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NORA — A Microfounded Model for Fiscal Policy Analysis in Norway

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Preface

NORA is one of the economic models in the portfolio of models maintained by the Research Department at Statistics Norway. The model aims to capture features of the Norwegian economy to aid in the analysis of fiscal policy in Norway. The first version of the model was originally developed by a team of economists on behalf of the Ministry of Finance. That version was calibrated to match particular dynamic responses to economic shocks. Responsibility for NORA was transferred to SSB at the start of 2020. One major project at Statistics Norway has been to undertake a complete estimation of the dynamic parameters of the model on Norwegian data. This version of the documentation presents the results of that estimation project and provides a snapshot of the current state of NORA.

The development of a model of this type is an ongoing process. Further updates of this document will therefore be released in the future as the model evolves. Development projects are already underway to further improve the model's properties and reestimation of the model will be necessary as new data become available.

Statistics Norway would like to thank the current NORA project team for their hard work on this update and would like to thank former members of the NORA team, Thor Andreas Aursland, Ivan Frankovic, Inga Heiland, Birol Kanik and Magnus Saxegaard, for their contributions.

Statistics Norway, January 17, 2024

Linda Nøstbakken

Abstract

This document describes NORA, a microfounded model for fiscal policy analysis in Norway. The model is based on relatively standard dynamic stochastic general equilibrium (DSGE) models of the type used in many central banks and international policy institutions. The standard framework is however modified 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 tradeable 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 links with the rest of the economy. The model parameters are determined partly through a calibration of the model's steady state to long-run averages in the data and partly through Bayesian estimation using quarterly time series for the Norwegian economy for the period 1999Q1 to 2019Q4. We illustrate the properties of the model by showing how it responds to some common macroeconomic shocks, by presenting a number of fiscal policy simulations that illustrate typical use cases, and by comparing fiscal multipliers with those from existing models.

Version: NORA 2.0

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1. Introduction

This document describes the model NORA (**NOR**wegian fiscal policy **A**nalysis model) which is designed for analysis of fiscal policy in Norway. NORA was originally developed by a team of economists on behalf of the Norwegian Ministry of Finance in collaboration with Statistics Norway and Norges Bank. The model now belongs to the suite of models that the research department at Statistics Norway continuously develops and maintains as tools for economic analysis of the Norwegian economy. NORA belongs to the class of standard dynamic stochastic general equilibrium (DSGE) models 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). The standard framework is modified to account for particular features of the Norwegian economy to allow for a realistic analysis of the general-equilibrium effects of fiscal policy in Norway. 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 GPFG for fiscal financing purposes. NORA also includes a number of distinctive features 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.

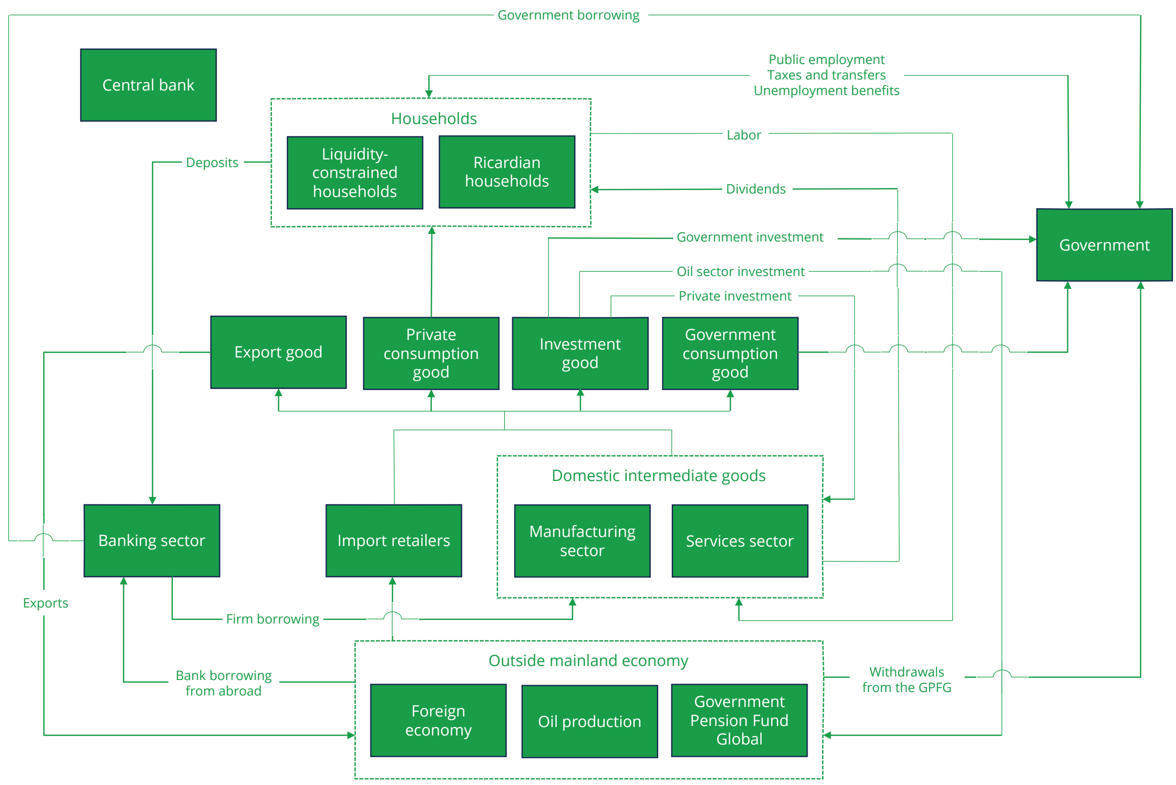
The remainder of this documentation is organized as follows. Section 2 provides a short non-technical summary of the model followed by a longer more technical description. A detailed derivation of the model equations is provided in Appendix A. Section 3 describes how the parameters of the model are set. A subset of the model parameters are calibrated, generally by matching the steady state of the model to long-run averages in the data, and the remaining parameters are estimated using Bayesian estimation. Section 4 provides examples of the model's response to certain shocks and policy changes, and compares the magnitude of fiscal multipliers in NORA to values reported in the literature and to those in Statistics Norway's large-scale macroeconometric model KVARTS (Boug et al., 2023). This section also assesses the sensitivity of the multipliers to some key parameters and model features. Section 5 concludes.

2. The model

Figure 2.1 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

Figure 2.1 Graphical overview of NORA



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.[1]

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.

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

[1] 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.

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.[2] 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.

[2] 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.

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.

2.1 Variable and parameter naming conventions

Appendix E 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). In some cases it is important to distinguish between the initial and final steady states (permanent policy changes lead to a new steady state). Then we use the subscript $0, ss$ to denote the initial steady state.

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.[3]

[3]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

2.2.1 Ricardian household

Lifetime utility Expected lifetime utility of the Ricardian household at time 0, denoted by U_0, is given by

$$U_0 = E_0 \sum_{t=0}^{\infty} \beta^t \left[\exp(Z_t^U) \frac{\left(C_t^R - H_t\right)^{1-\sigma}}{(1-\sigma)(1-h)^{-\sigma}} \right]. \tag{2.1}$$

where β is the discount factor, C_t^R is consumption, and the parameter σ is the inverse of the intertemporal elasticity of substitution.[4] The term Z_t^U is a shock that increases households preference for consumption.

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.

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

$$\begin{aligned} OI_t^R = & \underbrace{LI_t^R}_{\text{labor income}} + \underbrace{UB_t(L_t - E_t)}_{\text{unemployment benefits}} + \underbrace{TR_t^R}_{\text{transfers}} + \underbrace{\frac{P_{t-1}}{P_t} DP_{t-1}^R (R_{t-1} - 1)}_{\text{return on deposits}} \\ & + \underbrace{\left(DIV_t^M + AV_t^M\right) S_{t-1}^{R,M} + \left(DIV_t^S + AV_t^S\right) S_{t-1}^{R,S}}_{\text{dividends and capital gains}}. \end{aligned} \tag{2.2}$$

Real labor income LI_t^R is given by

$$LI_t^R = W_t N_t^P + W_t^G N_t^G, \tag{2.3}$$

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

by Ricardians in NORA, while the later is captured by liquidity-constrained households.

[4]In contrast to most DSGE models we do not include disutility of labor in the utility function, which typically is necessary to derive the wage-setting behavior of households. Instead our wage formation model is based on Nash bargaining between a labor union and exposed sector firms, see Section 2.4.

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 $AV_t^M = \left(P_t^{Nom,E,M} - P_{t-1}^{Nom,E,M}\right)/P_t$, where $P_t^{Nom,E,M}$ denotes the nominal price of a share in the manufacturing sector (price of equity).[5] The term $DP_{t-1}^R(R_{t-1} - 1)$ captures (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 $\pi_t^{ATE} = P_t/P_{t-1}$.[6] 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

$$\begin{aligned} TB_t^{OIH,R} \quad = \quad & LI_t^R + UB_t(L_t - E_t) + TR_t^R + \frac{P_{t-1}}{P_t} DP_{t-1}^R(R_{t-1} - 1) - TD^{OIH} \\ & + \left(DIV_t^M + AV_t^M - RRA_t \frac{P_{t-1}^{Nom,E,M}}{P_t}\right) S_{t-1}^{R,M} \alpha_t^{OIH} \\ & + \left(DIV_t^S + AV_t^S - RRA_t \frac{P_{t-1}^{Nom,E,S}}{P_t}\right) S_{t-1}^{R,S} \alpha_t^{OIH}. \end{aligned} \tag{2.4}$$

The tax base for the ordinary income tax differs from actual ordinary income, see equation (2.2), 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

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

where RRA_t is a (net) rate-of-return allowance applied to the nominal value of stock holdings given by

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

[6] 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.

$P_{t-1}^{Nom,E,M} S_{t-1}^{R,M}$, for a more detailed exposition see Appendix A.7. 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.[7]

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

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

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").[8] The term TD^{LS} captures a deduction to the tax base of the labor surtax and social security contributions. Similar to the ordinary income tax base, the deduction is chosen to match the empirical value of the tax base for the labor surtax and social security in the steady state. The term $T_t^{L,R}$ represents other lump-sum taxes. For ease of exposition it is useful to define $\tau_t^W = \tau_t^{OIH} + \tau_t^{LS} + \tau_t^{SSH}$ 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

$$\begin{aligned} P_t DP_t^R + \left(P_t^{Nom,E,M} S_t^{R,M} + P_t^{Nom,E,S} S_t^{R,S}\right)\left(1 + F_t^S\right) &= P_{t-1} DP_{t-1}^R + P_{t-1}^{Nom,E,M} S_{t-1}^{R,M} + P_{t-1}^{Nom,E,S} S_{t-1}^{R,S} \\ &+ P_t OI_t^R - P_t T_t^R - P_t^{Nom,C} C_t^R - P_t^{Nom,I} Inv_t^{H,R} + \underbrace{P_t\left(AVT_t^R + \Pi_t^{X,R} + \Pi_t^{C,R} + \Pi_t^{F,R} + \Pi_t^{B,R}\right)}_{\text{other income and costs}}. \end{aligned} \quad (2.5)$$

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.[9] 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.[10] The nominal retail

[7] 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.

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

[9] 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.

[10] 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

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 $P^{E,M} = P_{t-1}^{Nom,E,M}/P_t$ (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 (2.1) subject to the budget constraint given by equation (2.5) we form the Lagrangian

$$\mathcal{L} = E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{\exp(Z_t^U) \left(C_t^R - H_t \right)^{1-\sigma}}{(1-\sigma)(1-h)^{-\sigma}} + \lambda_t \frac{1}{P_t} \left[\text{r.h.s of eq. (2.5)} - \text{l.h.s of eq. (2.5)} \right] \right),$$

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 (2.5) 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 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

$$\lambda_t = \beta E_t \left\{ \frac{\lambda_{t+1}}{\pi_{t+1}^{ATE}} \left[1 + (R_t - 1)(1 - \tau_{t+1}^{OIH}) \right] \right\}. \tag{2.6}$$

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 $1/\Delta_{t+1} = 1/\pi_{t+1}^{ATE} \left[1 + (R_t - 1)(1 - \tau_{t+1}^{OIH}) \right]$.

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

$$\lambda_t = \frac{\exp(Z_t^U)(C_t^R - H_t)^{-\sigma}}{P_t^C (1-h)^{-\sigma}}. \tag{2.7}$$

Hence, consumption is allocated in such a way that marginal utility of consumption (the right-hand side of equation (2.7)) equals the shadow value of one additional unit of savings. Combining equations (2.7) and (2.6) yields the well-known Euler equation

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

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.10 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.

which under certainty equivalence simplifies to

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

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

$$P_t^{E,M} = \sum_{j=1}^{\infty} \frac{1}{R_{t+j}^e} DIV_{t+j}^M, \tag{2.8}$$

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.[11]

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

$$\begin{aligned} P_t^C C_t^L \quad = \quad & P_t\left(W_t N_t^P + W_t^G N_t^G + UB_t(L_t - E_t) + TR_t^L\right) \\ & - P_t\left(W_t N_t^P + W_t^G N_t^G + UB_t(L_t - E_t) + TR_t^L - TD^{OIH}\right)\tau_t^{OIH} \\ & - P_t\left(W_t N_t^P + W_t^G N_t^G + UB_t(L_t - E_t) + TR_t^L - TD^{LS}\right)\left(\tau_t^{LS} + \tau_t^{SSH}\right), \end{aligned} \tag{2.9}$$

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

[11] 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.

government as

$$\begin{aligned} C_t &= \omega C_t^L + (1-\omega)C_t^R, \\ TR_t &= \omega TR_t^L + (1-\omega)TR_t^R. \end{aligned} \quad (2.10)$$

We implicitly assume that the total amount of hours worked in the private and public sector is proportional to the size of the household.[12]

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 households 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.[13,14] 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.[15] The latter captures the commonly-observed discouraged worker effect whereby workers who believe that their chances of finding a job are low in a recession (when unemployment is high) leave the labor force rather than incur the monetary and psychological costs of searching for a job, see Dagsvik et al. (2013). The reduced-form processes for participation rates take the form

$$L_t^j = f^j\left(U_{t-1,\dots,t-n}, (1-\tau_{t-1,\dots,t-n}^W)W_{t-1,\dots,t-n}, L_{t-1,\dots,t-n}^j\right). \quad (2.11)$$

Since each group j 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.[16] Total labor supply is then given by the sum

[12] 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.

[13] 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.

[14] 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.

[15] 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.

[16] The functional forms of the age-specific participation rates are based on Gjelsvik et al. (2013) and are provided in Appendix A.2.

of group-specific participation rates weighted by the relative size of the population groups

$$L_t = \sum_{j=1}^{7} w_j L_t^j + Z_t^L, \tag{2.12}$$

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).[17] 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.

[17] 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.[18] 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 a high wage rarely occurs 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 workers' pre-tax real wages.[19] 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.[20,21] We will show later that a higher level of unemployment decreases

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

[19] 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.

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

[21] The reference utility can also be viewed as a driving force for agreement. In this interpretation a higher unemployment rate makes

wage claims by the union. The payoff function of the employer organization representing firms in the exposed sector is assumed to be given by the monetary value of profits in the manufacturing sector, which ceteris paribus is falling with the level of wages. The reference utility of firms is set to zero on the assumption that failure to reach an agreement implies no production and zero profits.

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

$$W_t^{NB} = \underset{W}{\operatorname{argmax}} \left[V\left(W\right) - V^0\left(U_t\right)\right]^{\gamma} \left[\Pi_t^M\left(W\right)\right]^{1-\gamma}, \tag{2.13}$$

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.[22] The parameter γ changes the importance of the union's payoff function in the Nash product and thus their bargaining power. The payoff function has the same functional form as the households utility function over consumption in equation (2.1) and is given by

$$V(W) = c^N + \frac{\frac{(1-I^\tau\tau_t^W)}{(1-I^\tau\tau_t^C)}(W)^{1-\sigma_N}}{1-\sigma_N}, \tag{2.14}$$

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).[23] The payoff function in equation (2.14) 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

$$V_t^0 = -\nu_U \log\left(\frac{U_t}{U_{ss}} \exp\left(Z_t^V\right)\right),$$

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 (2.13) with respect to the real wage and setting the resulting term to zero. The resulting first-order condition is given by

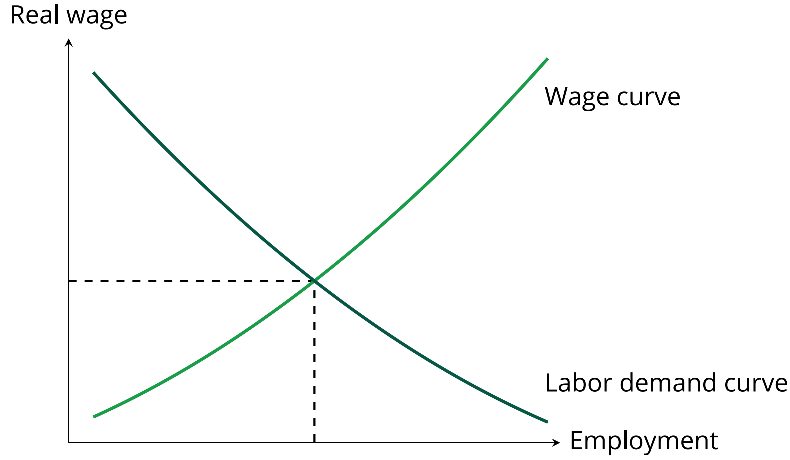
$$\frac{\frac{(1-I^\tau\tau_t^W)}{(1-I^\tau\tau_t^C)}^{1-\sigma_N}(W_t^{NB})^{-\sigma_N}}{V(W_t^{NB}) - V^0(U_t)} = \frac{1-\gamma}{\gamma}\frac{(1+\tau_t^{SSF})N_t^M}{\Pi_t^M(W_t^{NB})}, \tag{2.15}$$

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.

[22]As shown in Appendix A.3, assuming instead that the payoff function of firms is given by the firm profit share $\Pi_t^M / \left(P_t^M Y_t^M\right)$, where $P_t^M Y_t^M$ captures total earnings, does not change our results.

[23]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.

