the decline in after-tax labor income resulting from the increase in labor taxes, which outweighs the effect of the increased government spending on wages and employment, and forces liquidity-constrained households to reduce their consumption. Ricardian households also reduce their consumption, but much more gradually due to consumption habits and their ability to access financial markets to smooth their consumption profile. The pace and strength of the subsequent crowding-out also falls with the share of liquidity-constrained households over the short- to medium-term. This is once again because a higher share of Ricardian households increases the importance of consumption habits, which causes consumption to undershoot its long-run equilibrium. Note that the share of liquidity-constrained households does not affect the long-run outcome of the simulation, only the transition to the new equilibrium. It is also worth noting that the fact that the impact multiplier is lower when the share of liquidity-constrained consumers is higher does not hold for all policy experiments. For example, an increase in government purchases financed by lower transfers to Ricardians would result in liquidity-constrained households increasing consumption on impact, thereby amplifying the short-run effect of the increase in government spending on the economy. A higher share of liquidity-constrained households would, in this case, result in significantly higher multipliers.

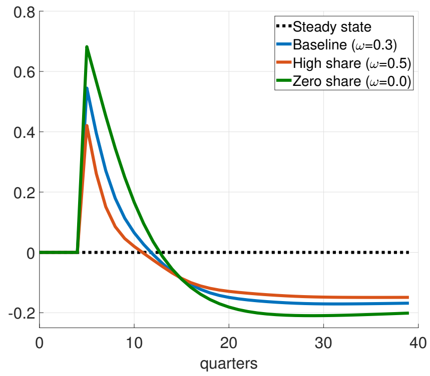
Figures 12b, 12c, 12d, and 12e look at how the fiscal multiplier is affected by the magnitude of the real and nominal rigidities in NORA. In general, these rigidities do not affect the long-run outcome of the model, but may affect the impact multiplier and the transition path of the economy to the new steady state. Figure 12b looks at how the multiplier is affected by the strength of consumption habits, which is a form of real rigidities in the model. In the absence of any consumption habits (green line), Ricardian households are willing to reduce consumption much more rapidly in response to the permanent increase in taxes. Hence, crowding-out occurs much more rapidly and the increase in GDP on impact is therefore significantly muted. As noted previously, consumption habits introduces some overshooting in consumption (and hence in output) but leaves the long-run outcome for the economy unchanged. Figure 12d shows how the fiscal multiplier is affected by changes in the magnitude of investment adjustment costs, another form of real rigidity. As is evident from the graph, the impact of varying investment costs are relatively small in this simulation. Low investment adjustment costs (red) slightly reduce the impact multiplier as it amplifies the initial decline in investment due to higher interest rates (see figure 7 for further details). However, because the movement in investment itself is pretty modest in this simulation, the effects of changing investment adjustment costs is also pretty small.

Figure 12c shows how the fiscal multiplier changes if we change the magnitude of price adjustment costs in NORA, which is a type of nominal rigidity. The impact multiplier and long-run multiplier are unaffected by changes to the magnitude of price adjustment costs. However, low price adjustment costs (red line) increase the pace of crowding out, while high price adjustment costs (green line) slow the adjustment of the economy. This is because lower price adjustment costs allow prices to increase more rapidly in response to the increase in aggregate demand, accelerating the decline in private sector demand . Figure 12e investigates how the multiplier is affected by the amount of wage stickiness in the model, specifically the speed at which real wages adjust to changes in the Nash bargaining wage. A low degree of wage stickiness (green line) reduces the impact multiplier slightly, while a high degree of wage stickiness (red line) increases it marginally relative to the benchmark calibration. The changes, though small, occur because a low degree of wage stickiness allows wages to increase more rapidly following the increase in aggregate demand. This raises inflation, triggering a sharper increase in the nominal interest rate that magnifies the appreciation of the real exchange rate on impact. A stronger real exchange rate lead households to substitute away from domestically-produced goods toward imports, with the result that overall imports increase more than in the benchmark calibration, reducing the magnitude of the multiplier.

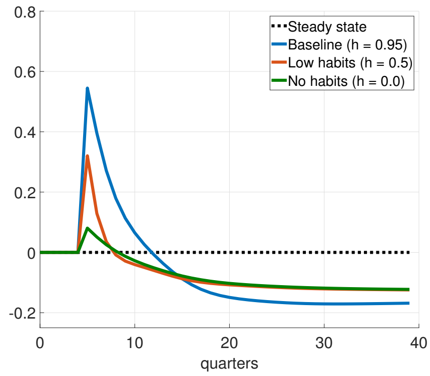
Finally, figure 12h shows how the fiscal multipliers changes if we vary the parameter ξ_{NFA} that determines the sensitivity of the external risk premium to net foreign assets. Varying the value of ξ_{NFA} does not have a significant impact on the impact multiplier. However, a high value of ξ_{NFA} (green line) increases the pace and strength of crowding-out over the short- to medium-term. This is because dissaving by Ricardian households who want to smooth their consumption profile forces banks to increase their foreign borrowing. A higher value of ξ_{NFA} magnifies the impact this has on the external risk premium. A higher risk premium dampens the appreciation of the real exchange rate and magnifies the increase in inflation. This results in a more aggressive tightening of monetary policy, which triggers a larger decline in investment and consumption and puts additional downward pressure on GDP over the short- to medium-term. It is worth noting that these effects are temporary, with the long-run equilibrium broadly unaffected by changes in ξ_{NFA}.

Figure 12: Sensitivity of the fiscal multiplier

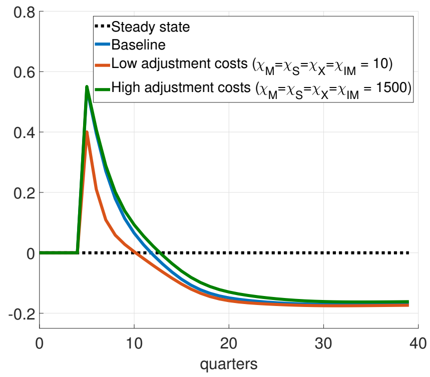
(a) Sensitivity to share of liquidity-constrained households



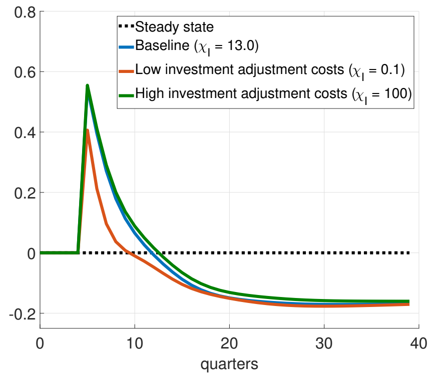
(b) Sensitivity to consumption habits



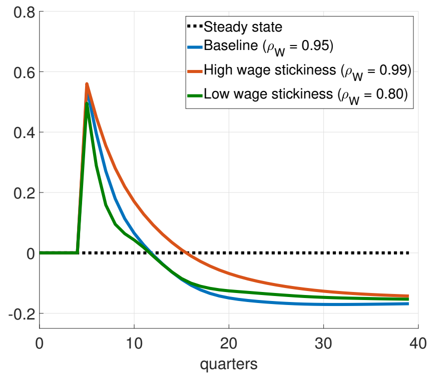
(c) Sensitivity to price adjustment costs



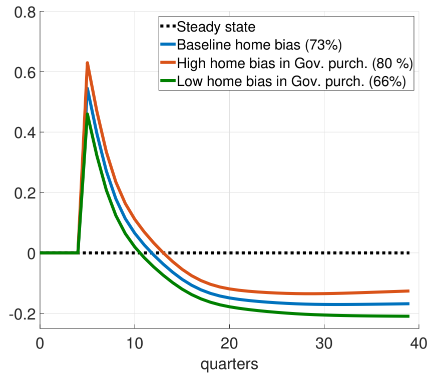
(d) Sensitivity to investment adjustment costs



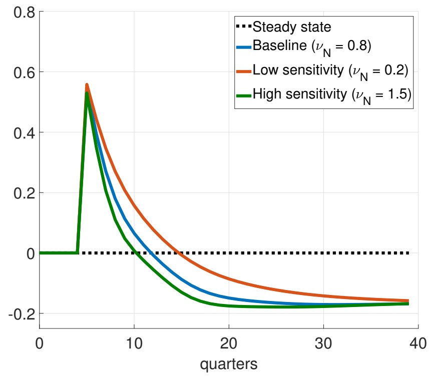
(e) Sensitivity to wage stickiness



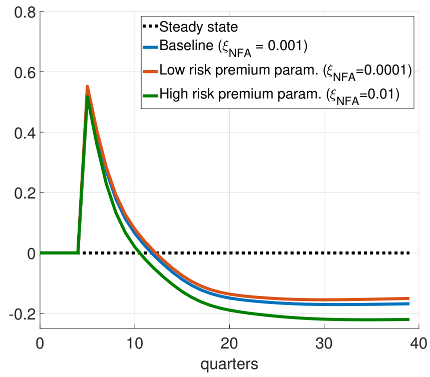
(f) Sensitivity to import share of gov. purchases



(g) Sensitivity of reference utility to unemployment



(h) Sensitivity to risk premium parameter



5 Summary

In this paper we have presented a microfounded macroeconomic model for fiscal policy analysis in Norway, which we have called NORA. NORA is the outcome of a two-year long project at the Ministry of Finance, and has been developed in collaboration with Statistics Norway and Norges Bank. Unlike most DSGE models that have been developed to analyse monetary policy, NORA features a rich government sector including the most important sources of government revenue and public expenditures in Norway. Notably, the model includes a realistic description of corporate profit tax in Norway as well as the taxation of shareholder income. 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. NORA 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.

Appendices

A Derivations

A.1 First-order conditions of the Ricardian household

1. The first-order condition with respect to deposits $\frac{\partial L}{\partial DP_t^R} = 0$ is given by

$$\begin{aligned} 0 &= \beta^{t+1} E_t \left[\frac{\lambda_{t+1}}{\pi_{t+1}^{ATE}} (1 + (R_t - 1)(1 - \tau_{t+1}^{OIH})) \right] - \beta^t \lambda_t \\ \Leftrightarrow \lambda_t &= \beta E_t \left[\frac{\lambda_{t+1}}{\pi_{t+1}^{ATE}} (1 + (R_t - 1)(1 - \tau_{t+1}^{OIH})) \right] \end{aligned} \quad (65)$$

2. The first-order condition with respect to consumption $\frac{\partial L}{\partial C_t^R} = 0$ is given by

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

3. Before deriving the first-order condition with respect to stocks we first note that the return on holding a stock $S_t^{R,M}$ (and of $S_t^{R,S}$ due to no-arbitrage) is given by

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

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

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

as the gross nominal return on stocks. The first-order condition with respect to stocks $\frac{\partial L}{\partial S_t^{R,M}} = 0$ is then given by

$$\begin{aligned} \beta^t \lambda_t P_t^{E,M} (1 + F_t^S) &= \beta^{t+1} E_t \left[\lambda_{t+1} \left(\frac{P_t^{E,M}}{\pi_{t+1}^{ATE}} + (1 - \tau_{t+1}^D)(P_{t+1}^{E,M} - \frac{P_t^{E,M}}{\pi_{t+1}^{ATE}} + DIV_{t+1}^M) + RRA_{t+1} \frac{P_t^{E,M}}{\pi_{t+1}^{ATE}} \tau_{t+1}^D \right) \right] \\ \lambda_t (1 + F_t^S) &= \beta E_t \left[\lambda_{t+1} \left(\frac{1}{\pi_{t+1}^{ATE}} + (1 - \tau_{t+1}^D)(P_{t+1}^{E,M} - \frac{P_t^{E,M}}{\pi_{t+1}^{ATE}} + DIV_{t+1}^M)/P_t^{E,M} + RRA_{t+1} \frac{1}{\pi_{t+1}^{ATE}} \tau_{t+1}^D \right) \right] \\ \lambda_t (1 + F_t^S) &= \beta E_t \left[\frac{\lambda_{t+1}}{\pi_{t+1}^{ATE}} \left(1 + \pi_{t+1}^{ATE} (1 - \tau_{t+1}^D)(P_{t+1}^{E,M} - \frac{P_t^{E,M}}{\pi_{t+1}^{ATE}} + DIV_{t+1}^M)/P_t^{E,M} + RRA_{t+1} \tau_{t+1}^D \right) \right] \\ \lambda_t (1 + F_t^S) &= \beta E_t \left[\frac{\lambda_{t+1}}{\pi_{t+1}^{ATE}} R_t^S \right] \end{aligned} \quad (66)$$

Subtracting equation (66) from equation (65) yields $F_t^S = E_t \left[\frac{\Delta_{t+1}}{\pi_{t+1}^{ATE}} \left(R_t^S - (1 + (R_t - 1)(1 - \tau_{t+1}^{OIH})) \right) \right]$. 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 nominal returns equals $F_t^S \pi_{t+1}^{ATE} / \Delta_{t+1}$. In steady state the equity premium in the model (in nominal terms) is given by $\frac{F^S \pi^{ATE}}{\beta}$. In the calibration section we will use this relationship to calibrate the equity premium to its empirical value.