Figure 2.2 The wage and labor demand curve



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.3, 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 function in equation (2.45) 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 2.2 as a function of total employment. The intersection of the wage curve and the downward-sloping labor demand curve in equation (2.45) determines the level of employment in NORA.

The level of unemployment is then simply the difference between total labor supply in equation (2.12) and total employment.

Wage stickiness The wage determined through Nash bargaining is not implemented in the manufacturing sector immediately. Instead we 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:

$$W_t^M = \rho_W W_{t-1}^M + (1-\rho_W) W_t^{NB}, \tag{2.16}$$

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.[24] Wages in this setup react, despite the lack of an explicit forward-looking term in equation (2.16), to news shocks (i.e. shocks known prior to their realization) as both Ricardian households and firms are forward-

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

looking and take decisions that affect the level of unemployment, prices and profitability in anticipation of future economic developments.[25]

Wages in the service sector The Nash bargaining solution in equation (2.15) determines wages in the manufacturing sector over time, see equation (2.16). 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):

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

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.[26]

2.5 Banking sector

To simplify the Ricardian household's portfolio choice problem it is convenient to include a 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

$$\underbrace{DP_t}_{\text{Deposits of Ric. hh.}} + \underbrace{RER_t B_t^F}_{\text{Foreign debt of bank}} = \underbrace{B_t^M + B_t^S}_{\text{Loans to firms}} + \underbrace{D_t}_{\text{Loans to government}}, \tag{2.17}$$

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

$$E_t \sum_{j=0}^{\infty} \Delta_{t,t+j} \Bigg[\frac{R_{t-1+j}^L}{\pi_{t+j}^{ATE}} \left(B_{t-1+j}^M + B_{t-1+j}^S + D_{t-1+j}\right) - \frac{R_{t-1+j}}{\pi_{t+j}^{ATE}} DP_{t-1+j} - \frac{R_{t-1+j}^{TP} RP_{t-1+j}}{\pi_{t+j}^{TP}} RER_{t+j} B_{t-1+j}^F \Bigg], \tag{2.18}$$

subject to the balance sheet constraint in equation (2.17). 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 (2.18) captures the cost of foreign borrowing where the foreign trading partners' gross interest rate R_t^{TP} is subject to a debt-elastic risk

[25]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.

[26]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.

premium RP_t.

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

$$RP_t = \exp\left(\xi_{NFA}(A_t - A_{0,ss}) - \xi_{OF} OF_t^{RP} + Z_t^{RP}\right),$$

where $A_t = \frac{RER_t B_t^F}{Y_t^{CPI}}$ is the domestic-currency value of private sector net foreign liabilities as a ratio to long-run GDP. The risk premium on foreign borrowing increases with private sector foreign indebtedness ($\xi_{NFA} > 0$). 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 for the GPFG (OF_t^{RP}) and thus reduce the risk-premium on foreign borrowing by the private sector ($\xi_{OF} > 0$). This is similar in spirit to the setup in Norges Bank's DSGE model NEMO (Kravik and Mimir, 2019), where the value of the GPFG affects the risk premium directly, and it is similar to the exchange rate equation discussed in Benedictow and Hammersland (2023) which is implemented in KVARTS, where a higher oil price is assumed to reduce the risk premium.[27] Z_t^{RP} is a shock to the risk premium.

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

$$E_t\left[\frac{\Delta_{t+1}}{\pi_{t+1}^{ATE}}(R_t^L - R_t)\right] = 0, \tag{2.19}$$

$$E_t\left[\Delta_{t+1}\left(\frac{R_t}{\pi_{t+1}^{ATE}} - \frac{R_t^{TP} RP_t}{\pi_{t+1}^{TP}}\frac{RER_{t+1}}{RER_t}\right)\right] = 0. \tag{2.20}$$

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.[28] This modification is motivated by the importance Norwegian policymakers place on preserving a viable non-

[27] 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.

[28] The industries defined as belonging to the manufacturing and service sector, respectively, are listed in Appendix B.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.

oil tradeable 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.[29]

In particular, the production side of the economy consists of two monopolistically-competitive intermediate good sectors, the manufacturing and the service sector, that use domestic labor and capital as factor inputs, finance investments via debt or retained profits and sell their output to a final goods sector. Monopolistically-competitive importing firms purchase the foreign good at the world market price and sell it to the final goods sector. 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 producers sell their goods in the domestic market and choose how quickly to pass through changes in consumption taxes and fees to retail prices.

2.6.1 Final goods sector

The production process of firms in the final goods sector can be separated into two stages as shown in Figure 2.3. 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 perfectly competitive for all four final goods, the second stage is monopolistically-competitive for the export and consumption good sectors.

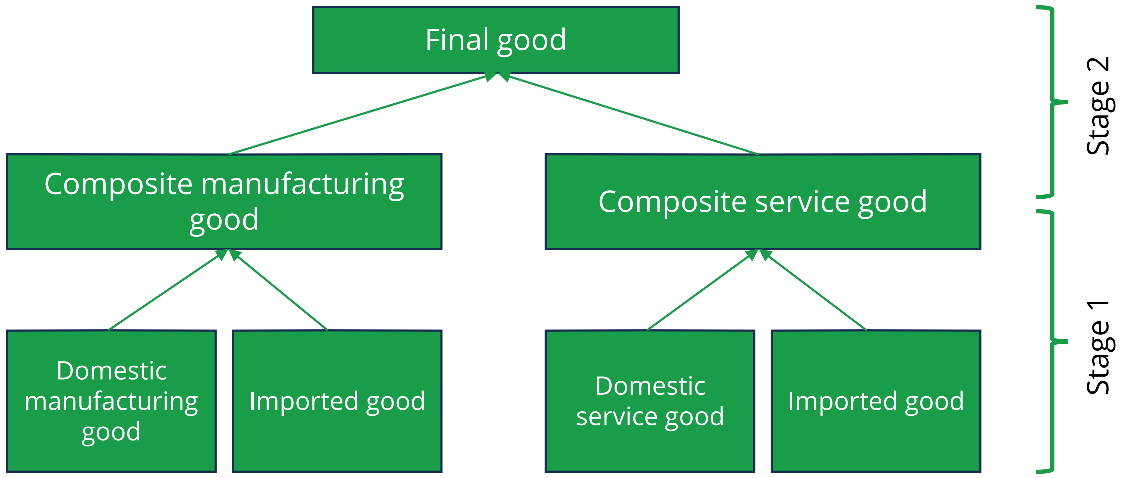
First stage: composite manufacturing and services sector good mFor each final good $Z_t \in \{C_t, I_t, X_t, G_t^C\}$, a composite manufacturing good of volume Z_t^M is produced using domestically-produced manufacturing sector goods of volume $Y_t^{M,Z}$, and imported goods of volume $IM_t^{M,Z}$ using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

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

Here $\alpha_t^{M,Z} = \alpha_{M,Z} \exp\left(Z_t^{IM,\alpha}\right)$, 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 $Z_t^{IM,\alpha}$ is an

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

Figure 2.3 Final good sector production



import share shock. The parameter $\eta_{M,Z}$ 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 $P_t^M = P_t^{Nom,M}/P_t$ 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.4 this cost minimization problem yields the following final-good-specific demand functions for domestically-produced manufacturing and imported goods:

$$Y_t^{M,Z} = \left(1-\alpha_t^{M,Z}\right)\left(P_t^M/P_t^{M,Z}\right)^{-\eta_{M,Z}} Z_t^M, \tag{2.21}$$

$$IM_t^{M,Z} = \alpha_t^{M,Z}\left(P_t^{IM}/P_t^{M,Z}\right)^{-\eta_{M,Z}} Z_t^M, \tag{2.22}$$

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

$$P_t^{M,Z} = \left[\left(1-\alpha_t^{M,Z}\right)\left(P_t^M\right)^{1-\eta_{M,Z}} + \alpha_t^{M,Z}\left(P_t^{IM}\right)^{1-\eta_M}\right]^{1/(1-\eta_{M,Z})}. \tag{2.23}$$

Because final goods firms are perfectly competitive it holds that the total value of the composite manufacturing good equals 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 equations (2.21) and (2.22). The relative price of the composite service good $P_t^{S,Z}$ is given by an expression equivalent to equation (2.23). 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

$$Z_t = \left[(1-\alpha_Z)^{1/\eta_Z} (Z_t^M)^{\frac{\eta_Z - 1}{\eta_Z}} + \alpha_Z^{1/\eta_Z} (Z_t^S)^{\frac{\eta_Z - 1}{\eta_Z}}\right]^{\eta_Z/(\eta_Z - 1)}, \tag{2.24}$$

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 prices of the composite manufacturing $P_t^{M,Z}$ and service $P_t^{S,Z}$ goods. The solution to this cost-minimization problem, which we relegate to Appendix A.4, yields the following final-goods-specific demand functions

$$Z_t^M = (1-\alpha_Z) \left(P_t^{M,Z}/P_t^Z\right)^{-\eta_Z} Z_t, \tag{2.25}$$

$$Z_t^S = \alpha_Z \left(P_t^{S,Z}/P_t^Z\right)^{-\eta_Z} Z_t. \tag{2.26}$$

The relative price of final good Z_t 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

$$P_t^I Inv_t = P_t^{M,I} I_t^M + P_t^{S,I} I_t^S, \tag{2.27}$$

$$P_t^{G^C} G_t^C = P_t^{M,G^C} G_t^{C,M} + P_t^{S,G^C} G_t^{C,S}. \tag{2.28}$$

Note that as equation (2.27) 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 sectors, we assume that the second stage of the final goods sector for consumption and export goods 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 goods sector we impose the value-added (consumption) tax onto firms (as opposed to households) with firms 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 for 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 results for the consumption sector problem in a reduced fashion. The final export good sector 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:

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

The elasticity of substitution across the differentiated export goods, ϵ_t^X, follows the exogenous process $\epsilon_t^X = \epsilon_X \exp(Z_t^{\epsilon_X})$, where $Z_t^{\epsilon_X}$ is a price markup shock.[30] 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

$$X_t(i) = \left(\frac{P_t^X(i)}{P_t^X} \right)^{-\epsilon_t^X} X_t. \tag{2.29}$$

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

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

$$X_t = \left(P_t^X \right)^{-\eta_t^{TP}} Y_t^{TP}, \tag{2.30}$$

where $\eta_t^{TP} = \eta_{TP} \exp(Z_t^{\eta_{TP}})$, $Z_t^{\eta_{TP}}$ is an export demand shock and Y_t^{TP} denotes output among foreign trading partners which will be discussed in Section 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

[30] 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 export and consumption good retailers as well as retailers in the manufacturing, services and import sectors, which will be introduced later. Due to the limited role these retailers play they have been omitted from the graphical overview in Figure 2.1 and the model overview at the beginning of this section.

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.[31] 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.

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

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

where α_X is the service good bias parameter for exports and η_X is the elasticity of substitution between the composite manufacturing and service goods, $X_t^M(i)$ and $X_t^S(i)$, 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 prices of the composite manufacturing and service goods, $P_t^{M,X}$ and $P_t^{S,X}$, derived earlier. The derivation of this problem closely follows Appendix A.4, 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 goods from the final export good sector:

$$X_t^M(i) = (1-\alpha_X)\left(P_t^{M,X}/MC_t^X(i)\right)^{-\eta_X} X_t(i), \tag{2.31}$$

$$X_t^S(i) = \alpha_X\left(P_t^{S,X}/MC_t^X(i)\right)^{-\eta_X} X_t(i), \tag{2.32}$$

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

$$MC_t^X = \left((1-\alpha_X)\left(P_t^{M,X}\right)^{1-\eta_X} + \alpha_X\left(P_t^{S,X}\right)^{1-\eta_X}\right)^{1/(1-\eta_X)}. \tag{2.33}$$

Cost minimization in the final consumption good sector is completely analogous. Note, however, that the consumption good sector is subject to a different service good bias parameter, α_C, and elasticity of substitution between the composite manufacturing and service goods, $C_t^M(i)$ and $C_t^S(i)$, given by η_C. Moreover, nominal marginal costs in the final consumption good 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 final consumption good sector is $MC_t^C = MC_t^{Nom,C}/P_t = 1$.

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

$$\Pi_t^X(i) = \left[\left(P_t^X(i)RER_t - MC_t^X\right)X_t(i) - AC_t^X(i)\right]. \tag{2.34}$$

[31] Note, however, that the model does not include a shock to this elasticity.

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

$$AC_t^X(i) = \frac{\chi_X}{2}\left(\frac{\frac{P_t^X(i)}{P_{t-1}^X(i)}\pi_t^{TP}}{\left(\frac{P_{t-1}^X}{P_{t-2}^X}\pi_{t-1}^{TP}\right)^{\omega_{Ind}}(\pi_{ss}^{TP})^{1-\omega_{Ind}}} - 1\right)^2 X_t RER_t P_t^X, \tag{2.35}$$

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.[32]

The solution to the price-setting problem, which involves maximizing the net present value of the expected future value of profits each period in equation (2.34) subject to the demand function given by equation (2.29), is provided in Appendix A.5. 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 markup over marginal costs:

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

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

$$\Pi_t^C(i) = \left[\left(P_t^C(i) - (1 + \tau_t^C + \tau_t^{CF})MC_t^C\right)C_t(i) - AC_t^C(i)\right]. \tag{2.36}$$

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.[33] Price adjustment costs are defined analogously to those in the export sector (with price adjustment cost parameter χ_C). Maximizing the present discounted value of profits in the final consumption good sector gives rise to a pricing equation analogous to the one in the export good sector. In particular, in steady state, the price of the consumption good to households is given by $P_t^C = \frac{\epsilon_C}{\epsilon_C - 1}(1 + \tau_t^C + \tau_t^{CF})$, and is thus given as a markup over the (after-tax) production cost of a consumption good.

[32]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.

[33]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.

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

$$Y_t^M(i) = \exp\left(Z_t^{Y^M}\right)\left(K_t^G\right)^{\kappa_M}\left(K_t^M(i)\right)^{\alpha_M}\left(N_t^M(i)\right)^{1-\alpha_M} - FC^M, \tag{2.37}$$

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 $\left(K_t^G\right)^{\kappa_M}$ where κ_M measures the effectiveness of public capital in increasing productivity in the manufacturing sector.[34]

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

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

The elasticity of substitution across goods produced by different manufacturing sector firms, ϵ_t^M, follows the exogenous process $\epsilon_t^M = \epsilon_M \exp\left(Z_t^{\epsilon_M}\right)$, where $Z_t^{\epsilon_M}$ is a price markup shock. 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

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

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 $P_t^M = \left(\int_0^1 P_t^M(i)^{1-\epsilon_t^M} di\right)^{\frac{1}{1-\epsilon_t^M}}$ 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.

[34] 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.

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.[35]

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

$$K_{t+1}^M(i) = Inv_t^M(i)\exp\left(Z_t^{MEI}\right) + (1-\delta_{KP})K_t^M(i), \tag{2.38}$$

where $Inv_t^M(i)$ denotes investments by firm i in the manufacturing sector, $\exp\left(Z_t^{MEI}\right)$ is a marginal efficiency of investment (MEI) shock, and δ_{KP} is the capital depreciation rate. The MEI shock affects both domestic intermediate goods sectors. The firm also incurs costs to adjusting the level of investment

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

where χ_{Inv} is a parameter determining the magnitude of investment adjustment costs, and Inv_t^M is the total amount of investment in the manufacturing sector.[36]

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

$$P_t B_t^M(i) \quad = \quad P_t BN_t^M(i) + P_{t-1}B_{t-1}^M(i), \tag{2.39}$$

where $BN_t^M(i)$ denotes the real value of new domestic borrowing. We define the debt-to-capital ratio in the manufacturing sector as

$$b_t^M \quad = \quad \frac{B_t^M}{\lambda_t^{K,M} K_t^M},$$

where $\lambda_t^{K,M}$ is the shadow price of capital defined below. 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 applied to manufacturing sector firms that increases with the amount of borrowing in the sector, as captured by the debt-to-capital ratio.[37] In

[35] 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 costs operate on the nominal price of the manufacturing good.

[36] The problem is symmetric for each individual firm in the manufacturing sector, so in equilibrium we have $Inv_t^M = Inv_t^M(i)$ for each i.

[37] That is, we assume that the individual firm i does not take into account the effect on the debt-to-capital ratio when making borrowing or capital accumulation decisions.

particular, we assume that

$$RP_t^{B,M} = \exp^{\xi_B\left(b_t^M - \beta^M\right)}, \tag{2.40}$$

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.11 for further details. The firm payments associated with the risk premium, i.e. the debt servicing costs exceeding the rate of lending charged by the bank, are assumed to be redistributed in a lump-sum fashion to the Ricardian household.[38] Additionally, firms face costs when adjusting the level of new borrowing.[39] Preserving the symmetry with investment adjustment costs we assume borrowing adjustment costs for firm i to be given by

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

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

$$\begin{aligned}\Pi_t^M(i) = \quad & \underbrace{P_t^M(i)Y_t^M(i)}_{\text{sales}} - \underbrace{(1+\tau_t^{SSF})W_t N_t^M(i)}_{\text{labor costs}} - \underbrace{\left(R_{t-1}^L RP_{t-1}^{B,M} - 1\right)\frac{B_{t-1}^M(i)}{\pi_t^{ATE}}}_{\text{interest on dom. borrowing}} \\ - \quad & \underbrace{\left(AC_t^M(i) + AC_t^{Inv,M}(i) + AC_t^{BN,M}(i)\right)}_{\text{Adj. costs}},\end{aligned} \tag{2.41}$$

where τ_t^{SSF} is the social security tax paid by firms. Note that equation (2.41) 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 for a manufacturing sector firm is then given by

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

Hence, deductible from profits is a depreciation allowance, where the tax depreciation rate is given by δ_τ. Following Sandmo (1974) differences between the tax depreciation rate and 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 definition 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

$$\Pi_t^M(i) = \Pi_t^{R,M}(i) + DIV_t^M(i) + TB_t^{\Pi,M}(i)\tau_t^{OIF}, \tag{2.42}$$

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

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

[39] In this we follow Alfaro et al. (2023) arguing that it is costly in terms of managerial time to change existing borrowing arrangements.

borrowing $BN_t^M(i)$

$$P_t^I Inv_t^M(i) = \Pi_t^{R,M}(i) + BN_t^M(i). \tag{2.43}$$

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

Firm's stock price As noted in equation (2.8), 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

$$DF_{t+j+1}^{DIV} = \frac{R_{t+j+1}^e}{R_{t+j}^e} = \frac{1 - \Delta_{t+j+1}/\pi_{t+j+1}^{ATE}\tau_{t+j+1}^D(1 + RRA_{t+j+1})}{\Delta_{t+j+1}(1 - \tau_{t+j+1}^D)}. \tag{2.44}$$

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} units in period $t+1$ (in real terms) as DF_{t+1}^{DIV} captures 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 $DF_{t+1}^{DIV} - 1$.[41] 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

[40] This becomes evident when rearranging equation (2.43) to obtain $\Pi_t^{R,M}(i) = P_t^I Inv_t^M(i) + \left(-BN_t^M(i)\right)$ where the last term captures debt repayment. Hence, any rise in corporate profits can potentially increase investments but also non-investment saving of firms.

[41] 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, will 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 $DF_{t+1}^{DIV} - 1$.

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 (equation 2.38) and firm debt (equation (2.39)) accumulates, and the need to satisfy the demand that materializes at the prevailing wage and price using the production technology in equation (2.37).

The first-order condition on ***labor*** (further details can be found in Appendix A.6) is given by

$$(1-\tau_t^{OIF})(1+\tau_t^{SSF})W_t = \lambda_t^{Q,M}(i)(1-\alpha_M)\frac{Y_t^M(i)+FC^M}{N_t^M(i)}. \tag{2.45}$$

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 times the marginal value to the firm of producing one more unit of output, $\lambda_t^{Q,M}(i)$.

The first-order condition on ***investment*** is a complicated and lengthy expression that we relegate to Appendix A.6. 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).[42]

$$\frac{\epsilon_t^M-1}{\epsilon_t^M}P_{t+1}^M\frac{\partial Y_{t+1}^M}{\partial K_{t+1}^M} = P^I\left(R_t^K+\delta_{KP}+\frac{\tau_{t+1}^{OIF}(\delta_{KP}-\delta_\tau)}{1-\tau_{t+1}^{OIF}}\right). \tag{2.46}$$

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 markup.[43] 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 directly increases 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.6) 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

[42]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.6 for the derivation of the full optimality condition on capital as well as the simplified version given here.

[43]In Sandmo (1974) firms are perfectly competitive such that the markup term collapses to one.

level of debt $B_t^M(i)$, which is given by

$$R_t^K + \frac{\pi_{t+1}^{ATE} - 1}{(1-\tau_{t+1}^{OIF})\pi_{t+1}^{ATE}} = \frac{R_t^L RP_t^{B,M} - 1}{\pi_{t+1}^{ATE}}. \tag{2.47}$$

The right-hand side of equation (2.47) captures the marginal cost of borrowing. It depends on the interest rate charged by banks on firm loans R_t^L, and the risk premium on firm borrowing $RP_t^{B,M}$. The left-hand side of equation (2.47) captures the cost of equity financing.[44] In particular the cost of equity declines with the rate-of-return allowance RRA_t, see the 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.[45]

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

$$(1-\tau^{OIF})P^M = \frac{\epsilon_M}{\epsilon_M - 1}\lambda^{Q,M}. \tag{2.48}$$

Hence, the after-tax price of the manufacturing good in steady-state is set as a markup over the value of one unit of production.[46]

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. We consider the import retailers to be a part of the Norwegian mainland economy, while the individual importing firms are foreign entities. Therefore, profits made by these firms are kept abroad.

Import retailers produce the homogeneous imported good using the following bundling function

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

The elasticity of substitution across imported goods sold by individual importers, ϵ_t^{IM}, follows the exogenous process $\epsilon_t^{IM} = \epsilon_{IM}\exp(Z_t^{\epsilon_{IM}})$, where $Z_t^{\epsilon_{IM}}$ is a price markup shock. Output maximization, analogous to

[44] Note, that the cost of equity-financing, as opposed to equation (2.46), 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.

[45] In Appendix A.7, 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 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 (2.5) 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.

[46] In our framework firms operate as stock price maximizers rather than cost minimizers as is 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 (2.48), the term $\lambda_t^{Q,M}$ can be interpreted as the marginal cost in the manufacturing sector such that the after-tax price is set as a markup, a function of the elasticity ϵ_M, over the marginal cost.

the retailers in the export and intermediate goods sectors, by import retailers then implies

$$IM_t(i) = \left(\frac{P_t^{IM}(i)}{P_t^{IM}}\right)^{-\epsilon_t^{IM}} IM_t. \tag{2.49}$$

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 $P_t^{IM} = \left(\int_0^1 P_t^{IM}(i)^{1-\epsilon_t^{IM}} di\right)^{\frac{1}{1-\epsilon_t^{IM}}}$ for imported goods.

Individual importing firms set prices in order to maximize profits

$$\Pi_t^{IM}(i) = (P_t^{IM}(i) - RER_t)IM_t(i) - AC_t^{IM}(i), \tag{2.50}$$

where the "cost of production" equals the real exchange rate RER_t since this is the price at which the individual importing firm can purchase one unit of output abroad. Price adjustment costs are analogous to those in the domestic intermediate good 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 (2.50) subject to the demand function given by equation (2.49), is given in Appendix A.8. The result implies that all these firms set the same price $P_t^{IM}(i) = P_t^{IM}$, and that in the 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 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 generalized Taylor rule:

$$R_t = \tilde{R}_t\left(\frac{R_{t-1}}{\tilde{R}_t}\right)^{\rho_R}\left(\left(\frac{\pi_t^{ATE}}{\pi_{ss}^{ATE}}\right)^{\psi_\pi}\left(\frac{Y_t}{\tilde{Y}_t}\right)^{\psi_Y}\right)^{1-\rho_R}\exp(Z_t^R), \tag{2.51}$$

where $\tilde{R}_t$ and $\tilde{Y}_t$ denote the (potentially time-varying) "target" values of the interest rate and output, which we discuss further below. The parameters ρ_R, ψ_π, and ψ_Y capture the weight placed by the central bank on smoothing changes in the interest rate, preventing deviations of price inflation from target as well as keeping output at potential. 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

Table 2.1 Overview of 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

and level of potential output changes.[47] 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 moving average processes

$$\begin{aligned}\tilde{R}_t &= \left(R_T \tilde{R}_{t-1}^{\rho_{\tilde{R}}}\right)^{\frac{1}{\rho_{\tilde{R}}+1}}, \\ \tilde{Y}_t &= \left(Y_T \tilde{Y}_{t-1}^{\rho_{\tilde{Y}}}\right)^{\frac{1}{\rho_{\tilde{Y}}+1}},\end{aligned}$$

where R_T and Y_T are the new steady-state values of the interest rate and output. 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 parameters $\rho_{\tilde{R}}$ and $\rho_{\tilde{Y}}$.

Finally, note that Beaudry et al. (2023) point out that the specification of a Taylor rule in this type of model is somewhat arbitrary. Here the interest rate is assumed to be a function of current inflation and the current output gap. Both of these variables are functions of the state variables of the model, but it is not clear that this specification captures the true relationship between the state variables and the interest rate. An alternative could, for example, be to specify a Taylor rule as a function of expected inflation and the expected output gap. These are two other functions of the state variables in the model, and it is not clear that one of these specifications yields a more correct link between the interest rate and the state variables than the other.[48] Our baseline specification is commonly used in the literature.

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, also referred to as the "oil fund"). The tax instruments available to the government are summarized in Table 2.1.

[47] 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.

[48] We have also estimated a version of the model with a forward looking Taylor rule. Neither of the two estimations gives a clearly better fit to the data (based on the estimated models' marginal likelihoods). Parameter estimates for the alternative specification are available upon request.

Total government revenue is thus given by

$$
\begin{aligned}
T_t = \; & \underbrace{T_t^L}_{\text{Lump-sum tax}} + \underbrace{C_t\left(\tau_t^C + F_t^C/P_t\right)}_{\text{Consumption taxes and fees}} + \underbrace{\left(W_t N_t^P + W_t^G N_t^G\right)\tau_t^{SSF}}_{\text{Social security contributions of employers}} \\
& + \underbrace{(W_t N_t^P + W_t^G N_t^G + UB_t(L_t - E_t) + TR_t + \frac{DP_{t-1}}{\pi_t^{ATE}}\left(R_{t-1} - 1\right) - TD^{OIH})\tau_t^{OIH}}_{\text{Ordinary income tax on personal income}} \\
& + \underbrace{\left(W_t N_t^P + W_t^G N_t^G + UB_t(L_t - E_t) + TR_t - TD^{LS}\right)\left(\tau_t^{LS} + \tau_t^{SSH}\right)}_{\text{Additional taxes on Labor income and transfers}} \\
& + \underbrace{\left(TB_t^{\Pi,M} + TB_t^{\Pi,S}\right)\tau_t^{OIF}}_{\text{Corporate income taxation}} + \underbrace{\left(DIV_t + AV_t - RRA_t P_{t-1}^E\right)\alpha_t^{OIH}\tau_t^{OIH}}_{\text{Dividend and capital gains tax}},
\end{aligned} \tag{2.52}
$$

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

$$
\begin{aligned}
G_t = \; & \underbrace{P_t^{G^C} G_t^C}_{\text{Government purchases}} + \underbrace{P_t^I G_t^I}_{\text{Government investment}} + \underbrace{UB_t(L_t - E_t)}_{\text{Unemployment benefits}} \\
& + \underbrace{TR_t + AVT_t}_{\text{Lump-sum transfers}} + \underbrace{W_t^G N_t^G(1 + \tau_t^{SSF})}_{\text{Government wage bill}}.
\end{aligned} \tag{2.53}
$$

We can now write the government budget constraint (in real terms) as

$$
\underbrace{T_t}_{\text{total tax revenue}} + \underbrace{OFW_t}_{\text{oil fund withdrawals}} + \underbrace{D_t}_{\text{debt}} = \underbrace{G_t}_{\text{primary expenditure}} + \underbrace{\frac{R_{t-1}^L}{\pi_t^{ATE}} D_{t-1}}_{\text{debt repayments}}, \tag{2.54}
$$

where D_t is real government debt at time t and OFW_t are withdrawals from the oil fund. In other words, the government finances total expenditures (right hand side) with tax revenues, oil fund withdrawals, and debt.

From this we get that the change in debt equals the total government deficit:

$$
\underbrace{D_t - \frac{D_{t-1}}{\pi_t^{ATE}}}_{\text{change in debt}} = \underbrace{G_t - T_t}_{\text{primary deficit}} + \underbrace{\frac{\left(R_{t-1}^L - 1\right)}{\pi_t^{ATE}} D_{t-1}}_{\text{net interest payments}} - \underbrace{OFW_t}_{\text{oil fund withdrawals}}. \tag{2.55}
$$

The oil-corrected budget deficit ("oljekorrigert budsjettunderskudd", OBU) is defined as the deficit without oil fund withdrawals:

$$
OBU_t = \underbrace{G_t - T_t}_{\text{primary deficit}} + \underbrace{\frac{\left(R_{t-1}^L - 1\right)}{\pi_t^{ATE}} D_{t-1}}_{\text{net interest payments}}. \tag{2.56}
$$

This is the deficit that would occur without the use of oil money.

During simulations the user selects one or more "fiscal instruments" such as withdrawals from the GPFG, tax rates, and transfers or other categories of government primary expenditures, that adjust in such a way that the government budget constraint (2.54) always holds. When estimating the model, we choose transfers to Ricardian households (TR_t^R) as the fiscal instrument, and hold government debt D_t and oil fund withdrawals OFW_t constant.

2.7.3 Government revenue and current spending

Unless they are "fiscal instruments" used to balance the budget in equation (2.54), 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

$$X_t = X_{ss} + \rho_X(X_{t-1} - X_{ss}) + Z_t^X, \tag{2.57}$$

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

$$X_t = X_{ss}\left(\frac{X_{t-1}}{X_{ss}}\right)^{\rho_X}\exp(Z_t^X), \tag{2.58}$$

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 (2.57) and (2.58), 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.[49] 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.[50]

[49] 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 (2.57) 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 (2.58) 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.

[50] 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.7 this implies that the RRA_t depends on

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 $J \geq 1$ periods for a given authorized public investment project to become public capital. The accumulation of the public capital stock is then given by

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

where δ_{KG} is the depreciation rate of public capital and $G^{I,Auth}_{t-J+1}$ is the authorized amount of public investment $J - 1$ 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 j from authorization to completion of the project are given by ω_j. Hence, ω_j indicates what share of the total authorized investment is constructed in the jth period since the investment was authorized. Public investment volume each period G^I_t is then given by

$$G^I_t = \sum_{j=0}^{J-1} \omega_j G^{I,Auth}_{t-j}. \tag{2.59}$$

Equation (2.59) captures the amount of public investment in period t on all ongoing public investment

the prevailing interest rate and the household's ordinary income tax rate

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

It is currently not possible to independently shock the RRA_t.

projects dating back to $J-1$ periods ago. Since public investments have to be fully funded over the implementation period, $\sum_{j=0}^{J-1}\omega_j = 1$ holds.

The amount of authorized public investments follows the autoregressive process

$$G_t^{I,Auth} = G_{ss}^{I,Auth}\left(\frac{G_{t-1}^{I,Auth}}{G_{ss}^{I,Auth}}\right)^{\rho_A}\exp(Z_t^{G^{I,Auth}}), \tag{2.60}$$

where $G_{ss}^{I,Auth}$ is the steady-state level of authorized investment, $Z_t^{G^{I,Auth}}$ is a shock to authorized public investment, and ρ_A is an autoregressive parameter that determines the speed at which a shock $Z_t^{G^{I,Auth}}$ 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.[51] The third simplification relates to the fact that we assume a constant real rate of return on the fund. These simplifications 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:

$$OF_t = R^{OF}OF_{t-1} - \frac{OFW_t}{RER_{ss}}, \tag{2.61}$$

where R^{OF} is the constant gross 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 (2.61) 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.[52]

In the second case, equation (2.61) 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

$$TOR_{ss} = R^{OF} - 1.$$

This can be achieved in several ways. For example, a temporary increase in oil fund withdrawals followed by

[51] 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.

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

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

We model the foreign sector using an exogenous block of equations 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}. This is similar to the approach taken in Norges Bank's DSGE model NEMO, see Kravik and Mimir (2019). However, 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 as dependent on the oil price.

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

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

where σ^{TP} can be interpreted as the inverse of the intertemporal elasticity of substitution for Norway's trading partners. 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:

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

where $\omega_{Y,TP}$ captures the steady-state share of trading partners' output in total global output.

Inflation in Norway's trading partners reacts to the oil price and gradually adjusts towards $\pi_t^{F,TP}$, the rate that follows from a traditional new Keynesian Phillips curve:

$$\pi_t^{TP} = \pi_{ss}^{TP} \left(\frac{\pi_{t-1}^{TP}}{\pi_{ss}^{TP}}\right)^{\rho_{\pi^{TP}}} \left(\frac{\pi_t^{F,TP}}{\pi_{ss}^{F,TP}}\right)^{1-\rho_{\pi^{TP}}} \left(\frac{P_t^{Oil}}{P_{ss}^{Oil}}\right)^{\psi_{\pi^{TP},P^{Oil}}}, \quad (2.62)$$

$$\pi_t^{F,TP} = \pi_{ss}^{F,TP} \left(\frac{\pi_{t+1}^{F,TP}}{\pi_{ss}^{F,TP}}\right)^{\beta^{TP}} \left(\frac{Y_t^{TP}}{Y_{ss}^{TP}}\right)^{\frac{\left(\sigma^{TP}+\varphi^{TP}\right)\left(1-\xi^{TP}\right)\left(1-\beta^{TP}\xi^{TP}\right)}{\xi^{TP}}} \exp(Z_t^{\pi^{TP}}), \quad (2.63)$$

where β^{TP} is the discount factor, φ^{TP} is the inverse Frisch elasticity of labor supply, and ξ^{TP} is the Calvo parameter of price rigidity in Norway's trading partners.[53] 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 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

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

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

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

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

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 behavior 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.

[53] After log-linearizing Equation (2.63) we obtain the well-known expression of the new-Keynesian Phillips curve $\hat{\pi}_t^{F,TP} = \beta^{TP} E_t \hat{\pi}_{t+1}^{F,TP} + \left(\sigma^{TP}+\varphi^{TP}\right) \frac{\left(1-\xi^{TP}\right)\left(1-\beta^{TP}\xi^{TP}\right)}{\xi^{TP}} \hat{Y}_t^{TP} + Z_t^{\pi^{TP}}$, where hatted variables denote log deviations from the steady state. See, for example, Walsh (2010, Chapter 6, p. 258).

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.[54] Housing investments are assumed to evolve in line with long-run changes in GDP

$$Inv_t^H = Inv_{ss}^H \frac{\tilde{Y}_t}{Y_{ss}} \exp\left(Z_t^{Inv^H}\right),$$

where $Z_t^{Inv^H}$ is a housing investment shock. 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 net return on housing capital. We are agnostic about who owns the housing capital and consumes the associated housing services and therefore do 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

$$\begin{aligned}
Y_t^M &= Y_t^{M,C} + Y_t^{M,I} + Y_t^{M,G^C} + Y_t^{M,X}, \\
Y_t^S &= Y_t^{S,C} + Y_t^{S,I} + Y_t^{S,G^C} + Y_t^{S,X}, \\
IM_t &= IM_t^{M,C} + IM_t^{M,I} + IM_t^{M,G^C} + IM_t^{M,X} + IM_t^{S,C} + IM_t^{S,I} + IM_t^{S,G^C} + IM_t^{S,X}. \qquad (2.64)
\end{aligned}$$

Hence, total output in the manufacturing, service, and import sector consists of the corresponding first-stage

[54] This approach avoids having to calibrate corporate investments to an 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.

inputs into the production of the four final goods. Since, as shown in Figure 2.3, 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 (2.64) consists of a total of eight terms.[55]

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:

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

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

$$P_t^Y Y_t^D = P_t^M Y_t^M + P_t^S Y_t^S + VA_t^X X_t, \tag{2.65}$$

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 (2.33). 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 (2.35).