In order to further simplify equation (66) we resort to certainty equivalence that holds to a first-order approximation and in perfect foresight. Under this assumption we can write

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

The above equation can be iterated forward to obtain

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

where $R_{t+j}^e = \prod_{l=1}^{j}\frac{1+F_{t+l-1}^S - \Delta_{t+l}/\pi_{t+l}^{ATE}\tau_{t+l}^D(1+RRA_{t+l})}{\Delta_{t+l}(1-\tau_{t+l}^D)}$. Completely analogously we can derive that

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

A.2 Wage bargaining

We take the first derivative of the Nash product $\Phi^{NP}(W) := (V - V_t^0)^\gamma(\Pi_t^M)^{1-\gamma}$ and set it to zero to obtain a condition which the Nash bargaining wage needs to fulfill

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

Dividing by each component of the Nash product yields

$$\frac{\partial}{\partial W}\Phi^{NP}(W) = \gamma\frac{\frac{\partial V}{\partial W}}{V-V_t^0} + (1-\gamma)\frac{\frac{\partial}{\partial W}\Pi_t^M}{\Pi_t^M} = 0 \tag{67}$$

which can be rearranged to obtain

$$\frac{\frac{\partial V}{\partial W}}{V-V_t^0} = -\frac{1-\gamma}{\gamma}\frac{\frac{\partial}{\partial W}\Pi_t^M}{\Pi_t^M}.$$

Note that if we assume it is the profit share $\frac{\Pi_t^M}{P_t^M Y_t^M}$ that mattered in bargaining rather than the level of profits

Π_t^M then we would have obtained the exact same solution.[87]

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

$$\frac{\frac{(1-I^{\tau}\tau_t^W)}{(1-I^{\tau}\tau_t^C)}^{1-\sigma_N} W^{-\sigma_N}}{V(W)-V_t^0} = \frac{1-\gamma}{\gamma}\frac{(1+\tau_t^{SSF})N_t^M}{\Pi_t^M(W)}.$$

Equation (67) 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.

$$\frac{\partial^2}{\partial W^2}\Phi^{NP}(W) < 0. \tag{68}$$

Given this, it can be observed that any increase in $\frac{\frac{\partial V}{\partial W}}{V-V_t^0}$ (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 (67) holds again. This is because $\frac{\partial}{\partial W}\Phi^{NP}(W)$ falls with the wage, see equation (68).

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

$$\begin{aligned}\frac{\frac{\partial}{\partial W}\Pi_t^M(W)}{\Pi_t^M(W)} &= \frac{-(1+\tau_t^{SSF})N_t^M}{\Pi_t^M(W)}\\ &= \frac{-(1+\tau_t^{SSF})N_t^M}{P_t^M Y_t^M-(1+\tau_t^{SSF})WN_t^M-\delta_{KP}P_t^I K_t^M-(R_{t-1}^L RP_{t-1}^{B,M}-1)\frac{B_{t-1}^M}{\pi_t^{ATE}}-(AC_t^M+AC_t^{Inv,M})}.\end{aligned}$$

It then becomes clear that a reduction in τ_t^{SSF}, 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.[88]

A.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

$$\min_{Z_t^M, Z_t^S} P_t^{M,Z} Z_t^M + P_t^{S,Z} Z_t^S$$

giving rise to the Langrangian

[87] To see this, note that $\frac{\partial V}{\partial W}\frac{\Pi_t^M}{P_t^M Y_t^M} = \frac{1}{P_t^M Y_t^M}\frac{\partial V}{\partial W}\Pi_t^M$. Hence we obtain

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

which yields an identical first-order condition to the one derived above.

[88] 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.

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

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

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

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

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

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

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

A.4 Intermediate sector export price setting

The optimization problem of the exporter is

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

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

$$
\begin{aligned}
0 \;=\;& \beta^t\lambda_t\Bigg\{RER_tX_t(i)+P_t^X(i)RER_t(-\epsilon_t^X)\left(\frac{P_t^X(i)}{P_t^X}\right)^{-\epsilon_t^X-1}\frac{X_t(i)}{P_t^X}-MC_t^X(-\epsilon_t^X)\frac{(P_t^X(i))^{-\epsilon_t^X-1}}{(P_t^X)^{-\epsilon_t^X}}X_t(i)\\
&-\chi_X X_tP_t^X RER_t\left[\frac{\frac{P_t^X(i)}{P_{t-1}^X(i)}\pi_t^{TP}}{\left(\frac{P_{t-1}^X}{P_{t-2}^X}\pi_{t-1}^{TP}\right)^{\omega_{Ind}}(\pi_{ss}^{TP})^{1-\omega_{Ind}}}-1\right]\left[\frac{\pi_t^{TP}}{\left(\frac{P_{t-1}^X}{P_{t-2}^X}\pi_{t-1}^{TP}\right)^{\omega_{Ind}}(\pi_{ss}^{TP})^{1-\omega_{Ind}}P_{t-1}^X(i)}\right]\Bigg\}\\
&-\beta^{t+1}\lambda_{t+1}\Bigg\{\chi_X X_{t+1}P_{t+1}^X RER_{t+1}\left[\frac{\frac{P_{t+1}^X(i)}{P_t^X(i)}\pi_{t+1}^{TP}}{\left(\frac{P_t^X}{P_{t-1}^X}\pi_t^{TP}\right)^{\omega_{Ind}}(\pi_{ss}^{TP})^{1-\omega_{Ind}}}-1\right]\\
&\times\left[\frac{\pi_{t+1}^{TP}P_{t+1}^X(i)}{\left(\frac{P_t^X}{P_{t-1}^X}\pi_t^{TP}\right)^{\omega_{Ind}}(\pi_{ss}^{TP})^{1-\omega_{Ind}}(-1)(P_t^X(i))^2}\right]\Bigg\}
\end{aligned}
$$

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

$$
\begin{aligned}
0 \;=\;& \beta^t\lambda_t\Bigg\{(1-\epsilon_t^X)RER_tX_t-MC_t^X(-\epsilon_t^X)(P_t^X)^{-1}X_t\\
&-\chi_X X_tP_t^X RER_t\left[\frac{\frac{P_t^X}{P_{t-1}^X}\pi_t^{TP}}{\left(\frac{P_{t-1}^X}{P_{t-2}^X}\pi_{t-1}^{TP}\right)^{\omega_{Ind}}(\pi_{ss}^{TP})^{1-\omega_{Ind}}}-1\right]\left[\frac{\pi_t^{TP}}{\left(\frac{P_{h,t-1}^*}{P_{h,t-2}^*}\pi_{t-1}^{TP}\right)^{\omega_{Ind}}(\pi_{ss}^{TP})^{1-\omega_{Ind}}P_{t-1}^X}\right]\Bigg\}\\
&-\beta^{t+1}\lambda_{t+1}\Bigg\{\chi_X X_{t+1}P_{t+1}^X RER_{t+1}\left[\frac{\frac{P_{t+1}^X}{P_t^X}\pi_{t+1}^{TP}}{\left(\frac{P_t^X}{P_{t-1}^X}\pi_t^{TP}\right)^{\omega_{Ind}}(\pi_{ss}^{TP})^{1-\omega_{Ind}}}-1\right]\\
&\times\left[\frac{\pi_{t+1}^{TP}P_{t+1}^X}{\left(\frac{P_t^X}{P_{t-1}^X}\pi_t^{TP}\right)^{\omega_{Ind}}(\pi_{ss}^{TP})^{1-\omega_{Ind}}(-1)(P_t^X)^2}\right]\Bigg\}
\end{aligned}
$$

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

$$
DAC_t^X=(1-\epsilon_t^X)+\epsilon_t^X\frac{MC_t^X}{RER_tP_t^X}+\beta\frac{\lambda_{t+1}}{\lambda_t}\frac{X_{t+1}}{X_t}\frac{RER_{t+1}}{RER_t}\left(\frac{P_{t+1}^X}{P_t^X}\right)DAC_{t+1}^X \tag{69}
$$

where

$$
DAC_t^X=\chi_X\left[\frac{\frac{P_t^X}{P_{t-1}^X}\pi_t^{TP}}{\left(\frac{P_{t-1}^X}{P_{t-2}^X}\pi_{t-1}^{TP}\right)^{\omega_{Ind}}(\pi_{ss}^{TP})^{1-\omega_{Ind}}}-1\right]\left[\frac{\pi_t^{TP}P_t^X}{\left(\frac{P_{t-1}^X}{P_{t-2}^X}\pi_{t-1}^{TP}\right)^{\omega_{Ind}}(\pi_{ss}^{TP})^{1-\omega_{Ind}}P_{t-1}^X}\right].
$$

A.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

$$\mathcal{L} = E_0 \sum_{t=0}^{\infty} \frac{1}{R_t^e} \Bigg\{ \Big[P_t^M Y_t^M - (1+\tau_t^{SSF}) W_t N_t^M - (R_{t-1}^L RP_{t-1}^{B,M} - 1) \frac{B_{t-1}^M}{\pi_t^{ATE}}$$
$$-(AC_t^M + AC_t^{Inv,M} + AC_t^{BN,M}) \Big] (1-\tau_t^{OIF}) + \tau_t^{OIF} \delta_\tau P_t^I K_t^M + \tau_t^{OIF} TD^{OIF} - \left[P_t^I Inv_t^M - BN_t^M \right] +$$
$$+\lambda_t^{K,M} \left[Inv_t^M + (1-\delta_{KP}) K_t^M - K_{t+1}^M \right]$$
$$+\lambda_t^{B,M} \left[BN_t^M + B_{t-1}^M / \pi_t^{ATE} - B_t^M \right]$$
$$+\lambda_t^{Y,M} \left[Y_t^M(i) - \left(\frac{P_t^M(i)}{P_t^M} \right)^{-\epsilon_M} Y_t^M \right] \Bigg\},$$

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

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

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

$$\begin{aligned} 0 &= -\frac{1}{R_t^e} P_t^I - \frac{(1-\tau_t^{OIF})}{R_t^e} \left(\chi_{Inv} (\frac{Inv_t^M}{Inv_{t-1}^M} - 1) Inv_t^M / Inv_{t-1}^M + \frac{\chi_{Inv}}{2} (\frac{Inv_t^M}{Inv_{t-1}^M} - 1)^2 \right) \\ &+ \frac{\lambda_t^{K,M}}{R_t^e} - \frac{(1-\tau_{t+1}^{OIF})}{R_{t+1}^e} \chi_{Inv} (\frac{Inv_{t+1}^M}{Inv_t^M} - 1) Inv_{t+1}^M \frac{-Inv_{t+1}^M}{(Inv_t^M)^2} \\ \Leftrightarrow P_t^I &= -(1-\tau_t^{OIF}) \left(\chi_{Inv} (\frac{Inv_t^M}{Inv_{t-1}^M} - 1) Inv_t^M / Inv_{t-1}^M + \frac{\chi_{Inv}}{2} (\frac{Inv_t^M}{Inv_{t-1}^M} - 1)^2 \right) \\ &+ \lambda_t^{K,M} + \frac{(1-\tau_{t+1}^{OIF})}{DF_{t+1}^{DIV}} \chi_{Inv} (\frac{Inv_{t+1}^M}{Inv_t^M} - 1) Inv_{t+1}^M \frac{Inv_{t+1}^M}{(Inv_t^M)^2} \end{aligned} \tag{70}$$