We use the Törnqvist-Index to construct the relative price of domestic output P_t^Y, which in turn allows us to obtain a measure of domestic output volume Y_t^D, see Appendix A.9 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

$$Y_t = Y_t^D + r^H K_t^H + \frac{(1+\tau_{0,ss}^{SSF})W_{0,ss}^G}{P_{0,ss}^Y} N_t^G + \frac{P_{0,ss}^I \delta_{KG}}{P_{0,ss}^Y} K_t^G + \Delta INV_t. \tag{2.66}$$

The public wage bill and public capital depreciation are divided by the relative price of domestic output to

[55] 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.

translate their values, which are given in CPI-terms, into units of the domestic good. For the terms preceding N_t^G and K_t^G in equation (2.66), we follow the national accounts convention that government employment and capital depreciation are to be valued at base-year 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. The base year is set to the initial steady state, and it is not updated even if there are permanent policy changes that change the steady state. This convention may have significant effects on GDP responses to permanent shifts in policy. Inventory changes ΔINV_t are given by an exogenous process.

GDP in CPI units Y_t^{CPI} is simply given by converting real GDP to CPI units via its relative price:

$$Y_t^{CPI} = P_t^Y Y_t.$$

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 mainland economy in NORA

$$NX_t + OFW_t + P_t^I Inv_t^{Oil} = \frac{EX_t P_t^{TP}}{P_t}(-B_t^F) - \frac{EX_t P_{t-1}^{TP}}{P_t}(-B_{t-1}^F) R_{t-1}^{TP} RP_{t-1}. \quad (2.67)$$

The left hand side of equation (2.67) 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.[56] The right hand side of

[56] 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

equation (2.67) captures the net change in foreign assets (excluding the GPFG) including interest income.[57]

2.9.6 Aggregate market clearing

We obtain the aggregate market clearing condition by inserting the balance of payments in equation (2.67), the government budget constraint in equation (2.54), the budget constraint for liquidity-constrained households in equation (2.9), the profit functions of intermediate goods firms in the manufacturing and service sector in equation (2.41), and the bank balance sheet in equation (2.17) into the budget constraint of Ricardian households in equation (2.5), yielding

$$P_t^Y Y_t^D = C_t + NX_t + P_t^I I_t + P_t^{G^C} G_t^C + AC_t + P_t^{IM} IM_t^{Res}, \tag{2.68}$$

where AC_t are total adjustment costs in the economy.[58] The aggregate market clearing condition in equation (2.68) differs from the definition of output in (2.65) in that the latter expresses total output as the sum of domestic production, i.e. from the supply side of the economy, whereas equation (2.68) expresses GDP as the sum of total demand. Together equations (2.65) and (2.68) 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. The shocks in the model are listed in Appendix D.1.

3. Parameterizing the model

The parameters of the model are set in two separate steps. The first step is to calibrate a subset of the parameters. This step mainly concerns the parameters that determine the steady state of NORA. The second step is to estimate the remaining parameters using Bayesian techniques. This step mainly concerns the parameters that determine the model's dynamic properties. In this section we describe the details of these two steps.

3.1 Calibration

The model parameters that determine the steady state of the model are chosen such that the model replicates a number of long-run moments in the data. In addition, some parameters that cannot be identified by matching a steady state value to a long-run moment are calibrated using values comparable to those used in Norges Bank's DSGE model NEMO (Kravik and Mimir, 2019) or the academic literature. Finally,

sector and the rest of the world, notably oil exports and transfers from the offshore oil sector to the GPFG.

[57] 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.

[58] Further details on the derivation of the aggregate market clearing condition can be found in the Appendix A.10

some parameters that govern the dynamics of fiscal policy variables are calibrated. These may be set by the user depending on the policy experiment being analyzed and are thus not estimated. The values of the calibrated parameters in NORA are reported in Table 3.2.

Some of the more than 40 empirical targets we seek to replicate (for an overview see Table 3.1) 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.[59] This is the case, for example, with the import content of private consumption. The technical details to this approach are provided in Appendix A.11. In what follows we provide a brief summary.

3.1.1 Preference and household parameters

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 NEMO (Kravik and Mimir, 2019). 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 chosen by Konjunkturinstitutet for their DSGE model SELMA for the Swedish economy (Konjunkturinstitutet, 2019), and within the range of estimates found by Campbell and Mankiw (1991).

3.1.2 Input shares in production

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 match the values in the input-output tables underlying the national accounts.[60] National account input-output tables also allow us to determine the import content of the composite manufacturing and service goods used in the production of all four final goods. 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 3.1. To match the empirical private sector capital to output ratio, we set α_S and α_M to 0.32. 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.

3.1.3 Elasticities of substitution in production

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 ($\eta_{S,Z}$) sectors 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

[59] 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 the effective rates as of 2017.

[60] These data are based on a version of the national accounts that correspond to the aggregation level in NORA.

Table 3.1 Calibration targets

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 trading partners	1.02	1.02	Yes
Nominal interest rate trading partners	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 rate from 2017.

Table 3.2 Calibrated parameters

Parameter	Description	Value
Preferences and households		
β	Discount factor	0.9973
σ	Inverse of the intertemporal elasticity of substitution	1.01
ω	Share of liquidity-constrained households	0.3
Input shares in production		
α_C	Service sector bias of final consumption good	0.65
α_{G^C}	Service sector bias of final government purchases good	0.83
α_I	Service sector bias of final investment good	0.84
α_X	Service sector bias of final export good	0.55
$\alpha_{M,C}, \alpha_{S,C}$	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_M, α_S	Capital elasticity in production function	0.32
Elasticities of substitution (EOS) in production		
$\eta_{M,C}$, $\eta_{S,C}$	EOS across imports and domestic goods for consumption	0.5
$\eta_{M,I}$, $\eta_{S,I}$	EOS across imports and domestic goods for investment	0.5
η_{M,G^C}, η_{S,G^C}	EOS across imports and domestic goods for government purchases	0.5
$\eta_{M,X}$, $\eta_{S,X}$	EOS across imports and domestic goods for exports	0.5
η_C	EOS across sectors for consumption	1.01
η_I	EOS across sectors for investment	1.01
η_{G^C}	EOS across sectors for government purchases	1.01
η_X	EOS across sectors for exports	1.01
ϵ_M	EOS across differentiated intermediate manufacturing sector goods	6
ϵ_S	EOS across differentiated intermediate service sector goods	6
ϵ_X	EOS across differentiated export goods	6
ϵ_{IM}	EOS across differentiated imported goods	6
ϵ_C	EOS across differentiated consumption goods	30
Government sector		
α_{ss}^{OIH}	Scale-up factor for taxation on divided income	1.44
δ_{KG}	Public capital depreciation (quarterly)	0.0201
δ_τ	Tax depreciation rate (quarterly)	0.0330
$MARKUP^{GW}$	Public wage markup	1.41
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

ρ_X	Persistence in fiscal instruments	0
J	Time to build public investment	1
ω_j	Share of public investment in period j	1
ρ_A	Persistence in authorized public investment	0
$\rho_{\tilde{Y}}$	Persistence in output target	10
$\rho_{\tilde{R}}$	Persistence in nominal interest rate target	10
Labor market		
c_N	Constant in union's utility function	103.1
ρ_E	Persistence in employment	0.72
σ_N	Curvature of union utility	1.01
γ	Bargaining power parameter	0.5
ν_U	Weight of unemployment in reference utility	0.8
Monetary and financial market parameters		
π_{ss}, π_{ss}^{ATE}	Inflation rates (quarterly)	$1.02^{1/4}$
ξ_B	Risk premium parameter on firm borrowing	0.025
χ_{BN}	Adjustment cost parameter for new debt	0.025
F^S	Financial fees on stocks (quarterly)	0.0074
R^{OF}	Rate of return of the oil fund (quarterly)	$1.0394^{1/4}$
r^H	Return on housing capital (quarterly)	0.0169
Other calibrated parameters in the domestic economy		
χ_C	Adjustment cost parameter for consumption goods	21
δ_{KP}	Private capital depreciation (quarterly)	0.0217
δ_H	Housing capital depreciation (quarterly)	0.0121
Foreign sector		
π_{ss}^{TP}	Inflation rate (quarterly) of Norway's trading partners	$1.02^{1/4}$
η_{TP}	Foreign elasticity of substitution across imports and domestic goods	1.5
$\omega_{Y,TP}$	Weight of trading partners' output in global output	0.1
φ^{TP}	Inverse Frisch elasticity of labor supply of Norway's trading partners	2
σ^{TP}	Coefficient of relative risk aversion of Norway's trading partners	1

multisectoral SNOW model (Rosnes et al., 2019). 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_{IM}), and exported goods (ϵ_X), which implies a markup of 20 percent. Following Voigts (2016) we set the elasticity of substitution across final consumption good firms, ϵ_C, to 30.

3.1.4 Government sector parameters

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 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 δ_τ is set to 0.033 corresponding to the average tax depreciation rate in the data, see Appendix B.2 for more details. The government wage bill as a share of GDP is calibrated to its empirical counterpart by setting the wage markup $MARKUP^{GW}$ to 1.41. We set the tax deduction parameters according to the values in Table 3.2 such that the tax base to GDP ratio is in line with the data. The model does a relatively good job at matching the tax base for the social security rate for firms despite not modeling any corresponding deduction that would allow us to match it directly.[61]

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 2.57) and various spending components (equation 2.58). The time-to-build parameter J, the spending weights ω_j, and the persistence parameter ρ_A in equations (2.59) and (2.60), specify the time-to-build profile of public investment programs. In the estimation we set $\rho_X = 0$, $J = 1$, $\omega_j = 1$, and $\rho_A = 0$ but in simulation exercises the model user can choose the parameter values depending on the desired dynamics of these variables.[62]

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 the nominal interest rate. We set both $\rho_{\tilde{Y}}$ and $\rho_{\tilde{R}}$ 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.

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.[63] We are not able to calibrate the amount of oil fund withdrawals OFW directly. This is because OFW is used as a balancing item to make sure the balance of payments holds. As shown in Table 3.1 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 an empirical counterpart, are used as a balancing item in the government budget and are therefore not calibrated.

3.1.5 Labor market parameters

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-

[61] No such deduction exists in the Norwegian tax code.

[62] For example, a model user might be interested in simulating a sudden increase in the tax rate from one period to another, and set 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.

[63] Further details on our methodology for calculating effective tax rate can be found in Appendix B.

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 the KVARTS model 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 the manufacturing and service sectors to the appropriate values, see Appendix A.11 for details. The constant in the union utility function c_N is set to 103.1 to ensure that the wage setting equation holds in steady state. 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 (2.13). 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.

3.1.6 Monetary and financial market parameters

The steady-state inflation rate adjusted for taxes in Norway π_{ss}^{ATE} is set so that inflation is two percent annually, consistent with Norges Banks inflation target. The inflation rate including consumption taxes and fees is identical in steady state ($\pi_{ss} = \pi_{ss}^{ATE}$).

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 parameter controlling the cost of adjusting the level of new borrowing, χ_{BN}, is also set to 0.025. In addition to debt, firms issue shares and pay dividends to their shareholders. In line with the assumptions in NOU 2016: 20 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.

In international financial markets, the fixed rate of return of the oil fund R^{OF} is set equal to the steady-state riskless return on foreign bonds R_{ss}^{TP} (see Section 3.1.8). 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. The net return on housing r^H is set to 0.0169 in order to match the empirically determined housing consumption to GDP ratio.

3.1.7 Other calibrated parameters in the domestic economy

The adjustment cost parameter in the final good consumption sector, χ_C, 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 percent 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 $\chi_C = 21$.

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.

In order to replicate the size of the labor income share in domestic production, we set fixed costs in the manufacturing and service sectors, FC^M and FC^S. See Appendix A.11 for more details.

3.1.8 Foreign sector parameters

The steady-state rate of inflation in Norway's trading partners π_{ss}^{TP} is set so that it equals 2 percent on an annual basis corresponding to the inflation target of the European Central Bank. This is the same as the domestic steady-state inflation rate, and the UIP condition in equation (2.20) then implies a steady-state nominal interest rate abroad of the same value as in Norway. That is, R_{ss}^{TP} is also equal to 3.94 percent (annual).

The elasticity of substitution between domestic and imported goods in 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 steady-state share of trading partners' output in total global output, $\omega_{Y,TP}$, is set to 0.10. This roughly matches the value we find our data, and is the same value used in NEMO. In our reduced form model of the foreign sector, some parameters can be given a structural interpretation. In that context, we set the preference parameters in Norway's trading partners to standard values: the coefficient of relative risk aversion is set to $\sigma^{TP} = 1$ and the inverse Frisch elasticity of labor supply is set to $\varphi^{TP} = 2$. The economic size of Norway's trading partners Y_{ss}^{TP} is set to be consistent with the Norway's export-to-GDP ratio.

3.2 Estimation

We estimate a log-linear approximation of the model around its steady state using Bayesian techniques. We estimate the remaining uncalibrated parameters of the model in two separate blocks. First, we estimate the remaining parameters of the foreign block of the model, i.e. the parameters discussed in Section 2.8. Second, we estimate the remaining domestic parameters. When estimating the domestic block of parameters, we take as given the posterior mode values of the estimated foreign parameters. In this way, we ensure that parameters in the Foreign block are not chosen to match features of the Norwegian economy. This corresponds with the small open economy assumption that the Foreign block is completely independent of developments in Norway.

3.2.1 Data

The model is estimated with quarterly data from 1999Q1 to 2019Q4.[64] The starting point corresponds with the appointment of Svein Gjedrem as governor of Norges Bank when the central bank arguably began targeting inflation.[65] We end the estimation period in 2019Q4 to avoid including data from the volatile period of the coronavirus pandemic that began in 2020Q1.

[64] We use the observations from 1995Q2 to 1998Q4 to initialize the Kalman filter.
[65] Formally, Norges Bank's mandate was changed to inflation targeting in March 2001.

Data for the foreign block

The foreign block described in Section 2.8 refers to several variables for Norway's trading partners. To construct series for these variables in the data we use weighted averages of series for Norway's main trading partners as determined by export weights. See Appendix C.1 for the details.

The observables we use for Norway's trading partners are then: trading partners' output ($Y_t^{TP,obs}$), inflation ($\pi_t^{TP,obs}$), and the short-term nominal interest rate ($R_t^{TP,obs}$). In addition, we use observables for global output ($Y_t^{Glob,obs}$), oil investment ($Inv_t^{Oil,obs}$), and the oil price ($P_t^{Oil,obs}$) to complete the set of observables used in the estimation of the foreign block.[66]

Data for the domestic block

The additional observables we use in the estimation of the domestic block of the model are the following series for the Norwegian economy: mainland GDP (Y_t^{obs}), private consumption (C_t^{obs}), government purchases of goods and services ($G_t^{C,obs}$), hours worked in the government sector ($N_t^{G,obs}$), government investment ($G_t^{I,obs}$), mainland private-sector investment ($I_t^{ML,P,obs}$), housing investment ($Inv_t^{H,obs}$), exports (X_t^{obs}), imports (IM_t^{obs}), hours worked in the private sector ($N_t^{P,obs}$), the short-term nominal interest rate (R_t^{obs}), CPI inflation excluding VAT and energy ($\pi_t^{ATE,obs}$), wage inflation ($\pi_t^{W,obs}$), inflation in imported good prices ($\pi_t^{IM,obs}$), and the real exchange rate (RER_t^{obs}).

Gap variables and observation equations

For each data series we construct a gap-variable that is mapped to the corresponding gap in the model. For the real observables (except the real exchange rate) we use the cyclical component from a Hodrick-Prescott filter of the log of the series. For the nominal observables and the real exchange rate we subtract the mean of the series, but we allow for different means before and after significant economic events like the financial crisis. See Appendix C.1 and C.2 for the details of the construction of these foreign and domestic observables respectively. The appendices also show plots of the data series and their trends—Figure C.1 for the foreign block and Figure C.3 for the domestic block—plots of the resulting gap-variables that are used in the estimation—Figure C.2 and Figure C.4—and provide details on the source of each data series.

For real variables in the model we want to map the constructed gap-variables in the data to log-deviations from the steady state for the corresponding variable in the model. However, we allow for measurement error in the observed series of mainland GDP and its expenditure components since we know that the data series used are imperfectly measured. Therefore, for those variables, the observation equations are given by

$$\mathcal{X}_t^{obs} = \log\left(\mathcal{X}_t\right) - \log\left(\mathcal{X}_{ss}\right) + E_t^{ME,\mathcal{X}},$$

with measurement errors $E_t^{ME,\mathcal{X}} \sim \mathcal{N}\left(0, \sigma_{\mathcal{X},ME}\right)$. This applies to

$$\mathcal{X} \in \left\{Y,\, C,\, G^C,\, N^G,\, G^I,\, I^{ML,P},\, Inv^H,\, X,\, IM,\, Inv^{Oil}\right\}.$$

Following Adolfson et al. (2007, 2008), Bergholt et al. (2019), and Christiano et al. (2011) the standard deviations $\sigma_{\mathcal{X},ME}$ are calibrated so that measurement error captures 10 percent of the variance of each

[66]The construction of the series for global output is also described in Appendix C.1.

data series.

For the remaining real variables in the model, and for the real oil price, the gap-variables in the data are mapped to the model variables via observation equations without measurement error:

$$\mathcal{X}_t^{obs} = \log(\mathcal{X}_t) - \log(\mathcal{X}_{ss}).$$

This applies to $\mathcal{X} \in \{Y^{TP}, Y^{Glob}, N^P, P^{Oil}, RER\}$.

The measurement equations for the nominal observables are

$$\mathcal{X}_t^{obs} = \mathcal{X}_t - \mathcal{X}_{ss},$$

for $\mathcal{X} \in \{\pi^{TP}, R^{TP}, R, \pi^{ATE}, \pi^W, \pi^{IM}\}$.

3.2.2 Normalizing shocks

Before estimating the model a few shocks are normalized so that we can use identical priors for all the standard deviations of the shocks in the model. The normalized price markup shocks η_t^i, for $i = IM, M, S, X$, are defined as follows so that they enter the linearized inflation equations in the different sectors with a unit coefficient:

$$\eta_t^i \equiv \frac{1}{\chi_i \left(1 + \frac{1}{DF^{DIV}} \omega_{Ind}\right)} Z_t^{\epsilon_i}. \tag{3.1}$$

The consumption preference shock and the marginal efficiency of investment (MEI) shock are normalized so that they enter the linearized equation of respectively consumption and mainland private-sector investment with a unit coefficient. The normalized shocks are defined as

$$\eta_t^U \equiv \frac{(1-\omega)(1-h)(1-\theta_U)}{\sigma(1+h)} Z_t^U, \tag{3.2}$$

$$\eta_t^{MEI} \equiv \left[\left(1 - \tau^{OIF}\right) \chi_{Inv} \left(1 + \frac{1}{DF^{DIV}}\right)\right]^{-1} Z_t^{MEI}. \tag{3.3}$$

In the estimation it is assumed that the technology shocks and the markup shocks in the domestic intermediate goods sectors are common to both sectors, i.e. a common technology shock

$$Z_t^Y = \theta_Y Z_{t-1}^Y + \sigma_Y E_t^Y,$$

and a common price markup shock

$$\eta_t^{Int} = \theta_{Int} \eta_{t-1}^{Int} + \sigma_{Int} E_t^{Int},$$

replace the sector-specific technology shocks $Z_t^{Y^M}$ and $Z_t^{Y^S}$, and the (normalized) sector-specific markup shocks $\eta_t^{\epsilon_M}$ and $\eta_t^{\epsilon_S}$.

Altogether, we allow for 20 shocks in the estimation of the model. In the domestic block of the model there

Table 3.3 Prior distributions of the structural parameters.

Parameter	Description	Type	Mean	Std.
Domestic block				
h	Habit persistence in consumption	$\mathcal{B}$	0.7	0.1
ρ_E	Persistence in employment	$\mathcal{B}$	0.72	0.10
ρ_W	Persistence in wage	$\mathcal{B}$	0.5	0.10
ω_{Ind}	Indexation of prices to past inflation	$\mathcal{B}$	0.5	0.15
ξ_P	Calvo price rigidity domestic intermediate goods	$\mathcal{B}$	0.5	0.1
ξ_X	Calvo price rigidity export goods	$\mathcal{B}$	0.5	0.1
ξ_{IM}	Calvo price rigidity import goods	$\mathcal{B}$	0.5	0.1
χ_{Inv}	Investment adjustment cost parameter	$\mathcal{G}$	5	1
ξ_{NFA}	Risk premium debt elasticity	$\mathcal{IG}$	0.01	2
ξ_{OF}	Risk premium sovereign wealth fund elasticity	$\mathcal{IG}$	0.01	2
$\rho_{OF,RP}$	Risk premium sovereign wealth fund proxy persistence	$\mathcal{B}$	0.5	0.15
ρ_R	Degree of interest rate smoothing	$\mathcal{B}$	0.5	0.15
ψ_π	Taylor rule inflation coefficient	$\mathcal{N}$	1.5	0.15
ψ_Y	Taylor rule output coefficient	$\mathcal{N}$	0.125	0.05
Foreign block				
$\rho_{Y^{TP}}$	Persistence in trading partners' output	$\mathcal{B}$	0.5	0.15
$\psi_{Y^{TP},P^{Oil}}$	Effect of oil price on trading partners' output	$\mathcal{N}$	0.005	0.001
$\psi_{Y^{TP},Y^{NTP}}$	Effect of non-trading partners on trading partners' output	$\mathcal{N}$	1	0.2
$\rho_{Y^{NTP}}$	Persistence in non-trading partners' output	$\mathcal{B}$	0.5	0.15
$\psi_{Y^{NTP},P^{Oil}}$	Effect of oil price on non-trading partners' output	$\mathcal{N}$	0.002	0.001
$\psi_{Y^{NTP},Y^{TP}}$	Effect of trading partners' on non-trading partners' output	$\mathcal{N}$	0.01	0.002
$\rho_{\pi^{TP}}$	Persistence in trading partners' inflation	$\mathcal{B}$	0.5	0.15
$\psi_{\pi^{TP},P^{Oil}}$	Effect of oil price on trading partners' inflation	$\mathcal{N}$	0.003	0.001
$100\left(1/\beta^{TP}-1\right)$	Trading partners' quarterly real interest rate	$\mathcal{G}$	0.25	0.1
ξ^*	Trading partners' Calvo price rigidity	$\mathcal{B}$	0.5	0.1
$\rho_{R^{TP}}$	Persistence in trading partners' interest rate	$\mathcal{B}$	0.5	0.15
$\psi_{\pi^{TP}}$	Trading partners' Taylor rule inflation coefficient	$\mathcal{N}$	1.5	0.15
$\psi_{R^{TP},Y^{TP}}$	Trading partners' Taylor rule output coefficient	$\mathcal{N}$	0.125	0.05
$\psi_{P^{Oil}}$	Weight on forward looking component in oil price	$\mathcal{N}$	0.2	0.02
$\psi_{P^{Oil},Y^{Glob}}$	Effect of global output on oil price	$\mathcal{N}$	4	0.1
$\rho_{Inv^{Oil}}$	Persistence in oil investment	$\mathcal{B}$	0.5	0.15
$\psi_{Inv^{Oil},P^{Oil}}$	Effect of oil price on oil investment	$\mathcal{G}$	0.1	0.05

Note: $\mathcal{B}$ represents beta, $\mathcal{G}$ gamma, $\mathcal{IG}$ inverse gamma, and $\mathcal{N}$ normal distributions.

are 14 shocks: a technology shock, Z_t^Y, a consumption preference shock, η_t^U, a monetary policy shock, Z_t^R, a risk premium shock, Z_t^{RP}, an import share shock, $Z_t^{IM,\alpha}$, an export demand shock, $Z_t^{\eta_{TP}}$, a Nash reference utility shock, Z_t^V, a markup shock in the export goods sector, $\eta_t^{\epsilon X}$, a markup shock in intermediate goods sectors, η_t^{Int}, a marginal efficiency of investment (MEI) shock, η_t^{MEI}, a housing investment shock, $Z_t^{Inv^H}$, a public employment shock, $Z_t^{N^G}$, a government purchases shock, $Z_t^{G^C}$, and a government investment shock, $Z_t^{G^{I,Auth}}$. In the foreign block there are 6 shocks: a trading partners' output shock, $Z_t^{Y^{TP}}$, a non-trading partners' output shock, $Z_t^{Y^{NTP}}$, a trading partners' inflation shock, $Z_t^{\pi^{TP}}$, a trading partners' monetary policy shock, $Z_t^{R^{TP}}$, an oil price shock, $Z_t^{P^{Oil}}$, and an oil sector investment shock, $Z_t^{Inv^{Oil}}$. We shut down the other shocks that appear in the description of the model in the preceding sections.[67]

3.2.3 Prior distributions

The prior distributions for the model parameters that we estimate are summarized in Tables 3.3 and 3.4. Most priors are standard in the literature (see, e.g., Smets and Wouters, 2007, Justiniano et al., 2010).

[67] See Appendix D.1 for an overview of all shocks in the full model.

Table 3.4 Prior distributions of the shock processes.

Parameter	Shock process	Type	Mean	Std.
Autoregressive coefficients				
θ_Y	Technology	$\mathcal{B}$	0.5	0.15
θ_U	Consumption preference	$\mathcal{B}$	0.5	0.15
θ_R	Monetary policy	$\mathcal{B}$	0.5	0.15
θ_{RP}	Risk premium	$\mathcal{B}$	0.5	0.15
$\theta_{IM,\alpha}$	Import share	$\mathcal{B}$	0.5	0.15
$\theta_{\eta_{TP}}$	Export demand	$\mathcal{B}$	0.5	0.15
θ_V	Nash reference utility	$\mathcal{B}$	0.5	0.15
θ_{MEI}	Marginal efficiency of investment	$\mathcal{B}$	0.5	0.15
θ_{Inv^H}	Housing investment	$\mathcal{B}$	0.5	0.15
θ_{N^G}	Hours worked government sector	$\mathcal{B}$	0.5	0.15
θ_{GC}	Government purchases	$\mathcal{B}$	0.5	0.15
$\theta_{G^{I,Auth}}$	Government investment	$\mathcal{B}$	0.5	0.15
θ_{Int}	Price markup domestic intermediate goods	$\mathcal{B}$	0.5	0.15
$\theta_{\epsilon_{IM}}$	Price markup import goods	$\mathcal{B}$	0.5	0.15
$\theta_{Y^{TP}}$	Trading partners' output	$\mathcal{B}$	0.5	0.15
$\theta_{Y^{NTP}}$	Non-trading partners' output	$\mathcal{B}$	0.5	0.15
$\theta_{\pi^{TP}}$	Foreign inflation	$\mathcal{B}$	0.5	0.15
$\theta_{R^{TP}}$	Foreign monetary policy	$\mathcal{B}$	0.5	0.15
θ_{POIL}	Oil price	$\mathcal{B}$	0.5	0.15
Standard deviations				
σ_Y	Technology	$\mathcal{IG}$	0.2	2
σ_U	Consumption preference	$\mathcal{IG}$	0.2	2
σ_R	Monetary policy	$\mathcal{IG}$	0.2	2
σ_{RP}	Risk premium	$\mathcal{IG}$	0.2	2
$\sigma_{IM,\alpha}$	Import share	$\mathcal{IG}$	0.2	2
$\sigma_{\eta_{TP}}$	Export demand	$\mathcal{IG}$	0.2	2
σ_V	Nash reference utility	$\mathcal{IG}$	0.2	2
σ_{MEI}	Marginal efficiency of investment	$\mathcal{IG}$	0.2	2
σ_{Inv^H}	Housing investment	$\mathcal{IG}$	0.2	2
σ_{N^G}	Hours worked government sector	$\mathcal{IG}$	0.2	2
σ_{GC}	Government purchases	$\mathcal{IG}$	0.2	2
$\sigma_{G^{I,Auth}}$	Government investment	$\mathcal{IG}$	0.2	2
σ_{Int}	Price markup domestic intermediate goods	$\mathcal{IG}$	0.2	2
$\sigma_{\epsilon_{IM}}$	Price markup import goods	$\mathcal{IG}$	0.2	2
$\sigma_{Y^{TP}}$	Trading partners' output	$\mathcal{IG}$	0.2	2
$\sigma_{Y^{NTP}}$	Non-trading partners' output	$\mathcal{IG}$	0.2	2
$\sigma_{\pi^{TP}}$	Foreign inflation	$\mathcal{IG}$	0.2	2
$\sigma_{R^{TP}}$	Foreign monetary policy	$\mathcal{IG}$	0.2	2
σ_{POIL}	Oil price	$\mathcal{IG}$	0.2	2
$\sigma_{Inv^{OIL}}$	Trading partners' output	$\mathcal{IG}$	0.2	2

Note: $\mathcal{B}$ represents beta and $\mathcal{IG}$ inverse gamma distributions.

The priors for the shock process parameters are the same for all shocks (see Table 3.4). The standard deviations (σ_X's) of the shock innovations are assumed to follow inverse-gamma distributions with a prior mean of 0.2 and a standard deviation of 2. The autoregressive coefficients (θ_X's) are beta distributed with mean 0.5 and standard deviation 0.15. We use the same prior for all other persistence parameters except for ρ_E and ρ_W. The prior of ρ_E is centred at 0.72 with a standard deviation of 0.10, which is in line with the calibration found in Aursland et al. (2020) which is justified by empirical results found in Holden and Sparrman (2018). For ρ_W however, we center the prior at 0.5 like the other persistence parameters, but set its standard deviation to match that of ρ_E. These two parameters govern the persistence of two tightly related processes and in order to ensure that the data is informative about their posterior distributions, we here implicitly incorporate in our priors that employment is more persistent than wages.

We use the mapping between Rotemberg (1982) and Calvo (1983) pricing to formulate priors about price rigidity in terms of Calvo instead of Rotemberg parameters as Calvo parameters can only take values between zero and one, whereas Rotemberg parameters can take on any positive value.[68] All Calvo probabilities are assumed to follow a beta distribution with mean 0.5. We choose a prior standard deviation of 0.1, which is the typical choice in the literature. We assume price rigidity in the manufacturing and service sectors to be identical and let ξ_P denote the Calvo parameter in both sectors.

Based on Justiniano et al. (2010) the prior distribution for the investment adjustment cost parameter, χ_{Inv}, is gamma with mean 5 and standard deviation 1. The prior for ξ_{NFA}, the debt-elasticity of the risk premium, is identical to the one used in Adolfson et al. (2008). We use the same prior for ξ_{OF}, the elasticity of the risk premium with respect to the sovereign wealth fund. We adopt normal priors for the Taylor rule coefficients ψ_π and ψ_Y with typical mean values.

The prior choices for the foreign block's parameters are as follows. For the discount factor in Norway's trading partners β^{TP} we formulate a prior in terms of the implied steady-state real interest rate $100\left(1/\beta^{TP}-1\right)$. The prior mean corresponds with an annual real interest rate of 1 percent. The priors for the foreign Calvo and Taylor rule parameters are identical to the domestic ones. The prior for $\psi_{InvOil,POil}$, the parameter that governs the effect of oil price on oil sector investment, is centered around 0.1, which is approximately equal to the value reported in Aursland et al. (2020). For the remaining parameters in the foreign block of the model we use the same priors as Kravik and Mimir (2019).

3.2.4 Posterior estimates

We obtain the posterior distributions of the parameters by means of the Metropolis-Hastings Markov Chain Monte Carlo (MH-MCMC) algorithm implemented in Dynare (Adjemian et al., 2022). As discussed above, we sample the marginal posterior distributions for the foreign and domestic parameters separately. The posterior modes for the foreign block parameters are taken as given in the sampling of the domestic block

[68] In the linear approximation of the model the two pricing mechanisms produce the same dynamics and a Rotemberg price parameter χ_i can be mapped to a Calvo price rigidity parameter ξ_i as follows

$$\chi_i \quad \rightarrow \quad \frac{\xi_i\left(\epsilon_i-1\right)}{\left(1-\xi_i\right)\left(1-\frac{1}{DF^{DIV}}\xi_i\right)},$$

for $i=\{IM,\, M,\, S,\, X\}$. For a discussion on the equivalence between Rotemberg and Calvo pricing see, for example, Ascari and Rossi (2012) and Born and Pfeifer (2020).

parameters.

Foreign block For the foreign block, we sample three chains of 50 million draws each for a total of 150 million draws. The foreign block has a relatively simple structure that allows for many draws at no exorbitant computational cost. Simulation diagnostics tools suggest that the three chains converged swiftly. We discard the first half of the samples from each chain as burn-in. Since draws generated by MCMC algorithms in general are autocorrelated, we use a random subsample of the remaining draws to do inference. On average, the draws in the subsample are uncorrelated.

Posterior estimation results are reported in Table 3.5 and 3.6 for the structural parameters and the shock processes respectively. We took an agnostic approach to the specification of most of the priors, especially when it comes to the shock processes. The posterior distributions deviate significantly from the priors in all instances, suggesting that the data is highly informative about these processes.

The data are also informative about the posterior distributions of the structural parameters in the majority of cases. There are however notable exceptions.[69] Most of these involve the relationships between macroeconomic aggregates and the real oil price. In essence, the relationship between the oil price and trading partners' output, global output and trading partners' inflation have posterior distributions similar in shape to the priors. The relationship between the oil price and non-trading partner output is identified, but has its posterior distribution shifted leftward away from the prior so that the 90% credible interval contains zero. ψ_P^{Oil}, the parameter that governs the forward-looking component of the oil price process, and the quarterly real interest rate of trading partners are however, not distinguishable from their prior distributions. The latter is a remapping of the discount factor β^{TP} done to make it easier to specify a prior distribution and estimate the parameter. It turns out that the data is not informative about this interest rate and the posterior mode is identical to the prior mode with an implied trading partner discount rate β^{TP} of 0.998. The trading partners' Taylor rule inflation coefficient is identified by the data, but some probability mass is up against the lower boundary set at 1. In order to ensure model determinacy, and as is common with feedback rules of this type, we have restricted this coefficient to not take on a value smaller than 1. This is reflected in the 90% credible interval lower bound being 1.00 for this parameter.

Domestic block The structure of the domestic block is considerably more elaborate than the foreign block. For this reason, it is not computationally feasible to obtain the same amount of draws for the parameters of the domestic block, and we sample three chains of 3 million draws each for a total of 9 million draws. With this number of draws, the convergence diagnostics are satisfactory. As with the foreign block, we use half of the sample from each chain as burn-in and pick a random subsample of the remaining draws to do inference.

Posterior estimation results are reported in Table 3.5 and 3.6 for the structural parameters and the shock processes respectively. As with the foreign block, we took an agnostic approach to the prior specifications. For the shock processes, all posterior distributions are different from the prior distribution in mean, mode and standard deviation. This suggest that the the domestic block observables are highly informative about

[69] These exceptions do overlap with attempts by Kravik and Mimir (2019) to estimate analogous parameters for Norges Bank's model NEMO.

Table 3.5 Estimation results of a Metropolis-Hastings posterior simulation of the structural parameters.