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

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

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

$$\begin{aligned} 0 &= -\frac{\lambda_t^{K,M}}{R_t^e} + \frac{\tau_{t+1}^{OIF} \delta_\tau P_{t+1}^I}{R_{t+1}^e} + \frac{\lambda_{t+1}^{K,M} (1-\delta_{KP})}{(R_{t+1}^e)} + \frac{\lambda_{t+1}^{Y,M}}{(R_{t+1}^e)} \alpha_M \frac{Y_{t+1}^M + FC^M}{K_{t+1}^M} \\ \Leftrightarrow \lambda_t^{K,M} DF_{t+1}^{DIV} &= \tau_{t+1}^{OIF} \delta_\tau P_{t+1}^I + \lambda_{t+1}^{K,M} (1-\delta_{KP}) + \lambda_{t+1}^{Y,M} \alpha_M \frac{Y_{t+1}^M + FC^M}{K_{t+1}^M} \end{aligned} \tag{71}$$

We can derive an expression for the implied (after-tax) rental rate on capital as in Sandmo (1974) when setting investment and price adjustment costs to zero and assuming a constant price for the investment good.[89] Under these assumption it holds that the marginal value of capital equals the price of the investment good, i.e. $P_t^I = P^I = \lambda_t^{K,M}$. Furthermore following equation (72) and the assumption of no price adjustment costs it holds that $\lambda_t^{Y,M} = \frac{\epsilon_M - 1}{\epsilon_M} P_t^M (1-\tau_t^{OIF})$. Inserting these expressions into equation (71), we obtain

$$\begin{aligned}
P^I(DF_{t+1}^{DIV} - 1) &= \tau_{t+1}^{OIF}\delta_\tau P^I - P^I\delta_{KP} + \frac{\epsilon_M - 1}{\epsilon_M} P_{t+1}^M (1-\tau_{t+1}^{OIF})\frac{\partial Y_{t+1}^M}{\partial K_{t+1}^M} \\
\Leftrightarrow \frac{\epsilon_M - 1}{\epsilon_M} P_{t+1}^M \frac{\partial Y_{t+1}^M}{\partial K_{t+1}^M} &= P^I \frac{DF_{t+1}^{DIV} - 1}{1-\tau_{t+1}^{OIF}} - \frac{\tau_{t+1}^{OIF}\delta_\tau P^I - P^I\delta_{KP}}{1-\tau_{t+1}^{OIF}} \\
\Leftrightarrow \frac{\epsilon_M - 1}{\epsilon_M} P_{t+1}^M \frac{\partial Y_{t+1}^M}{\partial K_{t+1}^M} &= P^I \left(\frac{DF_{t+1}^{DIV} - 1}{1-\tau_{t+1}^{OIF}} - \frac{\tau_{t+1}^{OIF}\delta_\tau - \delta_{KP} - \delta\tau_{t+1}^{OIF} + \delta_{KP}\tau_{t+1}^{OIF}}{1-\tau_{t+1}^{OIF}} \right) \\
\Leftrightarrow \frac{\epsilon_M - 1}{\epsilon_M} P_{t+1}^M \frac{\partial Y_{t+1}^M}{\partial K_{t+1}^M} &= P^I \left(R_t^K + \delta_{KP} + \frac{\tau_{t+1}^{OIF}(\delta_{KP} - \delta_\tau)}{1-\tau_{t+1}^{OIF}} \right)
\end{aligned}$$

as given in the main text.

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

$$\begin{aligned}
0 &= -\frac{\lambda_t^{B,M}}{R_t^e} - \frac{(1-\tau_{t+1}^{OIF})}{(R_{t+1}^e)}(R_t^L RP_t^{B,M} - 1 + R_t^L \frac{\partial RP_t^{B,M}}{\partial B_t^M} B_t^M)/\pi_{t+1}^{ATE} + \frac{\lambda_{t+1}^{B,M}}{(R_{t+1}^e)\pi_{t+1}^{ATE}} \\
\Leftrightarrow \lambda_t^{B,M} DF_{t+1}^{DIV}\pi_{t+1}^{ATE} &= -(1-\tau_{t+1}^{OIF})(R_t^L RP_t^{B,M}(1+\xi_B b_t^M) - 1) + \lambda_{t+1}^{B,M}
\end{aligned}$$

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

$$\begin{aligned}
DF_{t+1}^{DIV}\pi_{t+1}^{ATE} - 1 &= (1-\tau_{t+1}^{OIF})(R_t^L RP_t^{B,M}(1+\xi_B b_t^M) - 1) \\
\Leftrightarrow \frac{DF_{t+1}^{DIV} - 1/\pi_{t+1}^{ATE}}{1-\tau_{t+1}^{OIF}} &= \frac{R_t^L RP_t^{B,M}(1+\xi_B b_t^M) - 1}{\pi_{t+1}^{ATE}} \\
\Leftrightarrow R_t^K + \frac{\pi_{t+1}^{ATE} - 1}{(1-\tau_{t+1}^{OIF})\pi_{t+1}^{ATE}} &= \frac{R_t^L RP_t^{B,M}(1+\xi_B b_t^M) - 1}{\pi_{t+1}^{ATE}}
\end{aligned}$$

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

$$\begin{aligned}
0 = \; & \frac{1}{R_t^e}\Bigg((1-\tau_t^{OIF})(1-\epsilon_M)\left(\frac{P_t^M(i)}{P_t^M}\right)^{-\epsilon_M} Y_t^M + \lambda_t^{Y,M}\left[-\frac{-\epsilon_M}{P_t^M(i)} Y_t^M(i)\right] \\
& -(1-\tau_t^{OIF})\chi_M P_t^M Y_t^M(i)\left[\frac{\frac{P_t^M(i)}{P_{t-1}^M(i)}\pi_t^{ATE}}{\left(\frac{P_{t-1}^M}{P_{t-2}^M}\pi_{t-1}^{ATE}\right)^{\omega_{Ind}}\pi_{ss}^{1-\omega_{Ind}}} - 1\right]\left[\frac{\pi_t^{ATE}}{\left(\frac{P_{t-1}^M}{P_{t-2}^M}\pi_{t-1}^{ATE}\right)^{\omega_{Ind}}\pi_{ss}^{1-\omega_{Ind}} P_{t-1}^M(i)}\right]\Bigg) \\
& -\frac{1}{R_{t+1}^e}(1-\tau_{t+1}^{OIF})\chi_M P_{t+1}^M Y_{t+1}^M(i)\left[\frac{\frac{P_{t+1}^M(i)}{P_t^M(i)}\pi_{t+1}^{ATE}}{\left(\frac{P_t^M}{P_{t-1}^M}\pi_t^{ATE}\right)^{\omega_{Ind}}\pi_{ss}^{1-\omega_{Ind}}} - 1\right]\left[\frac{\pi_{t+1}^{ATE} P_{t+1}^M(i)}{\left(\frac{P_t^M}{P_{t-1}^M}\pi_t^{ATE}\right)^{\omega_{Ind}}\pi_{ss}^{1-\omega_{Ind}}(-1)(P_t^M(i))^2}\right]
\end{aligned}$$

For simplicity we introduce

[89]Note, that Sandmo (1974) derived his model under these simplifying assumptions.

$$DAC_t^M = \chi_M \left[\frac{\frac{P_t^M}{P_{t-1}^M}\pi_t^{ATE}}{\left(\frac{P_{t-1}^M}{P_{t-2}^M}\pi_{t-1}^{ATE}\right)^{\omega_{Ind}} \pi_{ss}^{1-\omega_{Ind}}} - 1 \right] \left[\frac{\pi_t^{ATE} P_t^M}{\left(\frac{P_{t-1}^M}{P_{t-2}^M}\pi_{t-1}^{ATE}\right)^{\omega_{Ind}} \pi_{ss}^{1-\omega_{Ind}} P_{t-1}^M} \right].$$

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

$$\begin{aligned} 0 &= (1-\tau_t^{OIF})(1-\epsilon_M)Y_t^M + \lambda_t^{Y,M}\left[-\frac{-\epsilon_M}{P_t^M}Y_t^M\right] \\ & \quad -(1-\tau_t^{OIF})Y_t^M DAC_t^M + \frac{R_t^e}{R_{t+1}^e}(1-\tau_{t+1}^{OIF})\frac{P_{t+1}^M}{P_t^M}Y_{t+1}^M DAC_{t+1}^M \\ \Leftrightarrow DAC_t^M &= (1-\epsilon_M) + \epsilon_M \frac{\lambda_t^{Y,M}}{P_t^M(1-\tau_t^{OIF})} + \frac{R_t^e}{R_{t+1}^e}\frac{Y_{t+1}^M}{Y_t^M}\frac{P_{t+1}^M}{P_t^M}\frac{1-\tau_{t+1}^{OIF}}{1-\tau_t^{OIF}}DAC_{t+1}^M \end{aligned} \tag{72}$$

A.6 Relief 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.

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

In the absence of RRA_t, households after-tax income from ownership of manufacturing sector shares is $(1-\tau_t^{OIH})(1-\tau_t^{OIF})(R_{t-1}^{E,M}-1)S_{t-1}^M$ 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.[90] 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

$$RRA_t = (R_{t-1}-1)(1-\tau_t^{OIH}).$$

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

$$(1-\tau_t^{OIF})(R_{t-1}^{E,M}-1)S_{t-1}^M = \left[(1-\tau_t^{OIF})(R_{t-1}^{E,M}-1)S_{t-1}^M - RRA_t S_{t-1}^M\right] + (R_{t-1}-1)(1-\tau_t^{OIH})S_{t-1}^M$$

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.[91] 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 $(R_{t-1}-1)(1-\tau_t^{OIH})$, transaction costs $F_t^S = 0$, and $\tau_t^{OIF} = \tau_t^{OIH}$ 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.

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

[91] 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.

- The blow-up factor α_t^{OIH} 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 DF^{DIV} it holds that

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

Using the first-order condition for deposits, equation (65), and above value of RRA_t we obtain

$$\begin{aligned}
DF_{t+1}^{DIV} &= \frac{F_t^S/\Delta_{t+1}}{(1-\tau_{t+1}^D)} + \frac{(1+(R_t-1)(1-\tau_{t+1}^{OIH}))/\pi_{t+1}^{ATE} - \tau_{t+1}^D(1+(R_t-1)(1-\tau_{t+1}^{OIH}))/\pi_{t+1}^{ATE}}{(1-\tau_{t+1}^D)} \\
&= \frac{F_t^S/\Delta_{t+1}}{(1-\tau_{t+1}^D)} + \frac{1-\tau_{t+1}^D + (R_t-1)(1-\tau_{t+1}^{OIH})(1-\tau_{t+1}^D))}{(1-\tau_{t+1}^D)\pi_{t+1}^{ATE}} \\
&= \frac{F_t^S/\Delta_{t+1}}{(1-\tau_{t+1}^D)} + \frac{1+(R_t-1)(1-\tau_{t+1}^{OIH})}{\pi_{t+1}^{ATE}} = \frac{F_t^S/\Delta_{t+1}}{(1-\tau_{t+1}^D)} + \frac{1}{\Delta_{t+1}}
\end{aligned}$$

If fixed costs are set to zero, then the discount factor of the household, Δ_{t+1}, equals the discount factor on dividends, $\frac{1}{DF_{t+1}^{DIV}}$ and thus the discount factor underlying the firm's decisions. Moreover, the discount factor is independent of α_t^{OIH} and does consequently not affect the decision of firms.
Inserting this into the first-order condition for borrowing of firms, equation (47), we obtain

$$\begin{aligned}
(DF_{t+1}^{DIV}\pi_{t+1}^{ATE} - 1) &= (1-\tau_{t+1}^{OIF})(R_t^L RP_t^{B,M}(1+\xi_B b_t^M) - 1) \\
\Leftrightarrow (R_t-1)(1-\tau_{t+1}^{OIH})/(1-\tau_{t+1}^{OIF}) &= (R_t^L RP_t^{B,M}(1+\xi_B b_t^M) - 1) \\
\Leftrightarrow 1 &= RP_t^{B,M}(1+\xi_B b_t^M) \Leftrightarrow 0 = b_t^M
\end{aligned}$$

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 $RP_t^{B,M}$ will be larger than 1 and for $b_t^M < 0$, $RP_t^{B,M}$ 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.