Parameter	Description	Mode	Mean	90% HPDI
Domestic block				
h	Habit persistence in consumption	0.74	0.75	[0.64, 0.86]
ρ_E	Persistence in employment	0.88	0.87	[0.83, 0.93]
ρ_W	Persistence in wage	0.69	0.65	[0.52, 0.78]
ω_{Ind}	Indexation of prices to past inflation	0.12	0.14	[0.04, 0.22]
ξ_P	Calvo price rigidity domestic intermediate goods	0.84	0.82	[0.79, 0.86]
ξ_X	Calvo price rigidity export goods	0.65	0.64	[0.55, 0.73]
ξ_{IM}	Calvo price rigidity import goods	0.83	0.83	[0.80, 0.87]
χ_{Inv}	Investment adjustment cost parameter	3.43	4.37	[3.06, 5.65]
ξ_{NFA}	Risk premium debt elasticity	0.01	0.01	[0.002, 0.011]
ξ_{OF}	Risk premium sovereign wealth fund elasticity	0.02	0.03	[0.01, 0.04]
$\rho_{OF,RP}$	Risk premium sovereign wealth fund proxy persistence	0.33	0.34	[0.15, 0.52]
ρ_R	Degree of interest rate smoothing	0.90	0.90	[0.88, 0.92]
ψ_π	Taylor rule inflation coefficient	1.59	1.56	[1.32, 1.80]
ψ_Y	Taylor rule output coefficient	0.12	0.11	[0.03, 0.18]
Foreign block				
$\rho_{Y^{TP}}$	Persistence in trading partners' output	0.52	0.53	[0.44, 0.62]
$\psi_{Y^{TP},P^{Oil}}$	Effect of oil price on trading partners' output	0.004	0.004	[0.003, 0.006]
$\psi_{Y^{TP},Y^{NTP}}$	Effect of non-trading partners on trading partners' output	1.19	1.13	[0.96, 1.30]
$\rho_{Y^{NTP}}$	Persistence in non-trading partners' output	0.57	0.57	[0.46, 0.68]
$\psi_{Y^{NTP},P^{Oil}}$	Effect of oil price on non-trading partners' output	0.001	0.001	[-0.001, 0.002]
$\psi_{Y^{NTP},Y^{TP}}$	Effect of trading partners' on non-trading partners' output	0.01	0.01	[0.007, 0.01]
$\rho_{\pi^{TP}}$	Persistence in trading partners' inflation	0.11	0.14	[0.05, 0.24]
$\psi_{\pi^{TP},P^{Oil}}$	Effect of oil price on trading partners' inflation	0.004	0.003	[0.002, 0.005]
$100\left(1/\beta^{TP}-1\right)$	Trading partners' quarterly real interest rate	0.22	0.25	[0.09, 0.40]
ξ^*	Trading partners' Calvo price rigidity	0.87	0.86	[0.83, 0.89]
$\rho_{R^{TP}}$	Persistence in trading partners' interest rate	0.85	0.84	[0.81, 0.88]
$\psi_{\pi^{TP}}$	Trading partners' Taylor rule inflation coefficient	1.28	1.24	[1.00, 1.44]
$\psi_{R^{TP},Y^{TP}}$	Trading partners' Taylor rule output coefficient	0.17	0.16	[0.12, 0.20]
$\psi_{P^{Oil}}$	Weight on forward looking component in oil price	0.20	0.20	[0.17, 0.24]
$\psi_{P^{Oil},Y^{Glob}}$	Effect of global output on oil price	4.00	4.02	[3.86, 4.18]
$\rho_{Inv^{Oil}}$	Persistence in oil investment	0.73	0.76	[0.67, 0.85]
$\psi_{Inv^{Oil},P^{Oil}}$	Effect of oil price on oil investment	0.04	0.06	[0.02, 0.09]

Note: HPDI refers to the 90% highest posterior density interval.

these shock processes. For other parameters, this also seems to be the case with some few notable exceptions. The first is the risk premium debt elasticity ξ_{NFA}, for which we have imposed an inverse gamma distribution and the prior and posterior means are identical. Compared to the prior however, the right tail of the posterior distribution holds less probability mass. This is part of the explanation why the reported mode and mean in Table 3.5 are the same up to two decimal points, which is typically not the case for this type of distribution. The Taylor-rule coefficients ψ_Y and ψ_π may also be poorly identified with posterior distributions that are just shifted slightly relative to their prior distributions.

Table 3.6 Estimation results of a Metropolis-Hastings posterior simulation of the shock processes.

Parameter	Shock process	Mode	Mean	90% HPDI
Autoregressive coefficients				
θ_Y	Technology	0.83	0.80	[0.73, 0.88]
θ_U	Consumption preference	0.44	0.40	[0.19, 0.60]
θ_R	Monetary policy	0.41	0.36	[0.24, 0.48]
θ_{RP}	Risk premium	0.79	0.74	[0.66, 0.82]
$\theta_{IM,\alpha}$	Import share	0.78	0.73	[0.62, 0.84]
$\theta_{\eta_{TP}}$	Export demand	0.71	0.71	[0.58, 0.83]
θ_V	Nash reference utility	0.37	0.40	[0.19, 0.60]
θ_{MEI}	Marginal efficiency of investment	0.19	0.23	[0.10, 0.37]
θ_{Inv^H}	Housing investment	0.83	0.83	[0.76, 0.90]
θ_{N^G}	Hours worked government sector	0.34	0.43	[0.29, 0.58]
θ_{GC}	Government purchases	0.71	0.71	[0.60, 0.82]
$\theta_{G^{I,Auth}}$	Government investment	0.30	0.25	[0.12, 0.38]
θ_{Int}	Price markup domestic intermediate goods	0.60	0.54	[0.38, 0.70]
$\theta_{\epsilon_{IM}}$	Price markup import goods	0.64	0.61	[0.44, 0.78]
$\theta_{Y^{TP}}$	Trading partners' output	0.41	0.45	[0.29,0.61]
$\theta_{Y^{NTP}}$	Non-trading partners' output	0.58	0.57	[0.46,0.68]
$\theta_{\pi^{TP}}$	Foreign inflation	0.32	0.33	[0.17,0.49]
$\theta_{R^{TP}}$	Foreign monetary policy	0.22	0.22	[0.11,0.32]
$\theta_{P^{Oil}}$	Oil price	0.66	0.68	[0.58,0.79]
Standard deviations				
σ_Y	Technology	0.65	0.72	[0.58, 0.86]
σ_U	Consumption preference	0.23	0.26	[0.15, 0.36]
σ_R	Monetary policy	0.11	0.11	[0.10, 0.13]
σ_{RP}	Risk premium	0.50	0.61	[0.42, 0.79]
$\sigma_{IM,\alpha}$	Import share	1.05	1.22	[0.98, 1.45]
$\sigma_{\eta_{TP}}$	Export demand	3.84	3.99	[3.30, 4.66]
σ_V	Nash reference utility	0.35	0.33	[0.21, 0.46]
σ_{MEI}	Marginal efficiency of investment	0.19	0.22	[0.15, 0.29]
σ_{Inv^H}	Housing investment	2.59	2.58	[2.13, 3.02]
σ_{N^G}	Hours worked government sector	0.72	0.77	[0.65, 0.88]
σ_{GC}	Government purchases	1.25	1.42	[1.18, 1.65]
$\sigma_{G^{I,Auth}}$	Government investment	6.34	5.84	[4.99, 6.69]
σ_{Int}	Price markup domestic intermediate goods	0.16	0.18	[0.13, 0.22]
$\sigma_{\epsilon_{IM}}$	Price markup import goods	0.18	0.18	[0.13, 0.22]
$\sigma_{Y^{TP}}$	Trading partners' output	0.28	0.29	[0.25,0.34]
$\sigma_{Y^{NTP}}$	Non-trading partners' output	0.37	0.38	[0.32,0.43]
$\sigma_{\pi^{TP}}$	Foreign inflation	0.17	0.20	[0.14,0.26]
$\sigma_{R^{TP}}$	Foreign monetary policy	0.07	0.07	[0.06,0.08]
$\sigma_{P^{Oil}}$	Oil price	10.52	10.72	[9.27,12.14]
$\sigma_{Inv^{Oil}}$	Oil investment	5.08	5.06	[4.10,6.00]

Note: HPDI refers to the 90% highest posterior density interval.

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 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 responses following 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 technology shocks in the manufacturing and service sectors (i.e. shocks to total factor productivity).

4.1.1 Monetary policy shock

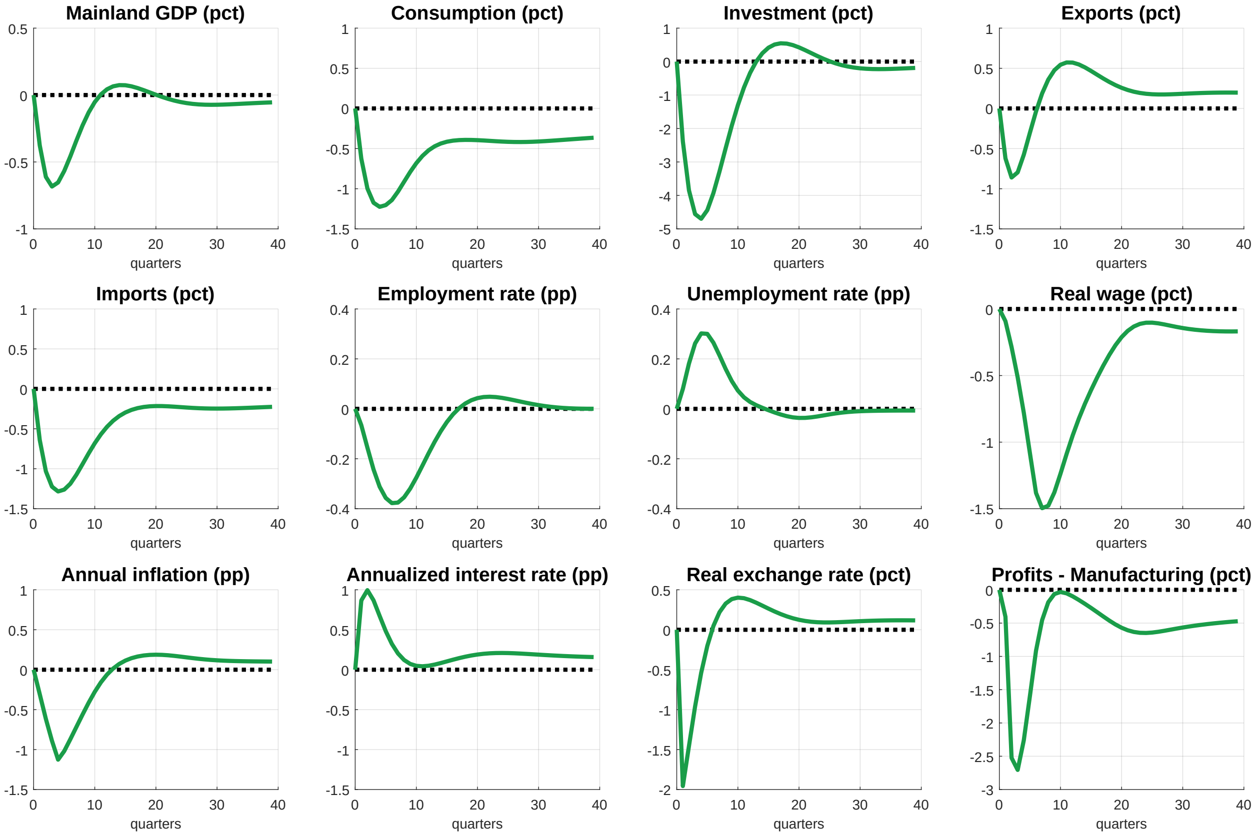
Figure 4.1 shows the response of the main macroeconomic variables to a 1 percentage point increase in the annualized nominal interest rate. Due to price stickiness, higher nominal interest rates are accompanied by an increase in the real interest rate. The increase in the real interest rate has a dampening effect on aggregate demand in the economy. Ricardian 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, leading to appreciation of 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 brief decline in export demand. The fall in both domestic and external demand results in a small decline in mainland GDP. It falls by about 0.7 percent and reaches its trough after 3 quarters. This magnitude is in the range of -0.5 to -1.3 percent that Bjørnland and Halvorsen (2014) find for the small open economies that they consider. It is smaller and faster than their result for Norway, however, which indicate a peak GDP decline of about 1.2 percent, that is only reached after 8 quarters.

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. The declining real wage leads consumption to drop also for liquidity-constrained households.

Lower wages reduce firms' marginal costs. This combined with lower import prices due to the appreciating exchange rates results in a decline in inflation. The appreciation of the real exchange rate of around 2

Figure 4.1 Impulse responses to a monetary policy shock



Note: "pct" denotes percentage deviation from the steady state, and "pp" denotes a deviation from the steady state in percentage points.

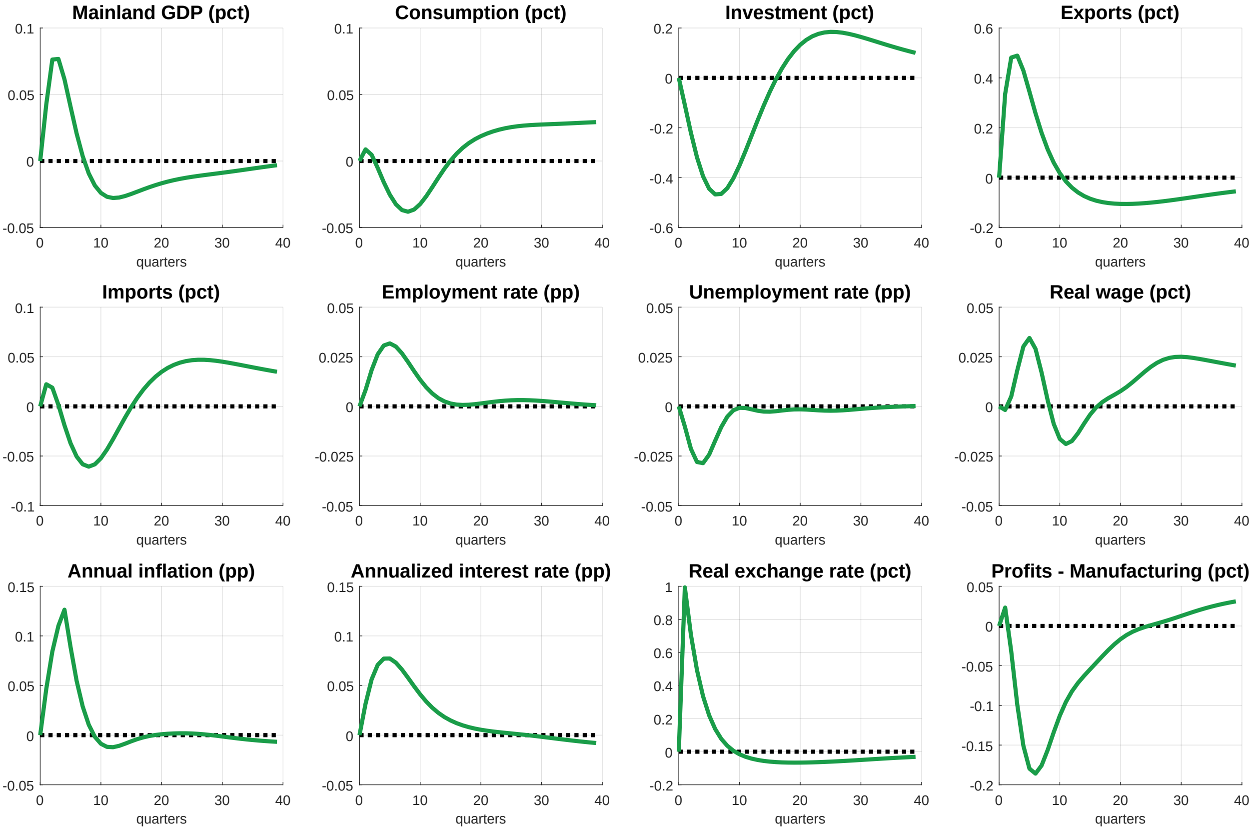
percent on impact is smaller than the results for Norway in Bjørnland and Halvorsen (2014). The peak decline in annual inflation of about 1.1 percentage points is larger than the decline of 0.5 percentage points that they report. In addition, in NORA this peak decline in inflation occurs after 4 quarters compared to 8 quarters in Bjørnland and Halvorsen (2014). However, their empirical results also indicate the presence of the "price puzzle" in the SVAR results using Norwegian data, as inflation initially increases slightly after the monetary tightening. This effect is not present in NORA.

4.1.2 Shock to the external risk premium

Figure 4.2 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 sticky prices) the 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 a decline in the foreign-currency price of exports which results in an increase in export demand. This increases production in both sectors and leads to higher demand for labor. Hence, the employment rate increases and the unemployment rate decreases. Imported goods are also a component in the final export good, and despite the increase in import prices the increased demand for exports leads to a slight increase in imports as well. The effect on imports is small relative to the effect

Figure 4.2 Impulse responses to a temporary increase in the external risk premium



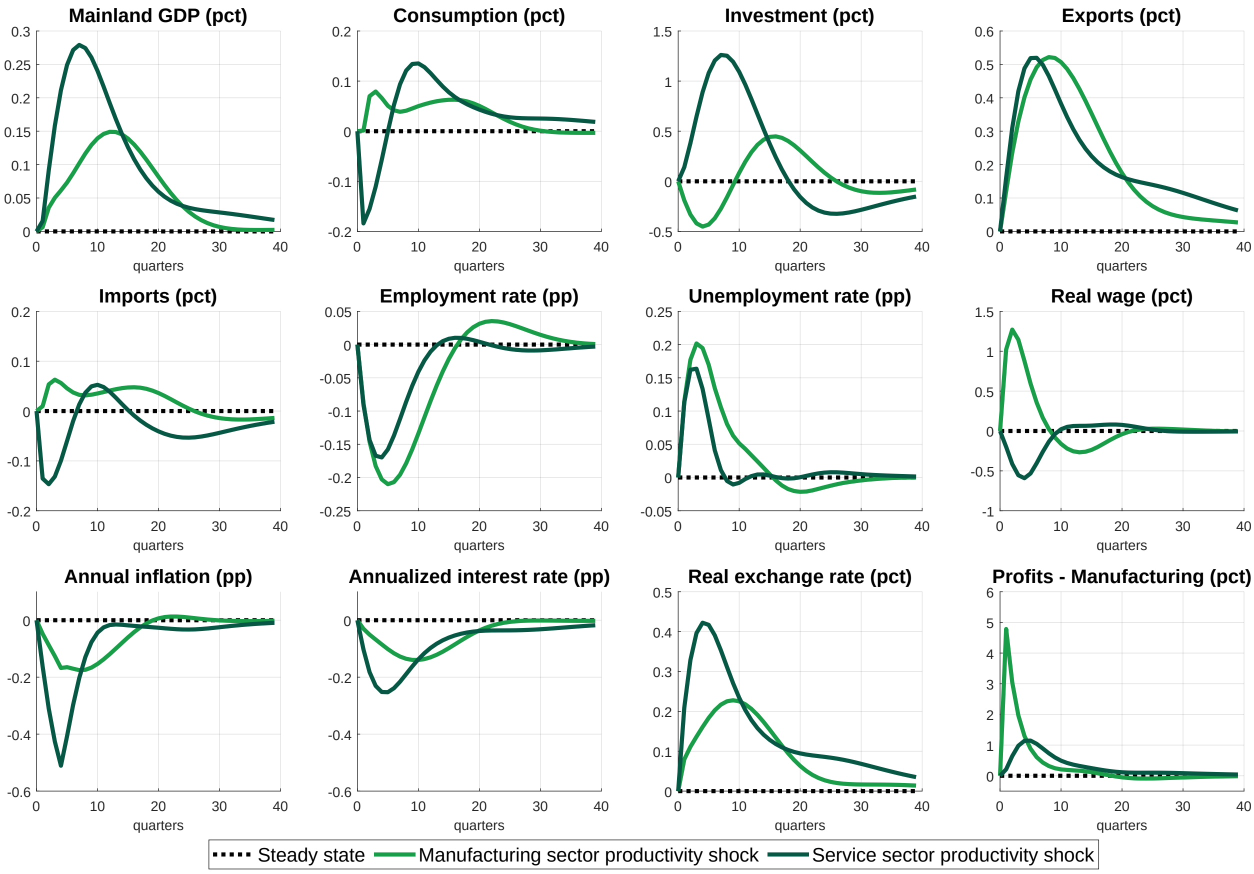
Note: "pct" denotes percentage deviation from the steady state, and "pp" denotes a deviation from the steady state in percentage points.

on exports, however, so the results is an increase in net exports and Mainland GDP.