A.7 Import sector price setting

The problem of the firm is

$$\max_{P_t^{IM}(i)} E_t \sum_{j=0}^{\infty} \Delta_{t,t+j} \left[(P_t^{IM}(i) - RER_t) IM_t(i) - AC_t^{IM}(i) \right].$$

Profit maximization then yields

$$\begin{aligned}
0 &= \beta^t \lambda_t \Bigg\{ (1-\epsilon_t^{IM}) \left(\frac{P_t^{IM}(i)}{P_t^{IM}}\right)^{-\epsilon_t^{IM}} IM_t(i) - RER_t(-\epsilon_t^{IM}) \frac{(P_t^{IM}(i))^{-\epsilon_t^{IM}-1}}{(P_t^{IM})^{-\epsilon_t^{IM}}} IM_t(i) \\
& -\chi_{IM} P_t^{IM} IM_t \left[\frac{\frac{P_t^{IM}(i)}{P_{t-1}^{IM}(i)}\pi_t^{ATE}}{\left(\frac{P_{t-1}^{IM}}{P_{t-2}^{IM}}\pi_{t-1}^{ATE}\right)^{\omega_{Ind}} \pi_{ss}^{1-\omega_{Ind}}} - 1 \right] \left[\frac{\pi_t^{ATE}}{\left(\frac{P_{t-1}^{IM}}{P_{t-2}^{IM}}\pi_{t-1}^{ATE}\right)^{\omega_{Ind}} \pi_{ss}^{1-\omega_{Ind}} P_{t-1}^{IM}(i)} \right] \Bigg\} \\
& -\beta^{t+1}\lambda_{t+1} \Bigg\{ \chi_{IM} P_{t+1}^{IM} IM_{t+1} \left[\frac{\frac{P_{t+1}^{IM}(i)}{P_t^{IM}(i)}\pi_{t+1}^{ATE}}{\left(\frac{P_t^{IM}}{P_{t-1}^{IM}}\pi_t^{ATE}\right)^{\omega_{Ind}} \pi_{ss}^{1-\omega_{Ind}}} - 1 \right] \\
& \times \left[\frac{\pi_{t+1}^{ATE} P_{t+1}^{IM}(i)}{\left(\frac{P_t^{IM}}{P_{t-1}^{IM}}\pi_t^{ATE}\right)^{\omega_{Ind}} \pi_{ss}^{1-\omega_{Ind}} (-1)(P_t^{IM}(i))^2} \right] \Bigg\}
\end{aligned}$$

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

$$DAC_t^{IM} = (1-\epsilon_t^{IM}) + \epsilon_t^{IM} RER_t (P_t^{IM})^{-1} + \beta \frac{\lambda_{t+1}}{\lambda_t} \frac{IM_{t+1}}{IM_t} \frac{P_{t+1}^{IM}}{P_t^{IM}} DAC_{f,t+1} \tag{73}$$

where

$$DAC_t^{IM} = \chi_{IM} \left[\frac{\frac{P_t^{IM}}{P_{t-1}^{IM}}\pi_t^{ATE}}{\left(\frac{P_{t-1}^{IM}}{P_{t-2}^{IM}}\pi_{t-1}^{ATE}\right)^{\omega_{Ind}} \pi_{ss}^{1-\omega_{Ind}}} - 1 \right] \left[\frac{\pi_t^{ATE} P_t^{IM}}{\left(\frac{P_{t-1}^{IM}}{P_{t-2}^{IM}}\pi_{t-1}^{ATE}\right)^{\omega_{Ind}} \pi_{ss}^{1-\omega_{Ind}} P_{t-1}^{IM}} \right].$$

A.8 Törnqvist index

The total value of domestic production is given by

$$\begin{aligned}
P_t^{Nom,Y} Y_t^D &= P_t^{Nom,M} Y_t^M + P_t^{Nom,S} Y_t^S + P_t VA_t^X X_t, \text{ or equivalently} \\
P_t^Y Y_t^D &= P_t^M Y_t^M + P_t^S Y_t^S + VA_t^X X_t
\end{aligned}$$

where P_t is the CPI adjusted for taxes and energy. 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 NORA, the price index of domestic production is given by

$$P_t^{Nom,Y} = \left(P_t^{Nom,M}/P_{ss}^{Nom,M}\right)^{\left([\frac{VAM_t}{TVA_t}+(\frac{VAM}{TVA})_{ss}]/2\right)} \left(P_t^{Nom,S}/P_{ss}^{Nom,S}\right)^{\left([\frac{VAS_t}{TVA_t}+(\frac{VAS}{TVA})_{ss}]/2\right)} \left(P_t VA_t^X/(P_{ss}VA_{ss}^X)\right)^{\left([s_t^X+s_{ss}^X]/2\right)}$$

where $\frac{VAM_t}{TVA_t}$ denotes the share of value added in the manufacturing sector, i.e. $\frac{VAM_t}{TVA_t} = (P_t^M Y_t^M)/(P^Y Y_t^D)$, and $\frac{VAS_t}{TVA_t}$ the share of value added in the service sector, i.e. $\frac{VAS_t}{TVA_t} = (P_t^S Y_t^S)/(P^Y Y_t^D)$.[92] Consequently, $s_t^X = 1 - \frac{VAM_t}{TVA_t} - \frac{VAS_t}{TVA_t}$. The notation X_{ss} denotes the steady-state value of X. It can be easily verified, that the relationship also holds for relative prices (under the assumption that $P_{ss}=1$), i.e:

$$P_t^Y = \left(P_t^M/P_{ss}^M\right)^{\left([\frac{VAM_t}{TVA_t}+(\frac{VAM}{TVA})_{ss}]/2\right)} \left(P_t^S/P_{ss}^S\right)^{\left([\frac{VAS_t}{TVA_t}+(\frac{VAS}{TVA})_{ss}]/2\right)} \left(VA_t^X/VA_{ss}^X\right)^{\left([s_t^X+s_{ss}^X]/2\right)}$$

[92] The expression can equivalently be expressed as

$$\Delta\log(P_t^Y) = \left([\frac{VAM_t}{TVA_t}+(\frac{VAM}{TVA})_{ss}]/2\right)\Delta\log(P_t^M) + \left([\frac{VAS_t}{TVA_t}+(\frac{VAS}{TVA})_{ss}]/2\right)\Delta\log(P_t^S) + \left([s_t^X+s_{ss}^X]/2\right)\Delta\log(P_t VA_t^X)$$

where $\Delta log(X_t) = log(X_t) - log(X_{ss})$.

A.9 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 the expectation operator everywhere to simplify notation.

$$
\begin{aligned}
&DP_t^R + P_t^E(1+F_t^S)\frac{1}{(1-\omega)} = 1/\pi_t^{ATE}(DP_{t-1}^R + P_{t-1}^E\frac{1}{(1-\omega)})\\
&+LI_t^R + UB_t(L_t-E_t) + TR_t^R - (LI_t^R + UB_t(L_t-E_t) + TR_t^R - TD^{OIH})\tau_t^{OIH}\\
&-(LI_t^R + UB_t(L_t-E_t) + TR_t^R - TD^{LS})(\tau_t^{LS} + \tau_t^{SSH}) + (1/\pi_t^{ATE}DP_{t-1}^R(R_{t-1}-1))(1-\tau_t^{OIH})\\
&+(DIV_t + AV_t)\frac{1}{(1-\omega)}(1-\alpha_t^{OIH}\tau_t^{OIH}) + \tau_t^{OIH}RRA_tP_{t-1}^E\alpha_t^{OIH}\frac{1}{(1-\omega)}\\
&-T_t^{L,R} - P_t^C C_t^R - P_t^I Inv_t^H + AVT_t^R + \Pi_t^{X,R} + \Pi_t^{C,R} + \Pi_t^{F,R} + \Pi_t^{B,R}
\end{aligned}
$$

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

$$
\begin{aligned}
&DP_t + P_t^E = 1/\pi_t^{ATE}(DP_{t-1} + P_{t-1}^E)\\
&+(1-\omega)(LI_t^R + UB_t(L_t-E_t)) + TR_t - \omega TR_t^L - (1-\omega)(LI_t^R + UB_t(L_t-E_t) + TR_t^R - TD^{OIH})\tau_t^{OIH}\\
&-(1-\omega)(LI_t^R + UB_t(L_t-E_t) + TR_t^R - TD^{LS})(\tau_t^{LS} + \tau_t^{SSH}) + (1/\pi_t^{ATE}DP_{t-1}(R_{t-1}-1))(1-\tau_t^{OIH})\\
&+DIV_t(1-\alpha_t^{OIH}\tau_t^{OIH}) + AV_t + \tau_t^{OIH}RRA_tP_{t-1}^E\alpha_t^{OIH}\\
&-T_t^L - (1-\omega)P_t^C C_t^R - P_t^I Inv_t^H + \Pi_t^X + \Pi_t^C + \Pi_t^B
\end{aligned}
$$

Note, that we employed the aggregation rules from section 2.2.3. Above, we have also cancelled Π_t^F against the financial fees, as well as the asset valuation tax refund AVT_t against the taxation of capital gains. Now, we insert the liquidity-constraint household's budget constraint, see equation (9), which yields

$$
\begin{aligned}
&DP_t = 1/\pi_t^{ATE}DP_{t-1} + (1-\omega)(LI_t^R + UB_t(L_t-E_t)) + TR_t - \omega P_t^C C_t^L\\
&+\omega(W_tN_t^P + W_t^GN_t^G + UB_t(L_t-E_t)) - \omega(W_tN_t^P + W_t^GN_t^G + UB_t(L_t-E_t) + TR_t^L - TD^{OIH})(\tau_t^{OIH})\\
&-\omega(W_tN_t^P + W_t^GN_t^G + UB_t(L_t-E_t) + TR_t^L - TD^{LS})(\tau_t^{LS} + \tau_t^{SSH})\\
&-(1-\omega)(LI_t^R + UB_t(L_t-E_t) + TR_t^R - TD^{OIH})\tau_t^{OIH}\\
&-(1-\omega)(LI_t^R + UB_t(L_t-E_t) + TR_t^R - TD^{LS})(\tau_t^{LS} + \tau_t^{SSH}) + (1/\pi_t^{ATE}DP_{t-1}(R_{t-1}-1))(1-\tau_t^{OIH})\\
&+DIV_t(1-\alpha_t^{OIH}\tau_t^{OIH}) + \tau_t^{OIH}RRA_tP_{t-1}^E\alpha_t^{OIH}\\
&-T_t^L - (1-\omega)P_t^C C_t^R - P_t^I Inv_t^H + \Pi_t^X + \Pi_t^C + \Pi_t^B
\end{aligned}
$$

We have also cancelled AV_t against the stock price terms. Using again the aggregation rules from section 2.2.3, we obtain

$$
\begin{aligned}
&DP_t = 1/\pi_t^{ATE}DP_{t-1} + W_tN_t^P + W_t^GN_t^G + UB_t(L_t-E_t) + TR_t\\
&-(W_tN_t^P + W_t^GN_t^G + UB_t(L_t-E_t) + TR_t - TD^{OIH})\tau_t^{OIH}\\
&-(W_tN_t^P + W_t^GN_t^G + UB_t(L_t-E_t) + TR_t - TD^{LS})(\tau_t^{LS} + \tau_t^{SSH}) + (1/\pi_t^{ATE}DP_{t-1}(R_{t-1}-1))(1-\tau_t^{OIH})\\
&+DIV_t(1-\alpha_t^{OIH}\tau_t^{OIH}) + \tau_t^{OIH}RRA_tP_{t-1}^E\alpha_t^{OIH}\\
&-T_t^L - P_t^C C_t - P_t^I Inv_t^H + \Pi_t^X + \Pi_t^C + \Pi_t^B
\end{aligned}
$$

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 (54), which yields

$$
\begin{aligned}
& DP_t = 1/\pi_t^{ATE} DP_{t-1} + W_t N_t^P + W_t^G N_t^G + UB_t(L_t - E_t) + TR_t \\
& -(W_t N_t^P + W_t^G N_t^G + UB_t(L_t - E_t) + TR_t - TD^{OIH})\tau_t^{OIH} \\
& -(W_t N_t^P + W_t^G N_t^G + UB_t(L_t - E_t) + TR_t - TD^{LS})(\tau_t^{LS} + \tau_t^{SSH}) + (1/\pi_t^{ATE} DP_{t-1}(R_{t-1} - 1))(1 - \tau_t^{OIH}) \\
& +DIV_t(1 - \alpha_t^{OIH}\tau_t^{OIH}) + \tau_t^{OIH} RRA_t P_{t-1}^E \alpha_t^{OIH} \\
& -(T_t^L - T_t) + OFW_t - G_t - DI_t - (D_{t-1}/\pi_t^{ATE} - D_t) - P_t^C C_t - P_t^I Inv_t^H + \Pi_t^X + \Pi_t^C + \Pi_t^B
\end{aligned}
$$

We now use definition of T_t in (52) to replace the remaining T_t term which leads to a number of tax terms dropping out. Additionally, we replace G_t with it's definition from (53) and obtain

$$
\begin{aligned}
& DP_t = 1/\pi_t^{ATE} DP_{t-1} + W_t N_t^P \\
& +1/\pi_t^{ATE} DP_{t-1}(R_{t-1} - 1) + DIV_t + C_t(\tau_t^C + \tau_t^{CF}) + W_t N_t^P \tau_t^{SSF} + (TB_t^{\Pi,M} + TB_t^{\Pi,S})\tau_t^{OIF} \\
& +OFW_t - P_t^{G^C} G_t^C - P_t^I G_t^I - DI_t - (D_{t-1}/\pi_t^{ATE} - D_t) - P_t^C C_t - P_t^I Inv_t^H + \Pi_t^X + \Pi_t^C + \Pi_t^B
\end{aligned}
$$

Using the definition of Π_t^C from (36) we obtain

$$
\begin{aligned}
& DP_t = 1/\pi_t^{ATE} DP_{t-1} + W_t N_t^P(1 + \tau_t^{SSF}) \\
& +1/\pi_t^{ATE} DP_{t-1}(R_{t-1} - 1) + DIV_t + (TB_t^{\Pi,M} + TB_t^{\Pi,S})\tau_t^{OIF} \\
& +OFW_t - P_t^{G^C} G_t^C - P_t^I G_t^I - DI_t - (D_{t-1}/\pi_t^{ATE} - D_t) - P_t^I Inv_t^H + \Pi_t^X - C_t - AC_t^C + \Pi_t^B
\end{aligned}
$$

Using the relationship between dividends and profits given in equation (42), as well as the definition of profits in (41), yields

$$
\begin{aligned}
& DP_t = 1/\pi_t^{ATE} DP_{t-1} + 1/\pi_t^{ATE} DP_{t-1}(R_{t-1} - 1) \\
& +P_t^M Y_t^M + P_t^S Y_t^S - (R_{t-1}^L RP_{t-1}^{B,M} - 1)\frac{B_{t-1}^M}{\pi_t^{ATE}} - (R_{t-1}^L RP_{t-1}^{B,S} - 1)\frac{B_{t-1}^S}{\pi_t^{ATE}} - AC_t^M - AC_t^S - AC_t^{Inv} - AC_t^{BN} \\
& -\Pi_t^{R,M} - \Pi_t^{R,S} + OFW_t - P_t^{G^C} G_t^C - P_t^I G_t^I - DI_t - (D_{t-1}/\pi_t^{ATE} - D_t) - P_t^I Inv_t^H + \Pi_t^X - C_t - AC_t^C + \Pi_t^B
\end{aligned}
$$

where $AC_t^{Inv} = AC_t^{Inv,M} + AC_t^{Inv,S}$ and $AC_t^{BN} = AC_t^{BN,M} + AC_t^{BN,S}$. We now use the bank balance sheet equation (17) to derive

$$
\begin{aligned}
& B_t^M + B_t^S + D_t - RER_t B_t^F = 1/\pi_t^{ATE}(B_{t-1}^M + B_{t-1}^S + D_{t-1} - RER_{t-1} B_{t-1}^F)R_{t-1} \\
& +P_t^M Y_t^M + P_t^S Y_t^S - (R_{t-1}^L RP_{t-1}^{B,M} - 1)\frac{B_{t-1}^M}{\pi_t^{ATE}} - (R_{t-1}^L RP_{t-1}^{B,S} - 1)\frac{B_{t-1}^S}{\pi_t^{ATE}} - AC_t^M - AC_t^S - AC_t^{Inv} - AC_t^{BN} \\
& -\Pi_t^{R,M} - \Pi_t^{R,S} + OFW_t - P_t^{G^C} G_t^C - P_t^I G_t^I - DI_t - (D_{t-1}/\pi_t^{ATE} - D_t) - P_t^I Inv_t^H + \Pi_t^X - C_t - AC_t^C + \Pi_t^B
\end{aligned}
$$

Cancelling the government debt terms as well as using the definition of retained profits in (43), as well as the new borrowing equation in (39), we obtain

$$
\begin{aligned}
& B_t^M + B_t^S - RER_t B_t^F = 1/\pi_t^{ATE}(B_{t-1}^M + B_{t-1}^S - RER_{t-1} B_{t-1}^F)R_{t-1} \\
& +P_t^M Y_t^M + P_t^S Y_t^S - (R_{t-1}^L RP_{t-1}^{B,M} - 1)\frac{B_{t-1}^M}{\pi_t^{ATE}} - (R_{t-1}^L RP_{t-1}^{B,S} - 1)\frac{B_{t-1}^S}{\pi_t^{ATE}} - AC_t^M - AC_t^S - AC_t^{Inv} - AC_t^{BN} \\
& -P_t^I(Inv_t^M + Inv_t^S) + B_t^M + B_t^S - 1/\pi_t^{ATE}(B_{t-1}^M + B_{t-1}^S) + OFW_t - P_t^{G^C} G_t^C - P_t^I G_t^I - P_t^I Inv_t^H + \Pi_t^X \\
& -C_t - AC_t^C + \Pi_t^B
\end{aligned}
$$

Ignoring the expectation in equation (19), we use $R^L_t = R_t$ and can simplify to

$$
\begin{aligned}
-RER_t B^F_t &= 1/\pi^{ATE}_t (B^M_{t-1} + B^S_{t-1} - RER_{t-1} B^F_{t-1}) R^L_{t-1} \\
&+ P^M_t Y^M_t + P^S_t Y^S_t - (R^L_{t-1} RP^{B,M}_{t-1}) \frac{B^M_{t-1}}{\pi^{ATE}_t} - (R^L_{t-1} RP^{B,S}_{t-1}) \frac{B^S_{t-1}}{\pi^{ATE}_t} - AC^M_t - AC^S_t - AC^{Inv}_t - AC^{BN}_t \\
&- P^I_t (Inv^M_t + Inv^S_t + Inv^H_t + G^I_t) + OFW_t - P^{G^C}_t G^C_t + \Pi^X_t - C_t - AC^C_t + \Pi^B_t
\end{aligned}
$$

Using the definition of Π^B_t ($\Pi^B_t = \frac{B^M_{t-1}}{\pi^{ATE}_t} R^L_{t-1}(RP^{B,M}_{t-1} - 1) + \frac{B^S_{t-1}}{\pi^{ATE}_t} R^L_{t-1}(RP^{B,S}_{t-1} - 1)$) we obtain

$$
\begin{aligned}
-RER_t B^F_t &= 1/\pi^{ATE}_t (-RER_{t-1} B^F_{t-1}) R^L_{t-1} + P^M_t Y^M_t + P^S_t Y^S_t - AC^M_t - AC^S_t - AC^{Inv}_t - AC^{BN}_t \\
&- P^I_t (Inv^M_t + Inv^S_t + Inv^H_t + G^I_t) + OFW_t - P^{G^C}_t G^C_t + \Pi^X_t - C_t - AC^C_t
\end{aligned}
$$

Using the definition of Π^X_t as well as the definition of total output from equation (61) yields

$$
\begin{aligned}
-RER_t B^F_t &= 1/\pi^{ATE}_t (-RER_{t-1} B^F_{t-1}) R^L_{t-1} + P^Y_t Y^D_t \\
&- P^I_t (Inv^M_t + Inv^S_t + Inv^H_t + G^I_t) + OFW_t - P^{G^C}_t G^C_t - C_t - AC_t
\end{aligned}
$$

where $AC_t = AC^M_t + AC^S_t + AC^{Inv}_t + AC^{BN}_t - AC^X_t - AC^C_t$ captures the entirity of adjustment costs in the model economy. We now use the balance of payments equation (63) as well as the UIP condition which yields

$$
NX_t + OFW_t + P^I_t Inv^{Oil}_t = P^Y_t Y^D_t - P^I_t (Inv^M_t + Inv^S_t + Inv^H_t + G^I_t) + OFW_t - P^{G^C}_t G^C_t - C_t - AC_t
$$

which after rearranging gives

$$
P^Y_t Y^D_t = C_t + NX_t + P^I_t I_t + P^{G^C}_t G^C_t + AC_t.
$$

A.10 Steady-state solution

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

$$
\begin{aligned}
\pi^{ATE} &= \pi^{ATE}_{ss} \\
\pi^{TP} &= \pi^{TP}_{ss}
\end{aligned}
$$

   where π^{ATE}_{ss} and π^{TP}_{ss} are given by empirical targets described in the calibration section.

2. **Taxes:** We identify effective tax rates in the data and set the steady-state tax rates to these empirically determined values.

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

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

3. **Relative prices, exchange rate, markup:** Rearranging the steady-state version of the equation (31) for the final consumption good sector yields (remembering that $MC^C_t = 1$ as the numeraire)

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

where the value of $\frac{P^{M,C}C^M}{C}$ is taken from the data and reflects the manufacturing share of the final consumption good. The parameter α_C is set to $1 - \frac{P^{M,C}C^M}{C}$ such that $P^{M,C} = 1$. It follows then from (32), that $P^{S,C} = 1$, as $\alpha_C = 1 - \frac{P^{M,C}C^M}{C} = \frac{P^{S,C}C^S}{C}$. Setting $1 - \alpha_{M,C} = \frac{P^M Y^{C,M}}{P^{S,C}C^S}$, reflecting the share of the domestic service good in the composite service good for consumption, yields ,using equation (21), that $P^M = 1$. Similarly, one obtains $P^S = 1$ after setting $1 - \alpha_{S,C} = \frac{P^S Y^{C,S}}{P^{S,C}C^S}$. From (22), it follows then directly, that $P^{IM} = 1$. For all other final good we set $\alpha_{M,Z}$ and $\alpha_{S,Z}$ accordingly and obtain $P^{M,Z} = P^{S,Z} = 1$. Finally, and returning to the second stage of the final good sector we find that, $P^z = 1$ for $z = G^C, I$. For the import sector, it then follows from the steady-state version of the optimal import pricing equation, (73), that

$$RER = P^{IM} \frac{\epsilon_t^{IM} - 1}{\epsilon_t^{IM}}.$$

Using the optimal home good pricing equation, (72), we derive the steady-state shadow value of production as

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

and the steady-state value of capital using equation (70) as $\lambda_t^{K,M} = P^I$. The corresponding variables for the service sector can be derived analogously.