Over time the increase in labor demand and corresponding fall in the unemployment rate leads to an increase in the real wage through the wage negotiations. The increase in import prices also leads to an increase in CPI inflation, and increases in both Mainland GDP and inflation lead the central bank to increase the interest rate. The result is that profits in the manufacturing sector decline both due to higher debt servicing costs and the higher negotiated real wage. Thus, these effects more than offset the improvement in competitiveness resulting from the depreciation of the real exchange rate. Over time, the effect on employment and unemployment dies out, while the effect on manufacturing sector profits lasts longer. This eventually leads to a reversal of the increase in the real wage.

Finally, the short term increase in consumption is driven by liquidity-constrained households increasing their consumption because of increased labor income. This dominates the short term decrease in consumption from Ricardian households responding to the increased real interest rate, but the effect quickly dies out. In the long term, however, consumption dynamics are driven by the model's tendency to take a long time to return to the steady state in response to certain shocks. The real interest rate declines below the steady state value for a long time while the real wage remains positive. This leads consumption from both types of households to stay positive for an extended period before returning to their steady-state values.

Figure 4.3 Impulse responses to a temporary increase in TFP in the manufacturing and service sectors



Note: "pct" denotes percentage deviation from the steady state, and "pp" denotes a deviation from the steady state in percentage points.

4.1.3 Technology shock

Figure 4.3 shows the impulse responses of key macroeconomic variables following a shock to total factor productivity in the manufacturing sector (green line) and the service sector (dark green line). The shocks are scaled in such a way that total factor productivity in the overall economy increases by 1 percent on impact.[70]

An increase in total factor productivity makes it possible for firms to produce the same amount of output with fewer inputs. Due to sticky prices, aggregate demand does not adjust immediately to the new productivity level. Hence, firms temporarily require less labor and regardless of which sector is affected by the shock, employment falls and unemployment increases. Increased productivity 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 despite the increase in unemployment. If the technology shock manifests itself in the wage-following service sector, the increase in manufacturing sector profits is smaller. Hence, the effect on wages of higher unemployment dominates and real wages fall.[71]

[70] 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 overall total factor productivity will also be smaller.

[71] 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: 13, where it is argued that real wages increase due to the improvement in

The decline in marginal costs that follows since more productive firms need less labor inputs in production induces firms in the sector affected by the shock to cut prices. The sector not affected by the shock will gradually increase its prices as demand for its intermediate good increases. The price change in the affected sector is larger however, so in both cases CPI inflation falls. When the productivity shock affects the service sector, the effect on inflation is larger as CPI inflation consists primarily of service sector goods (see Table 3.2 for further details).

The decline in inflation when the technology shock occurs 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 of sticky prices) the real exchange rate. In both cases, the depreciation of the real exchange reduces the foreign-currency price of exports which results in an increase in export demand.

For other important components of GDP the effect differs depending on whether productivity increased in the manufacturing or services sector. The short-term impact on consumption is mainly driven by the immediate response in consumption by the liquidity-constrained households. When the shock affects the service sector, the decline in hours worked is compounded by the decline in real wages which 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. When the productivity shock affects the manufacturing sector, the increase in the real wage is strong enough to increase real labor income. Hence, in that case, liquidity-constrained households increase their consumption in the short term. In either case, as prices adjust over time, aggregate demand starts to increase, prompting firms to increase labor demand and unwind the initial decline in employment. After a shock to service sector productivity, this gradually brings labor income back up. After a shock to manufacturing sector productivity, this gradually reduces manufacturing sector profits and brings the real wage and labor income back down. In both cases, the result is that the effect on consumption by liquidity-constrained households dies out.

For Ricardian households the response in consumption is more gradual due to consumption habits. In both cases consumption eventually increases due to a positive wealth effect stemming from increased total profits, but this effect is stronger when the productivity shock affects the services sector. In that case, profits increase in both sectors, but when manufacturing sector productivity increases, service sector profits initially fall due to the increase in the real wage. The asymmetric effect on consumption leads to an asymmetric effect on imports as imported goods are a component of the final consumption good.

The effect on investment also depends on which sector is affected by the productivity shock, and the effect is connected with the price of the final investment good and the response of profits in each sector. As shown in Table 3.2, the final investment good is heavily biased towards the service sector. After a shock to manufacturing sector productivity, the price of manufacturing goods gradually declines while the price of the service sector goods gradually increases. The effect on the price of the investment good is dominated by the price of the service sector good and investment thus becomes more expensive. The increase in the wage and corresponding drop in profits in the service sector also leads to a temporary drop in total profits available to finance investment. Over time the real wage effect is reversed and profits eventually increase in the service sector. Eventually total profits thus increase while the price of the investment good comes

manufacturing sector profitability. However, they do not discuss how movements in unemployment may affect this outcome.

back down, and investment increases. After a shock to service sector productivity, the price of investment falls while profits increase in both sectors. Hence, investment increases after the productivity shock in the service sector.

Overall, the effect of a productivity shock is to increase mainland GDP regardless of which sector is affected by the shock. The effect on output is stronger if the technology shock originates in the service sector than if it originates in the manufacturing sector. This reflects that the large movements in investment after a productivity shock dominates the effects on consumption, and that the effect on net exports is stronger after a productivity shock in the service sector.

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.[72]

4.2.1 Permanent increase in government spending

Figure 4.4 illustrates the impact of a permanent one percent of GDP increase in government purchases of goods and services (green line), the government wage bill (dark green line), and targeted transfers to liquidity-constrained households (blue 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. These three simulations were chosen because they 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.[73]

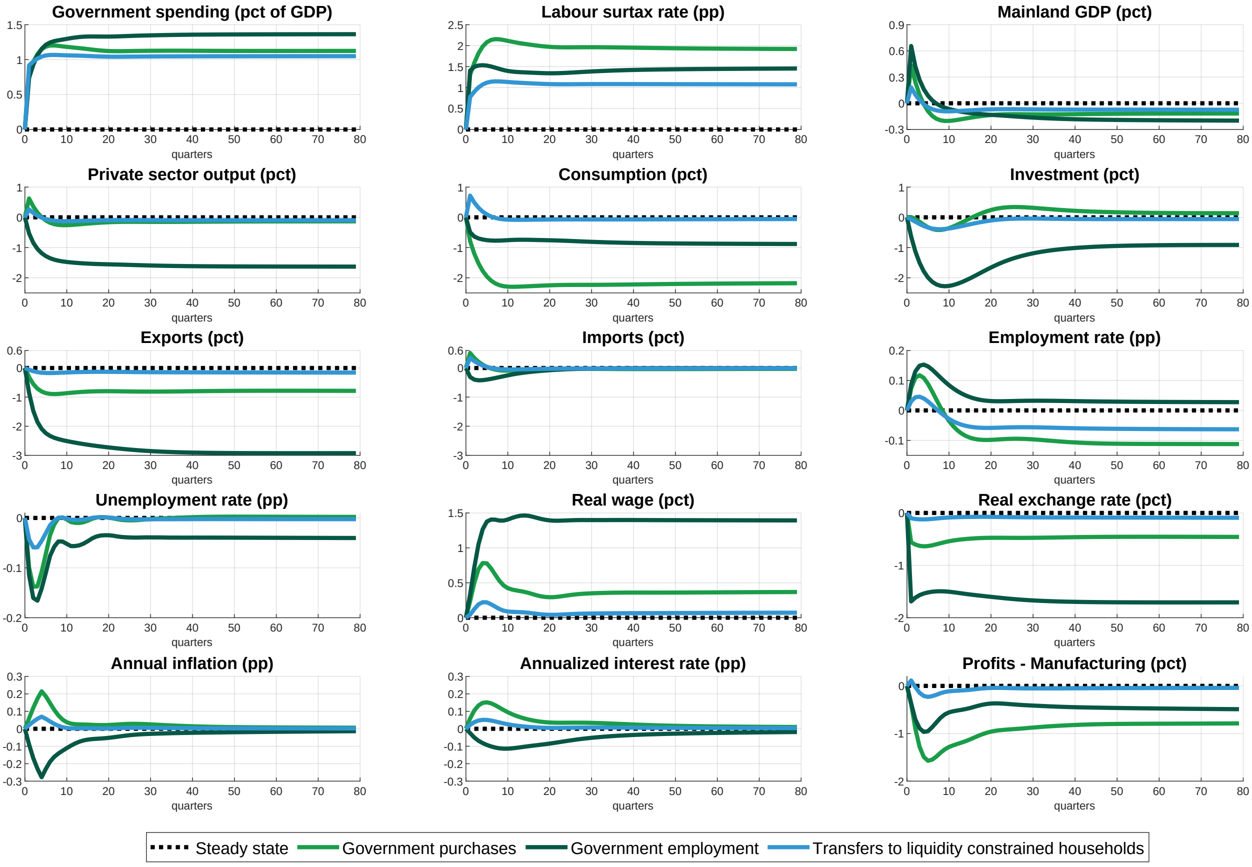
The increase in government spending results in an immediate increase in mainland GDP in all three simulations. The effect is direct following an increase in government purchases and government employment, as both of these are components of GDP. The effect is more indirect (and smaller) following an increase 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 of taxes increase in transfers is muted. The taxation of transfers explains why the long-run increase in the labor surtax rate necessary to balance the budget is lower following an increase in transfers 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 swiftly reduces private employment (not shown) and private sector output.[74]

[72] These 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 transitory so that the model economy can return to its original steady state.

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

[74] 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 4.4 Permanent increase in government purchases financed by the labor surtax



Note: "pct" denotes percentage deviation from the steady state, and "pp" denotes a deviation from the steady state in percentage points.

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. In the cases of the government spending shock and the transfer to liquidity constrained households, this response is due to higher interest rates. The decline in private sector employment following an expansion in public employment reduces the marginal productivity of capital, putting a strong downward pressure on investment in this scenario. In the medium to long run investment stays subdued due to the persistent decline in private sector output. Following an expansion of government purchases of goods and services, however, investment mildly increases in the long run as the increase in real wages induces firms to become more capital intensive.

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 than in the other scenarios.

The increase in real wages leads to an increase in marginal costs for the firms. This effect is more pronounced in the cases of an expansions in government purchases of goods and services and government employment. Increasing marginal costs makes imported goods relatively cheaper as firms gradually adjust prices upwards and this in turn leads to a permanent appreciation of the real exchange rate.[75] The relatively cheaper imported goods naturally leads to higher imports in the short run. However, this does not happen after the increase in government employment because in that case the decreases in private sector output, private consumption and investments are considerable. Exports decline across all three simulations due to the appreciation of the real exchange rate that leads exporters to increase the foreign-currency price of exports. This is further amplified by the higher marginal costs from increased prices of domestically produced intermediate goods.

The increase in government spending triggers a short-term 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. In the long run in these cases, employment settles at a permanently lower level. The reason for this is mainly due to a reduction in the after-tax real wages that leads to a decline in the labor force.

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. In the case of higher government employment, the real exchange rate appreciation and the resulting decrease in import prices is so large that it has a deflationary effect. 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 in the long run.

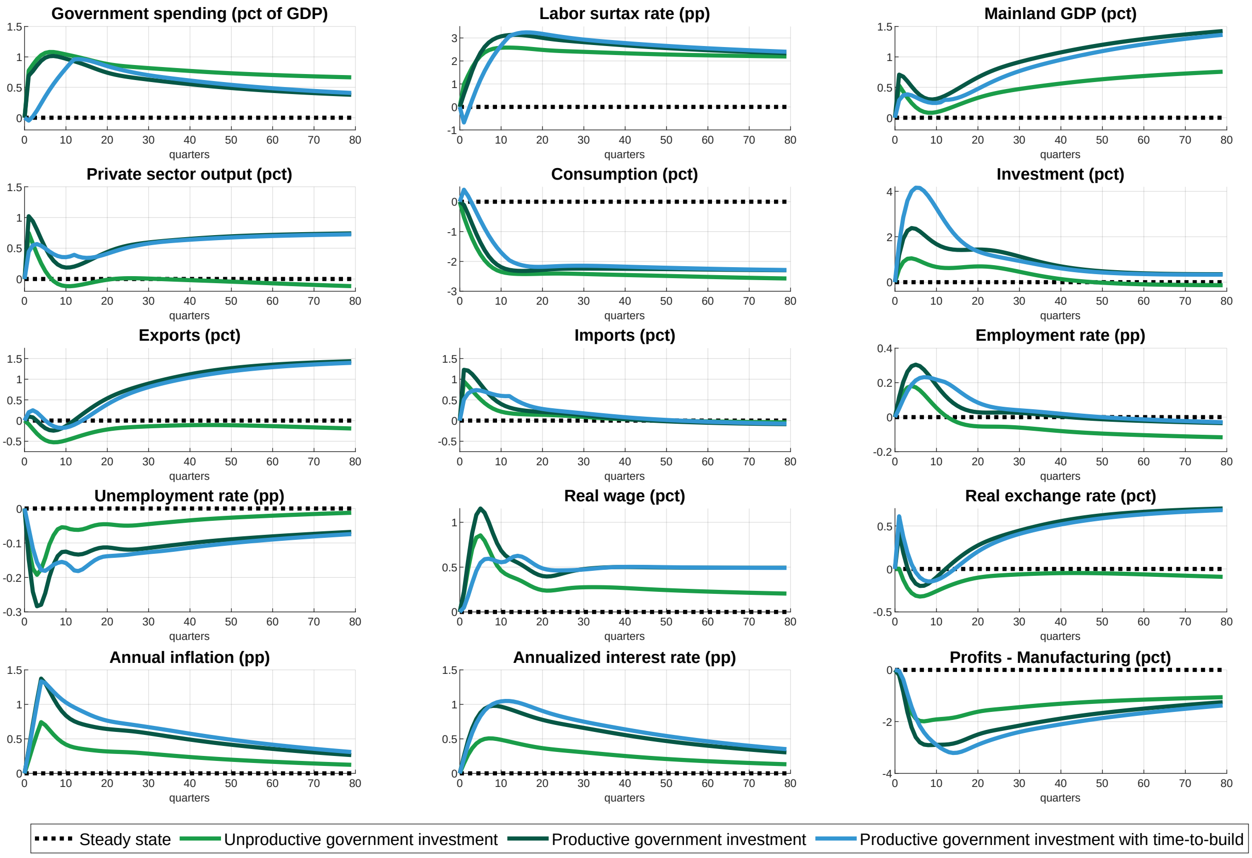
Figure 4.5 simulates the impact of a permanent one percent of GDP increase in government authorized investment financed by an increase in labor surtaxes. The first simulation (green line) assumes that the additional public capital is unproductive in the sense that it does not increase firms' total factor productivity.

[75] 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 4.5 Permanent increase in government investment financed by the labor surtax



Note: "pct" denotes percentage deviation from the steady state, and "pp" denotes a deviation from the steady state in percentage points.

The second simulation (dark green line) assumes that the additional public capital increases total factor productivity, while the third simulation (blue 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.[76]

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 (green and dark green lines) this increase in spending materializes after one period, while in the scenario with time-to-build of 12 quarters (blue 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 thus reduces unemployment. The increase in employment is immediate when there is no time-to-build (green and dark green 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

[76]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 (green line) and 0.05 in the simulations with productive public capital (dark green and blue lines).

gradually reversed. In the scenario where public capital is unproductive (green line) employment falls below its initial level in the medium to long run as higher labor taxes pushes workers to leave the labor force, triggering a permanent decline in the employment rate that encourages unions to keep demanding higher real wages. In the scenario where public capital is productive (dark green and blue lines) the increase in total factor productivity encourages firms to keep employment above its initial level in the medium run, putting additional downward pressure on unemployment. The permanently lower level of unemployment in the long run puts upward pressure on real wages.

Over time the initial shock to aggregate demand is partially crowded out by an increase in real wages and higher nominal interest rate. In the scenario where public capital is unproductive (green line), this results in a gradual decline in private sector output which falls below its initial level in the long run as permanently higher real wages put a dampener on labor demand and employment. In addition, after tax real wages fall so that the long-run size of the labor force is permanently smaller. 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 (dark green and blue 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.[77]

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 (dark green and blue lines) the increase in investment is amplified by the increase in total factor productivity and by the large increase in real wages which encourage firms to become more capital intensive. Exports fall initially when investments are unproductive 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 (dark green and blue 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 lower marginal costs also make imported goods relatively more expensive and contribute to a permanent depreciation of the real exchange rate (see footnote 75).

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 (dark green and blue lines) as the exchange rate does not appreciate initially (and thus there is no resulting decline in imported inflation) in these simulations. The increase in inflation triggers an increase in the nominal interest rate.