Using the optimal pricing decisions for exports from equation (69), we obtain

$$P_x = \frac{\epsilon_t^X}{\epsilon_t^X - 1} \frac{MC^x}{Q}$$

where $MC^x = 1$ as follows from equation (33). Similarly and using the optimal price equation for consumption we obtain $P^C = \frac{\epsilon_C}{\epsilon_C - 1}(1 + \tau^C + \tau^{CF})$.

4. **Interest rates:** Using (65) we obtain

$$R = \frac{\frac{\pi^{ATE}}{\beta} - 1}{1 - \tau^{OIH}} + 1.$$

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_{ss} and the target for the nominal interest rate R.

Using (20) we then obtain

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

where we have used the fact that the risk premium $RP = 1$ in the steady state as follows from the definition of RP_t. From equation (19) we obtain that $R^L = R$. The rate-of-return allowance RRA as well as the discount variables θ and DF^{DIV} 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 (38), and the corresponding equation for the service sector, it follows, that

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

where both $\frac{P^I I}{Y^{CPI}}$ and $\frac{P^I K}{Y^{CPI}}$ can be determined empirically (Note, that the empirical target would only include private production capital excluding housing and public capital). Hence, we choose δ_{KP} such that we match the empirical private investment to GDP ratio.

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 (47), we can then determine the steady-state value of the firm risk premium as

$$RP^{B,M} = (\frac{DF^{DIV}\pi^{ATE} - 1}{1 - \tau^{OIF}} + 1)/(R^L(1 + \xi_B b^M)).$$

We then use equation (40) to set $\beta^M = b^M - \log(RP^{B,M})/\xi_B$ 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.[93] Using equation (71), we then obtain in steady state that

$$\begin{aligned}
\lambda_t^{K,M} DF^{DIV} &= \tau^{OIF}\delta_\tau P^I + \lambda_t^{K,M}(1-\delta_{KP}) + \lambda^{Y,M}\alpha_M \frac{Y^M + FC^M}{K^M} \\
\lambda_t^{K,M}(DF^{DIV} - 1 + \delta_{KP}) - \tau^{OIF}\delta_\tau P^I &= \lambda^{Y,M}\alpha_M \frac{Y^M + FC^M}{K^M} \\
\underbrace{\lambda_t^{K,M}(DF^{DIV} - 1 + \delta_{KP}) - \tau^{OIF}\delta_\tau P^I}_{:=\theta_{K,M}} &= \lambda^{Y,M}\alpha_M \frac{Y^M}{K^M}(1 + \frac{FC^M}{Y^M})
\end{aligned} \tag{74}$$

Rearranging the first-order condition for labor demand, equation (45), we obtain the expression

$$(1 + \frac{FC^M}{Y^M}) = \frac{(1+\tau^{SSF})WN^M}{P^M Y^M} P^M \frac{1-\tau^{OIF}}{\lambda^{Y,M}} \frac{1}{(1-\alpha_M)}.$$

Having identified empirically the labor share in the manufacturing sector, $\frac{(1+\tau^{SSF})WN^M}{P^M Y^M}$, 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 (74) 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 (74). 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 (45) by (74), we obtain

$$\frac{W}{\theta_{K,M}} = \frac{1}{(1-\tau^{OIF})(1+\tau^{SSF})} \frac{(1-\alpha_M)}{\alpha_M} \frac{K^M}{N^M} \tag{75}$$

From the steady-state version of equation (37), we obtain

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

[93] 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.

Using this and equation (75) 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.[94] We obtain the same wage rate in the service sector due to the identical assumptions made for the sectors.

9. **Employment 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 (45), 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 (45) 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. $FC^M = \frac{FC^M}{Y^M} Y^M$. 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 $\frac{P^X RERX}{Y^{CPI}}$, we set $X = \frac{P^X QX}{Y^{CPI}} Y^{CPI}/(P^X Q)$. Using equation (30), we then chose Y^{TP}, such that the imposed level of X is consistent with foreign demand, i.e.

$$Y^{TP} = X / \left((P^X)^{-\eta_{TP}} \right).$$

.

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

$$W^G = \frac{(1 + \tau^{SSF}) W^G N^G}{Y^{CPI}} \frac{Y^{CPI}}{N^G (1 + \tau^{SSF})}$$

13. **Sector inputs, consumption and labor supply:** Given that the final goods I, G^C, 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.

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

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 c_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

[94] 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.

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 $\frac{RERB}{Y^{CPI}}$ we set $D = \frac{D}{Y^{CPI}} Y^{CPI}$ and $B^F = \frac{RERB^F}{Y^{CPI}} \frac{Y^{CPI}}{RER}$. In order for the balance of payments to hold, we solve (63) for OFW and derive

$$OFW = B^F RER(R^{TP} RP/\pi^{TP} - 1) - NX - P^I Inv^{OIL}.$$

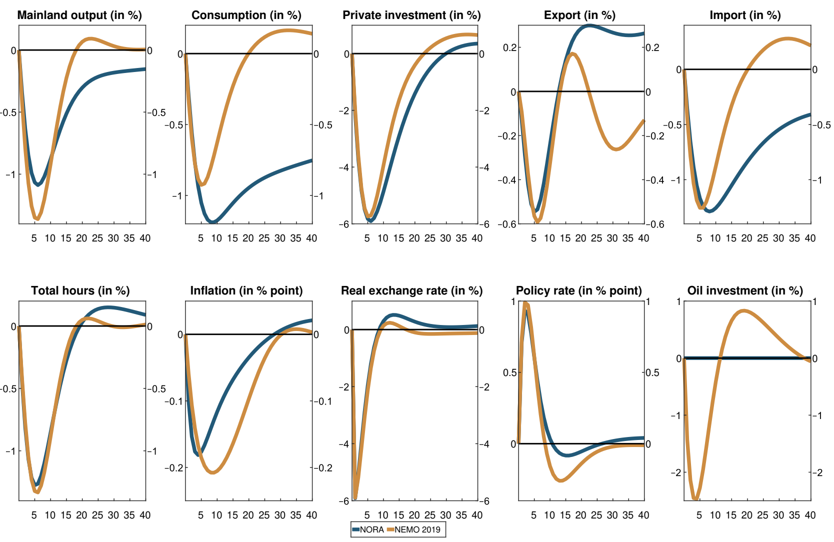
The government budget constraint from equation (54) can then be resolved to obtain T^L, since all other components of the budget constraint are known at this point.

B Impulse response matching

We implement an IRF matching procedure in which we determine 13 dynamic parameters, see the fourth column in table 4 for an overview. More specifically, we match in the impulse responses in NORA to 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.[95] The 10 variables included in the matching procedure include mainland GDP, private consumption, private investment, oil sector investments, exports, imports, hours worked, the nominal interest rate, CPI inflation, and the real exchange rate. The resulting plots are shown in 13 to 16.

We impose equality between the shock processes across the two models. The the government budget is assumed to be balanced in each point of time by lump-sum taxes on Ricardian households. Overall NORA does a reasonably good job at matching the impulse responses from NEMO. It is important to note that a better fit would be possible if we were to only match one shock at the time. Instead, the IRF-matching procedure tries to trade-off differences across shocks.

Figure 13: Monetary policy shock



[95]We do not show the technology shock in NEMO as this shock has not been officially published by Norges Bank.

Figure 14: Risk premium shock

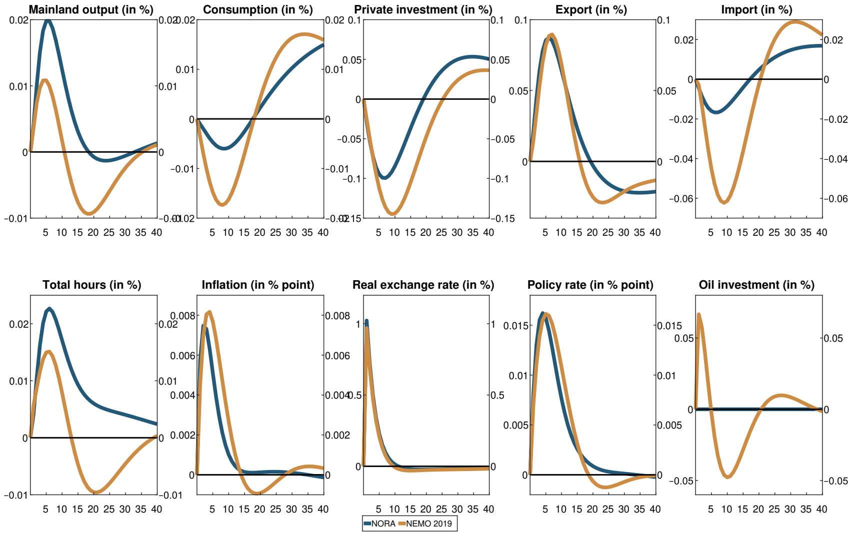


Figure 15: Oil price shock

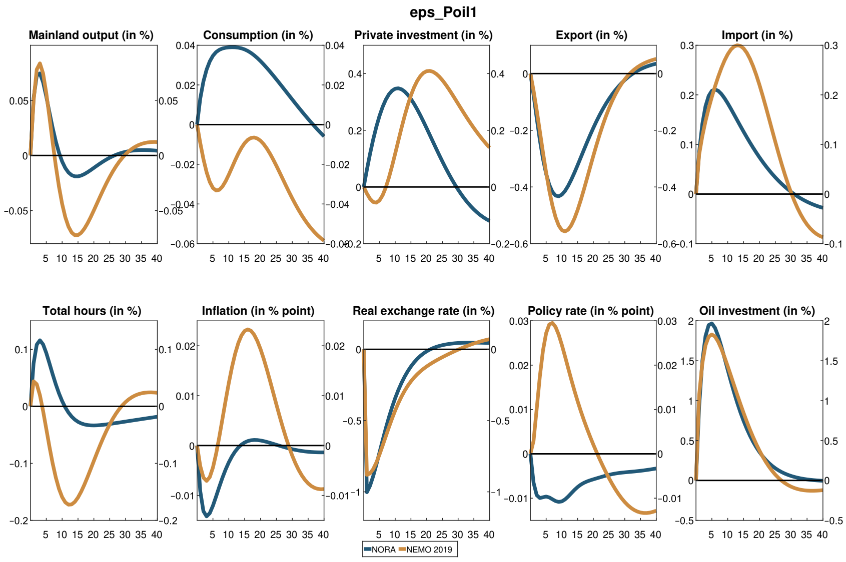
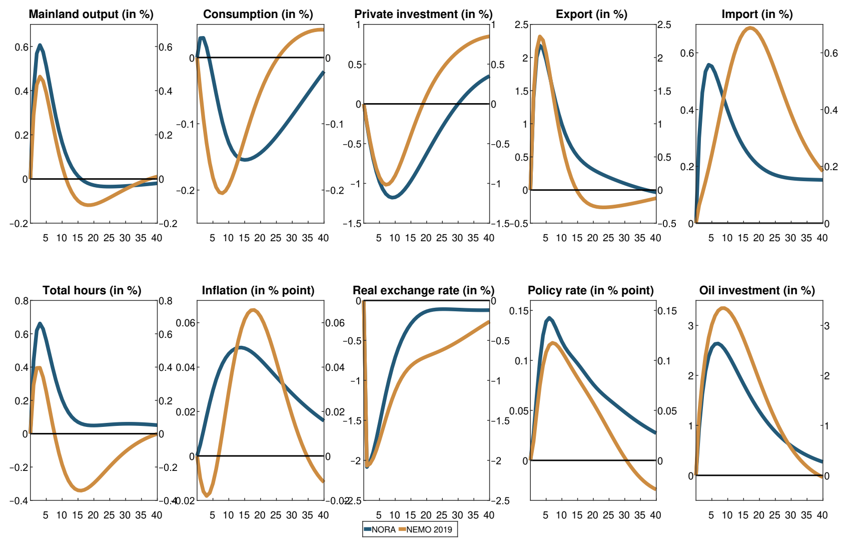


Figure 16: Global demand shock



C Data and calibration targets

This section lists data used in the calibration exercise. In particular, table 5 lists the data series used. The left column provides the table number and name (as on Statistics Norway's webpages). In the case where multiple categories of variables are available, the specific category is listed below the table number. Clicking the table number takes the reader to the corresponding table online. The middle column lists the variables used from the table. The right column gives each variable a code used for calculations in tables 6 and 7. To the greatest extent possible, variable names have been kept from the online tables in order to facilitate easy access by external users. Prefixes have been added whenever multiple categories from a table is used, the variable code is a number, or the variable code is common across tables. Based on the variable codes in table 5, the second column of table 6 provide the formula to calculate the empirical ratio in the first column. Table 7 describe how to obtain the empirical counterpart to the model's tax revenues and tax bases.

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 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	$Z09$
	Labor surtax 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		
In percent of the population, both sexes, seasonally adjusted		
	Labor Force	$LF1574$
	Employed persons	$ER1574$
Table 09172 Final consumption expenditure of households		
Current prices		
	Dwelling services	$nr62bolig$
Table 09174 Wages and salaries, employment and productivity		

Table 5: Data sources

Category/Units	Variable description	Variable code
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 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		
Fixed assets, current prices		
	Mainland Norway	$FA.nr24\_5$
	General Government	$FA.nr24\_$
Consumption of fixed capital, current prices		
	General Government	$D.nr24\_$
Table 09189 Final expenditure and gross domestic product		
Current prices		
	Final consumption exp. of households and NPISHs	$koh.nrpriv$
	Final consumption exp. 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	$imp.nrtradvare$
	GDP 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	$FA346RS3$

Table 5: Data sources

Category/Units	Variable description	Variable code
	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	$FL343RS3$
	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

Table 6: Empirical great ratios.

Ratio	Forumula
$P^C C/P^Y Y$	$koh.nrpriv/bnpb.nr23\_9fn$
$P^H C^H/P^Y Y$	$nr62bolig/bnpb.nr23\_9fn$
$P^{NH} C^{NH}/P^Y Y$	$(koh.nrpriv - nr62bolig)/bnpb.nr23\_9fn$
$P^I I^P/P^Y Y$	$bif.nr83\_6fnxof/bnpb.nr23\_9fn$
$P^I I^G/P^Y Y$	$bif.nr84\_5/bnpb.nr23\_9fn$
$P^I I^{OIL}/P^Y Y$	$bif.nr83oljroer/bnpb.nr23\_9fn$
$\delta_{KG} P^I K^G/P^Y Y$	$W3/bnpb.nr23\_9fn$
$P^{G^C} G^C/P^Y Y$	$(koo.nroff - B1 - W3)/bnpb.nr23\_9fn$
$\left(1+\tau^{SSF}\right) W^G N^G/P^Y Y$	$B1/bnpb.nr23\_9fn$
$P^X RERX/P^Y Y$	$(x.nrtradvare + x.puboljdiv + x.pubreise + x.nratjen)/bnpb.nr23\_9fn$
$P^{IM} IM/P^Y Y$	$im.nrtot/bnpb.nr23\_9fn$
$D/P^Y Y$	$C\_OFF999/bnpb.nr23\_9fn$
$B/P^Y Y$	$\left[\left(FA3 - \sum_{j\neq3} FAj\right) - \left(FL3 - \sum_{i\neq3} FLi\right)\right]/bnpb.nr23\_9fn$
$UB/P^Y Y$	$COF\_105/bnpb.nr23\_9fn$
L	$LF1574$
N	$ER1574$
U	$(LF1574 - ER1574)/LF1574$
$OFW/P^Y Y$	-
$P^{IM} C^{IM}/P^C C$	-
$P^{IM} I^{IM}/P^I I$	-
$P^I K^P/P^Y Y$	$(FA.nr24\_5 - FA.nr24\_)/bnpb.nr23\_9fn$
$P^I K^G/P^Y Y$	$FA.nr24\_/bnpb.nr23\_9fn$
N^G/N	$N.nr24\_5/N.nr23\_6fn$
W^G/W^P	$\left(\frac{Y.nr23\_6fn}{N.nr23\_6fn} - \frac{N^G}{N}\frac{Y.nr24\_5}{N.nr24\_5}\right)/\left(1-\frac{N^G}{N}\right)$
Labor share	$(Y.nr23\_6fn - Y.nr24\_5)/(bnpb.nr23\_9fn - D.nr24\_ - Y.nr24\_5)$
$TR/P^Y Y$	$(B5 + B6 - COF105)/bnpb.nr23\_9fn$

Table 7: Empirical tax revenues and tax bases.

Tax	Revenue	Base
Consumption value-added	$A21$	$koh.nrpriv$
Consumption volume fees	$A24 + A25 + A26$	$koh.nrpriv$
Import duties	$A22$	$imp.nrtradvare$
Social security contributions (Firms)	$A42$	$W11 - W115 - W116$
Social security contributions (Households)	$Z13$	$Z05 + Z04 + Z36 + Z31 + Z35$
Ordinary income (Households)	$Z09 + Z12$	$Z03$
Ordinary income (Firms)	IT_{A_U}	TI_{A_U}
Labor surtax	$Z40$	$Z01$

C.1 Calibration of final goods shares

The four final goods and eight aggregates of the two intermediate good sectors from section 2.6.1 and 2.6.2 leave twelve share parameters and twelve substitution elasticities to pin down. Section 3 describes how elasticities are set according to existing studies. To determine the share parameters we have received significant help from Statistics Norway in order to aggregate the input-output tables to the aggregation level consistent with the model.

Because the production functions are for value added there is a conceptual challenge in how to calibrate the import shares in the first stage of production. Consider an increase in exports arising from the manufacturing sector alone. This increase has no direct effect on the service sector or imports of any goods. However, services and imported goods are used as intermediate goods in production. To capture this we consider a vertically integrated version of the manufacturing (and service) composites when calibrating the import shares of these CES aggregates. Furthermore, value added arising in the service sector due to demand from the manufacturing sector is treated as if it was created in the manufacturing sector. An alternative to the current approach would be to directly model the use of intermediate goods in each sector.

We adopt the definition used by "Det tekniske beregningsutvalget for inntektsoppgjørene" (TBU henceforth), when constructing the empirical analogue to the manufacturing sector. The manufacturing sector is made up of the industries[96]

1. Manufacture of wood and wood products, except furniture
2. Basic metals
3. Manufacture of paper and paper products
4. Food products, beverages and tobacco
5. Repair and installation of machinery and equipment
6. Building of ships, oil platforms and modules, and other transport equipment
7. Refined petroleum, chemical and pharmaceutical products
8. Machinery and other equipment n.e.c
9. Textiles, wearing apparel, leather
10. Rubber, plastic and mineral products
11. Furniture and other manufacturing n.e.c

The service sector is constructed as the remaining industries with the exception of general government, owner-occupied dwellings, oil and gas extraction, and ocean transport.

C.2 Average tax depreciation rates

To calculate the average tax depreciation rate of capital in the mainland economy we use data from the KVARTS database and proceed as follows.[97] First, we calculate the share of each capital type in total capital within each sector. Next, we represent the share of each capital type within each industry as its average over the

[96] Users of the macroeconomic model KVARTS will recognize this aggregate as sector 3. Items 1, 4, 7 (excl. chemical products), 9, 10 and 11 make up sector 20, a sub-sector of sector 3, in the same model. Similarly, items 2, 3 and 7 (excl. refined petroleum and pharamceutical products) make up sub-sector 30. Items 5, 6 and 8 make up sub-sector 45.

[97] KVARTS operates with seven capital types in contrast to the nine found in the national accounts. Acquisitions less disposals of valuables has been added to intellectual property products except oil exploration, and cultivated biological resources have been added to building and construction.

calibration period. Furthermore, we give attention to the capital types on which we have tax depreciation rates and normalize the previous weights by the share of capital we cover.[98,99] Next we use these shares as weights when calculating the weighted average tax depreciation rate in the two sectors. These two rates are then weighted according to the share of manufacturing and service sector capital in total mainland private capital in the model (15.2 percent and 84.2 percent respectively). This gives an economy-wide average tax depreciation rate of 13.8 percent per annum, equivalent to quarterly depreciation rate of 3.3 percent.

D Variable overview

Table 8: Variable Names

Variable name	Variable description
λ_t	Marginal utility of consumption - lagrange multiplier
C_t^R	Consumption of ricardian households
AC_t^W	Wage adjustment costs in wage setting
DAC_t^W	Change in wage adjustment costs in wage setting
W_t	Wage
W_t^{NB}	Nash bargaining wage
π_t^W	Nominal wage inflation, quarterly
V_t	Nash reference utility
C_t^L	Consumption of liquidity-constrained households
C_t	Consumption
N_t	Hours worked
E_t	Employment rate
NE_t	Hours per worker
L_t	Participation rate, smoothed
L_t^{15-19}	Participation rate for 15-19 year olds
L_t^{20-24}	Participation rate for 20-24 year olds
$L_t^{K,25-61}$	Participation rate for women between 25-61 years old
$L_t^{K,62-66}$	Participation rate for women between 62-66 years old
$L_t^{M,25-61}$	Participation rate for men between 25-61 years old
$L_t^{M,62-66}$	Participation rate for men between 62-66 years old
L_t^{67-74}	Participation rate for 67-74 year olds
U_t	Unemployment rate
RP_t	Risk premium on foreign borrowing
OF_t^{RP}	Oil fund proxy in risk premium
π_t^{ATE}	CPI inflation excluding VAT and energy, quarterly
π_t	CPI inflation, quarterly
$\pi_t^{ATE,Ann}$	CPI inflation excluding VAT and energy, annualized quarterly
R^L	Lending rate of banks, quarterly
PE_t^M	Price of equity, manufacturing sector
PE_t^S	Price of equity, service sector
DF_t^{DIV}	Discount factor for dividends
Inv_t^M	Investment in manufacturing sector
Inv_t^S	Investment in service sector

[98] See comment by Thomas von Brasch in MMU meeting October 2019 (link).

[99] The considered capital types make up 98.3 percent and 94.0 percent of total capital in the manufacturing and service sectors respectively.

Table 8: Variable Names

Variable name	Variable description
N_t^P	Hours worked in private sector
N_t^M	Hours worked in manufacturing sector
N_t^S	Hours worked in service sector
K_t	Private sector capital stock
K_t^M	Capital stock in manufacturing sector
K_t^S	Capital stock in service sector
$\lambda_t^{K,M}$	Lagrange muliplier for capital in manufacturing sector
$\lambda_t^{K,S}$	Lagrange muliplier for capital in service sector
B_t^M	Domestic firm bonds in manufacturing sector
B_t^S	Domestic firm bonds in service sector
$\frac{B_t}{P_t^I K_t^M}$	Ratio of domestic borrowing to total assets in manufactuing sector
$\frac{B_t}{P_t^I K_t^S}$	Ratio of domestic borrowing to total assets in service sector
BN_t^M	New domestic borrowing in manufacturing sector
BN_t^S	New domestic borrowing in service sector
$AC_t^{BN,M}$	Adjustment costs for new domestic borrowing in manufacturing sector
$AC_t^{BN,S}$	Adjustment costs for new domestic borrowing in service sector
$DAC_t^{BN,M}$	Change in adjustment costs for new domestic borrowing in manufacturing sector
$DAC_t^{BN,S}$	Change in adjustment costs for new domestic borrowing in service sector
$\lambda_t^{B,M}$	Lagrange multiplier for firm bonds in manufacturing sector
$\lambda_t^{B,S}$	Lagrange multiplier for firm bonds in service sector
$RP_t^{B,M}$	Risk premium on firm bonds in manufacturing sector
$RP_t^{B,S}$	Risk premium on firm bonds in service sector
$\lambda_t^{Y,M}$	Lagrange multiplier for production in manufacturing sector
$\lambda_t^{Y,S}$	Lagrange multiplier for production in service sector
MC_t^M	Marginal cost in manufacturing sector
MC_t^S	Real marginal cost in service sector
AC_t^M	Price adjustment costs in manufacturing sector
DAC_t^M	Change in price adjustment costs in manufacturing sector
P_t^M	Relative price of domestically-produced manufacturing goods
AC_t^S	Price adjustment costs in service sector
DAC_t^S	Change in adjustment costs in service sector
P_t^S	Relative price of domestically-produced service goods
Y_t^M	Domestic production in manufacturing sector
Y_t^S	Domestic production in service sector
TFP_t^{Tot}	Total factor productivity in intermediate good sector
ULC_t^M	Unit labor cost in manufacturing sector
ULC_t^S	Unit labor cost in service sector
LS_t^M	Labor share in manufacturing sector
LS_t^S	Labor share in service sector
$Y_t^{M,C}$	Domestically-produced manufacturing sector good used for final consumption good
$IM_t^{M,C}$	Imported good used in manufacturing sector for final consumption good
$P_t^{M,C}$	Relative price of the composite manufacturing sector good used for final consumption good
$Y_t^{S,C}$	Domestically-produced service sector good used for final consumption good
$IM_t^{S,C}$	Imported good used in service sector for final consumption good
$P_t^{S,C}$	Relative price of the composite service sector good used for final consumption good

Table 8: Variable Names

Variable name	Variable description
$Y_t^{M,I}$	Domestically-produced manufacturing sector good used for final investment good
$IM_t^{M,I}$	Imported good used in manufacturing sector for final investment good
$P_t^{M,I}$	Relative price of the composite manufacturing sector good used for final investment good
$Y_t^{S,I}$	Domestically-produced service sector good used for final investment good
$IM_t^{S,I}$	Imported good used in service sector for final investment good
$P_t^{S,I}$	Relative price of the composite service sector good used for final investment good
$Y_t^{M,GC}$	Domestically-produced manufacturing sector good used for final government consumption good
$IM_t^{M,GC}$	Imported good used in manufacturing sector for final government consumption good
$P_t^{M,GC}$	Relative price of the composite manufacturing sector good used for government consumption good
$Y_t^{S,GC}$	Domestically-produced service sector good used for final government consumption good
$IM_t^{S,GC}$	Imported good used in service sector for final government consumption good
$P_t^{S,GC}$	Relative price of the composite service sector good used for government consumption good
C_t^M	Final consumption good sector demand for the composite manufacturing good
C_t^S	Final consumption good sector demand for the composite service good
RER_t	Real exchange rate (price of foreign goods in domestic currency; + indicates depreciation)
I_t^M	Final investment good sector demand for the composite manufacturing good
I_t^S	Final investment good sector demand for the composite service good
P_t^I	Relative price of the investment good
GC_t^M	Final government consumption good sector demand for the composite manufacturing good
GC_t^S	Final government consumption good sector demand for the composite service good
P_t^{GC}	Relative price of the government consumption good
AC_t^C	Price adjustment costs in consumption good retail sector
DAC_t^C	Change in price adjustment costs in consumption good retail sector
P_t^C	Relative price of retail consumption good
IM_t	Imports
AC^IM_t	Price adjustment costs in imported goods
DAC^IM_t	Change in price adjustment costs in imported goods
P_t^{IM}	Relative price of imported good
TOT_t	Terms of trade; price of exports over imports
X_t	Exports
VA_t^X	Value added per unit of exports
MC_t^X	Marginal costs in final export sector
AC_t^X	Price adjustment costs in export sector
DAC_t^X	Change in price adjustment cost in export sector
P_t^X	Relative price of exported good to foreign price level
X_t^M	Exports from manufacturing sector
X_t^S	Exports from service sector
$Y_t^{M,X}$	Domestically-produced manufacturing sector good used for final export good
$IM_t^{M,X}$	Imported good used in manufacturing sector for final export good
$P_t^{M,X}$	Relative price of the composite manufacturing sector good used for final export good
$Y_t^{S,X}$	Domestically produced service sector goods used for final export good
$IM_t^{S,X}$	Imported good used in service sector for final export good
$P_t^{S,X}$	Relative price of the composite service sector good used for final export good
$\Pi_t^{R,M}$	Retained profits in manufacturing sector
$\Pi_t^{R,S}$	Retained profits in service sector

Table 8: Variable Names

Variable name	Variable description
Π_t^M	Profits in manufacturing sector
Π_t^S	Profits in service sector
DIV_t^M	Dividends from manufacturing sector
DIV_t^S	Dividends from service sector
π_t^M	Inflation of domestically-produced manufacturing sector good
π_t^S	Inflation of domestically-produced service sector good
π_t^X	Inflation of export good (in foreign currency)
$\pi_t^{X,Q}$	Inflation of export good (in domestic currency)
$\pi^I M_t$	Inflation of imported good
ΔE_t	Change in nominal exchange rate
K_t^H	Capital stock in housing
Inv_t^H	Investment in housing
C_t^H	Consumption in housing
I_t	Investment
I_t^{ML}	Investment in mainland
$I_t^{ML,P}$	Investment in mainland private sector
NX_t	Net exports
$\frac{VAM_t}{TVA_t}$	Ratio of manufacturing sector value added to total
$\frac{VAS_t}{TVA_t}$	Ratio of service sector value added to total
P_t^Y	Relative price of domestic output
Y_t^D	Domestic output in the mainland economy
Y_t	Mainland GDP
ΔINV_t	Change in inventory
IM_t^{Res}	Import residual
Y_t^{CPI}	Mainland GDP, deflated by CPI
BoP	Balance of Payments
DP_t	Deposits
B_t^F	Foreign borrowing
SV_t	Household saving
$\frac{BF_t}{Y_t}$	Ratio of foreign borrowing to GDP
R_t	Nominal domestic interest rate, quarterly
$\widetilde{R}_t$	Target nominal interest rate
R_t^{Ann}	Nominal domestic interest rate, yearly
$\widetilde{Y}_t$	Target GDP in monetary policy rule
$\widetilde{Q}_t$	Target real exchange rate in monetary policy rule
T_t	Total government revenue
T_t^C	Government revenue from consumption taxes
TB_t^{LS}	Tax base for labor surtax
T_t^{LS}	Tax revenue with labor surtax
TB_t^{SSH}	Tax base for social security contributions of households
T_t^{SSH}	Tax revenue from social security contributions of households
TB_t^{SSF}	Tax base for social security contributions of firms
T_t^{SSF}	Tax revenue from social security contributions of firms
$TB_t^{/Pi,M}$	Tax base for firm profits in manufacturing sector
$TB_t^{/Pi,S}$	Tax base for firm profits in service sector

Table 8: Variable Names

Variable name	Variable description
$T_t^{/Pi,M}$	Tax revenue from firm profits in manufacturing sector
$T_t^{/Pi,S}$	Tax revenue from firm profits in service sector
$TB_t^{DIV,M}$	Tax base for dividend earnings from manufacturing sector
$T_t^{DIV,M}$	Tax revenue from dividend earnings in manufacturing sector
$TB_t^{DIV,S}$	Tax base for dividend earnings from manufacturing sector
$T_t^{DIV,S}$	Tax revenue from dividend earnings in service sector
TB_t^{DP}	Tax base for deposit earnings
T_t^{DP}	Tax revenue from deposit earnings
TB_t^{AV}	Tax base for asset valuation
T_t^{AV}	Tax revenue from asset valuation
TB_t^{OIH}	Tax base for ordinary income of households
T_t^{OIH}	Tax revenue from ordinary income of households
G_t	Government spending
GS_t	Government surplus adjusted
GS_t^{Adj}	Government surplus adjusted for oil fund withdrawals
$G_t^{C,CPI}$	Government consumption in CPI units
$G_t^{I,CPI}$	Government investment in CPI units
G_t^{W}	Government wage bill
G_t^{UB}	Government spending on unemployment benefits
D_t	Government debt
RRA_t	Risk-free return allowance
G_t^{C}	Government purchases of goods and services
N_t^{G}	Hours worked in government sector
UB_t	Unemployment benefits
$MARKUP_t^{GW}$	Markup on government wage
$G_t^{I,Auth}$	Government investment, authorized
K_t^{G}	Public capital stock
G_t^{I}	Government investment
T_t^{L}	Tax revenue in lump sum
τ_t^{C}	Value-added tax rate
τ_t^{CF}	Consumption volume tax
τ_t^{OIH}	Ordinary income tax rate for households
τ_t^{OIF}	Ordinary income tax rate for firms
τ_t^{D}	Tax rate on dividends
α_t^{OIH}	Scalar to scale up the tax on excess dividend income of households
τ_t^{LS}	Labor surtax rate
τ_t^{SSH}	Rate on social security contributions of households
τ_t^{SSF}	Rate on social security contributions of firms
τ^{W}	Total tax on labor income
OFW_t	Oil fund withdrawals
OF_t	Value of the Oil Fund in foreign currency
R_t^{OF}	Rate of return of the oil fund
RER_t^{OF}	Real exchange rate for the oil fund
TR_t^{R}	Transfers to Ricardian households
TR_t^{L}	Transfers to liquidity-constrained households

Table 8: Variable Names

Variable name	Variable description
TR_t	Transfers to households
Inv_t^{Oil}	Investment good demand from oil sector
$Y_t^{F,TP}$	Forward looking component in trading partners output
Y_t^{TP}	Output in trading partners
Y_t^{NTP}	Output in non-trading partners
Y_t^{Glob}	Output in global economy
$\pi_t^{F,TP}$	Forward looking component in trading partners inflation
π_t^{TP}	Inflation in trading partners, quarterly
R_t^{TP}	Nominal interest rate in trading partners
P_t^{Oil}	Price of oil
Z_t^{Y}	Shock: Technology in manufacturing and service sector.
$Z_t^{Y^M}$	Shock: Technology in manufacturing sector.
$Z_t^{Y^S}$	Shock: Technology in service sector.
Z_t^{U}	Shock: Consumption preferences.
Z_t^{RP}	Shock: Risk premium.
Z_t^{R}	Shock: Monetary policy.
$Z_t^{Y^{TP}}$	Shock: Output in trading partners
$Z_t^{Y^{NTP}}$	Shock: Output in non-trading partners
$Z_t^{\pi^{TP}}$	Shock: Inflation in trading partners
$Z_t^{R^{TP}}$	Shock: Monetary policy in trading partners
Z_t^{GC}	Shock: Government purchases of goods and services
$Z_t^{\tau^L}$	Shock: Lump sum taxes
$Z_t^{\tau^C}$	Shock: Value-added tax
$Z_t^{\tau^{OIH}}$	Shock: Household ordinary income tax
$Z_t^{\tau^{OIF}}$	Shock: Firm ordinary income tax
$Z_t^{\tau^{LS}}$	Shock: Labor surtax
$Z_t^{\tau^{SSH}}$	Shock: Household social security contributions rate
$Z_t^{\tau^{SSF}}$	Shock: Firm social security contributions rate
$Z_t^{T^{OILR}}$	Shock: Oil fund withdrawals
Z_t^{NG}	Shock: Hours worked in government sector
$Z_t^{G^{I,Auth}}$	Shock: Government investment, authorized
$Z_t^{Inv^{Oil}}$	Shock: Investment in oil sector
$Z_t^{TR^L}$	Shock: Transfers to liquidity-constrained households
$Z_t^{TR^R}$	Shock: Transfers to ricardian households
$Z_t^{P^{Oil}}$	Shock: Price of oil
Z_t^{D}	Shock: Government debt
Z_t^{MA}	Shock: Monetary accomodation
Z_t^{RRA}	Shock: Risk-free return allowance
Z_t^{L}	Shock: Labor force participation
Z_t^{V}	Shock: Nash reference utility
$Z_t^{\Delta INV}$	Shock: Change in inventory
Z_t^{MEI}	Shock: Marginal efficiency of investment
Z_t^{Int}	Shock: Elasticity of substitution in domestic intermediate good sector
$Z_t^{IM,\alpha}$	Shock: Import share in final good production
$Z_t^{\eta^{TP}}$	Shock: Elasticity of substitution across differentiated goods in trading partners

Table 8: Variable Names

Variable name	Variable description
$Z_t^{MEI,M}$	Shock: Marginal efficiency of investment in manufacturing sector
$Z_t^{MEI,S}$	Shock: Marginal efficiency of investment in service sector

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