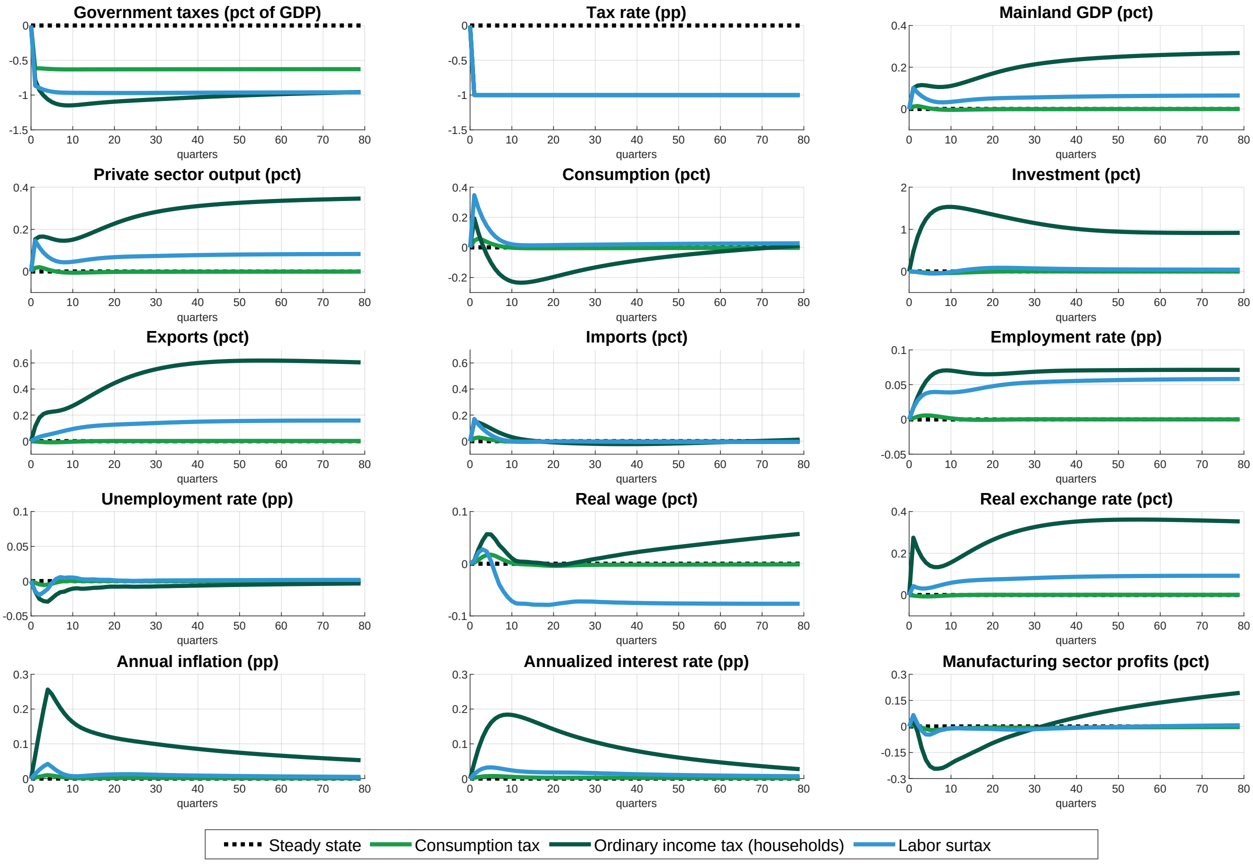
4.2.2 Permanent decrease in taxes

Reduction in household taxation Figure 4.6 simulates the impact of a decrease in the consumption tax rate (green line), the ordinary income tax rate on households (dark green line), and the labor surtax (blue line), financed in each case by a decrease in transfers to Ricardian households.[78] Each tax is reduced

[77] 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 1.75 percent in the scenarios where public capital is productive. It takes approximately 50 years for the economy to reach its new steady-state.

[78] 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.

Figure 4.6 Permanent decrease in household taxes financed by lower transfer to Ricardian households



Note: "pct" denotes percentage deviation from the steady state, and "pp" denotes a deviation from the steady state in percentage points. "Annual inflation" is based on the quarterly pre-tax measure of inflation (π_{ATE}), therefore, it is unaffected by the change in the consumption tax.

permanently by 1 percentage point.

The effect on total tax revenue as a share of GDP after the tax cut depends on both movements in the tax base and the long-run effect of the tax cut on GDP in each case. In the case of the consumption tax and the labor surtax, the drop in tax revenue is nearly entirely due to the fact that transfers to Ricardians (the financing instrument) are taxed as ordinary income. In the case of the decline in the ordinary income tax rate, the same effect is further amplified by a decline in dividends (not shown) which are also taxed as ordinary income.

A cut in the consumption tax rate (green line) increases aggregate consumption on impact due to a permanent increase in the purchasing power of liquidity-constrained households. However, this is gradually offset (due to consumption habits) by a decline in consumption by Ricardian households. Transfers to these households are reduced in order to finance the tax cut, and this triggers a negative wealth effect.[79] 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 6 quarters mainly due to the gradual decline in consumption. 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

[79] 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 households.

from Ricardian to liquidity-constrained households. Note that 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. This is a result of our approach to modeling wage formation in Norway.[80]

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, investment and pre-tax inflation is broadly unchanged and there is only a small increase in interest rates. Because the effect of the tax cut is short-lived, there is only a slight increase in employment 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 real wage remains broadly unchanged.

The response to a cut in the labor surtax (blue 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 and output. However, unlike the consumption tax cut, a cut in the labor surtax boosts labor force participation permanently (not shown) due to the increase in the after-tax real wage. 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. The permanent increase in domestic production also changes the long-run increase in the relative price of imports which is reflected in a long-run depreciation of the real exchange rate (see footnote 75). As for the consumption tax, the long-run effect on consumption is that consumption of liquidity-constrained households is higher due to the increase in after-tax labor income, but this is cancelled out by lower consumption for the Ricardian households who are financing the tax cut. In the long run the additional production is exported.

A cut in the ordinary income tax rate (dark green line) 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 mainly through an increase in the demand for stocks which decreases the cost of equity-financing. The increase in saving by households also reduces banks' reliance on international funding. 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 or 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

[80] The result that the consumption tax rate does not distort labor supply decisions no longer holds if we set I^{τ} in equation (2.14) to 1 so that the union's payoff function depends on after-tax rather than pre-tax real wages.

exchange rate (see footnote 75). 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 while the reduced taxation of ordinary income permanently increases the labor force. The net effect is to reduce unemployment for a sustained period. However, manufacturing sector profits initially drop due to the increase in borrowing costs faced by firms as they expand investment to boost their productive capacity. Initially the effect on unemployment drives the negotiated real wage up, but in the medium term the effect of unemployment dies out while manufacturing sector profits are still negative.

is effect drives the negotiated real wage down. 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. Over time the increased dividend income leads to a partial recovery of the consumption of the Ricardian households. Overall, the 1 percentage point cut in the ordinary income tax rate for household boosts mainland GDP by about 0.3 percent in the long run (not shown).[81]

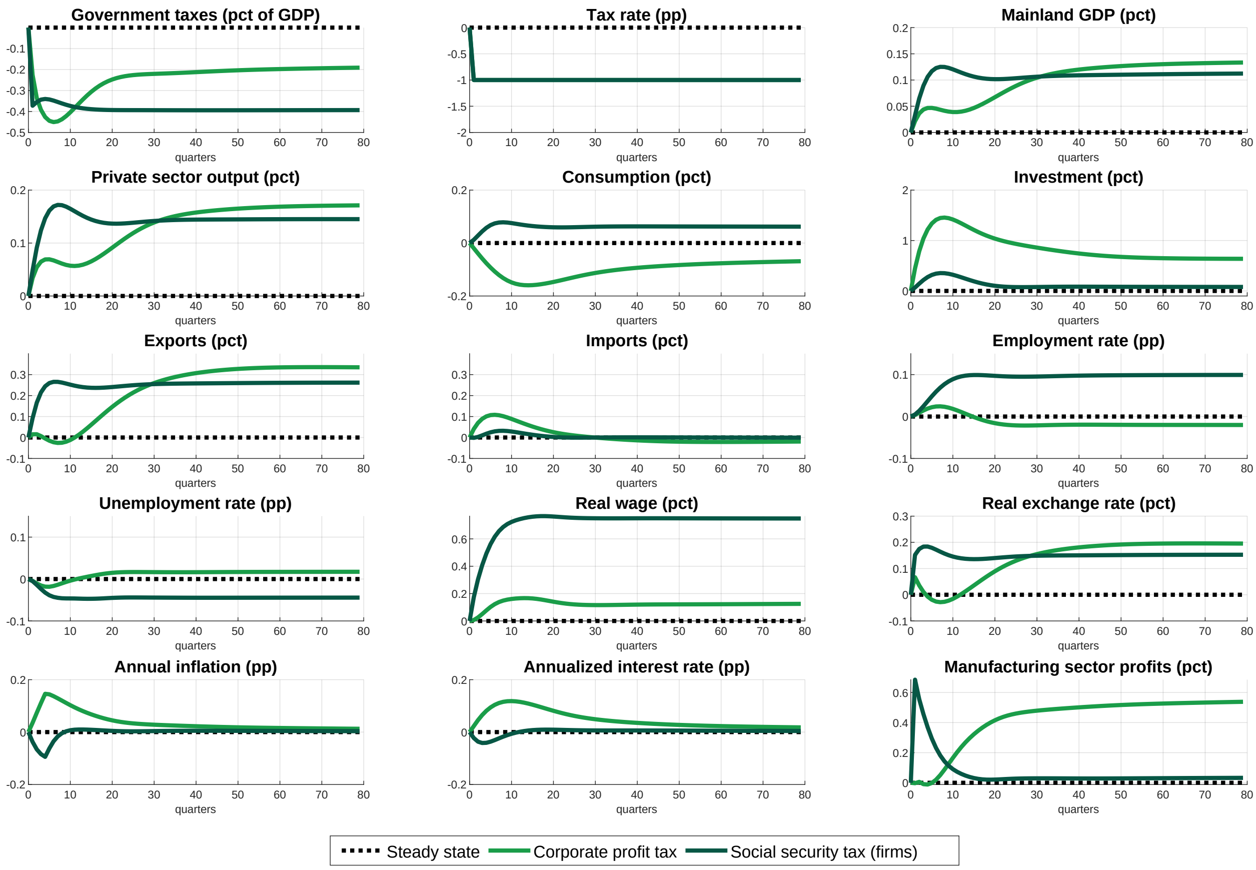
Reduction in corporate taxation In Figure 4.7 we simulate a decrease in the corporate profit tax rate (green line) and the social security tax rate for firms (dark green line). As in Figure 4.6 the tax rates are permanently reduced by 1 percentage point. The fall in tax revenue after the cut in the corporate profit tax is in the short run partly due to the cut in the transfers to Ricardian households and partly due to the short-term decline in dividends (see below). These effects lead to a short-term decline in tax revenue from the ordinary income tax on households. For the cut in the social security tax rate for firms, the fall in tax revenue is in the short run partly offset by increased revenue from the corporate profit tax and the ordinary income tax due to a short-term increase in dividends. In the long run however, revenue from the ordinary income tax is virtually unchanged as the lower transfers to Ricardian households is offset by increased labor income.

A cut in the corporate profit tax rate (green line) raises the marginal return on capital above the marginal cost of financing, and makes it optimal for firms to increase their capital stock. In the long run, firms facing a lower corporate profit tax will operate with permanently higher profits. This will result in a long-run increase in dividends paid by the firms, but in the short run, investment is partly financed by a decline in dividend payments. The higher long-run level of dividends immediately increases the share prices of firms in either sector, reducing the cost of equity financing. The short-term decline in dividends also facilitates a decline in firm borrowing, which is no longer as attractive given higher real interest rates and 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 in the short to medium term. This leads to a slight 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,

[81] Note however, that the long-run impact on real GDP depends on the accounting convention discussed in Section 2.9.4 of keeping prices fixed in a base year given by the initial steady state.

Figure 4.7 Permanent decrease in firm tax rates financed by lower transfers to Ricardian households



Note: "pct" denotes percentage deviation from the steady state, and "pp" denotes a deviation from the steady state in percentage points.

and over time the permanently higher profits of the manufacturing sector firms is shared with workers through a permanently higher real wage. The unwinding of the initial increase in employment combined with entry into the labor market in the short to medium term by workers attracted by the increase in wages, helps bring unemployment back towards its initial level. There is no increase in the labor force in the long run however, and there is an increase in unemployment and decline in employment. In the long run, with firms operating with permanently higher capital stocks, there is a sizeable increase in private sector output and mainland GDP.

The increase in aggregate demand triggered by the increase in investment pushes up inflation and encourages the central bank to raise interest rates. This leads Ricardian households to increase their savings rate and postpone spending. The increased saving is done through paying higher prices for the shares in the firms in both sectors. This effect along with the wealth effect on Ricardian households from the decrease in transfers necessary to finance the tax cut, more than outweighs the increase in consumption among liquidity-constrained households that follows from higher labor income. The result is that overall consumption falls.

Over time, the real exchange rate depreciates due to a fall in the price of domestically-produced goods made possible by the decline in the cost of capital (see footnote 75). 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.

Imports increase initially due to the increase in investment, but declines over time as the depreciation of the real exchange rate encourages agents to substitute away from imports towards domestically produced goods.

The reduction in social security contributions by firms (dark green line) lowers 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. Over time this brings manufacturing sector profits back down, but also leads to a permanent increase in the labor force. 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 due to a combination of a depreciated real exchange rate and lower marginal costs that allows for lower export prices. 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.

4.2.3 Temporary increase in government spending

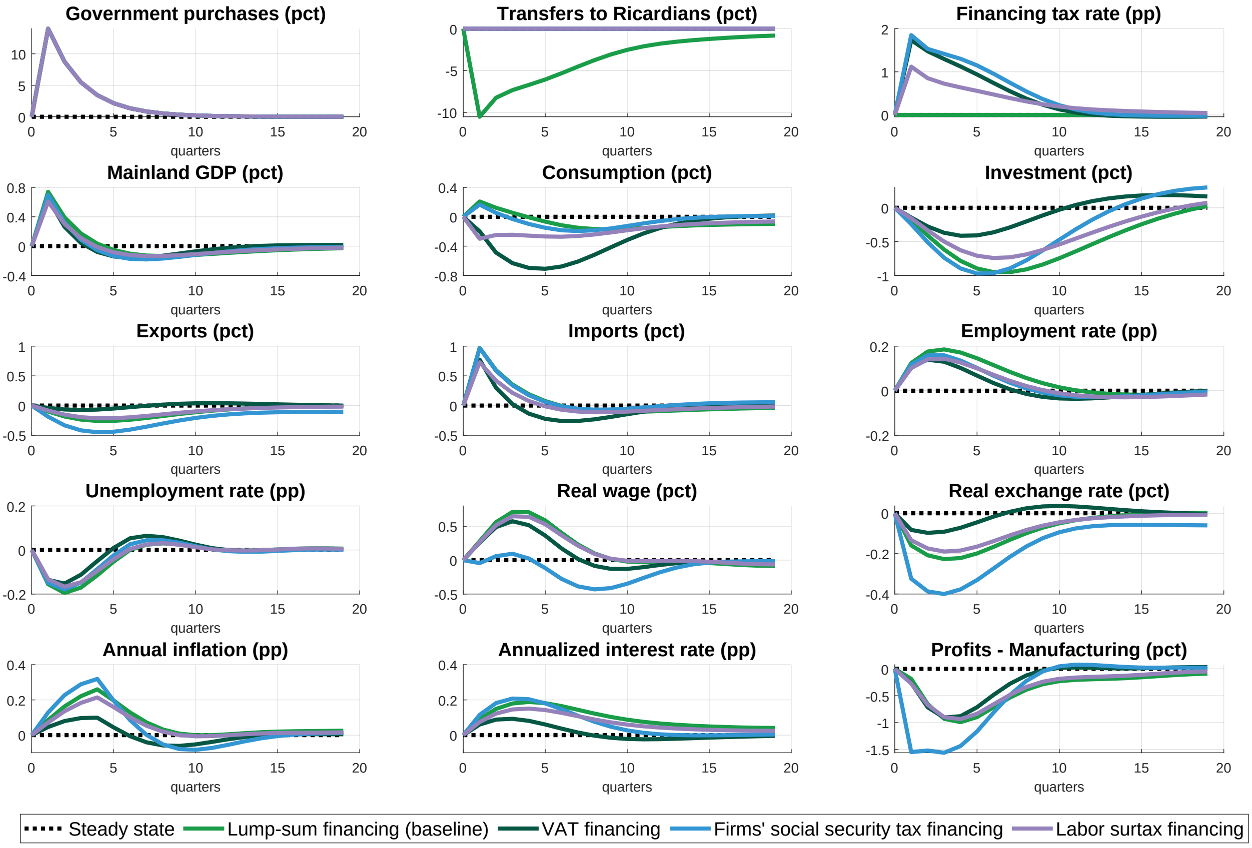
Figure 4.8 shows the responses to a temporary increase in government purchases of goods and services under different financing schemes. We concentrate our analysis on the case where purchases increase by one percent of mainland GDP at impact and gradually return to their original level following the estimated persistence of a government spending shock. The top left panel in Figure 4.8 plots the implied path of government purchases and shows that purchases return to their pre-stimulus level after around two to three years.

In the baseline financing scenario (green line) the fiscal expansion is financed by lower lump-sum transfers to Ricardian households. This scenario is equivalent to a deficit-financed spending increase and has received the most attention in the literature.[82] The baseline scenario is compared against alternative financing schemes where one of the following instruments are used to finance the spending increase: the value-added tax (VAT) on consumption (τ_t^C, dark green line), the social security tax paid by firms (τ_t^{SSF}, blue line), and the labor surtax (τ_t^{LS}, purple line). The top panels in Figure 4.8 show the necessary adjustments in the fiscal instruments to finance the spending increase.

Irrespective of the financing method, the fiscal expansion boosts mainland GDP for several quarters. The impact is highest under lump-sum/deficit financing and lowest under labor surtax financing, with impact multipliers of respectively 0.76 and 0.61.[83] Mainland GDP drops slightly after one year and returns to its

[82] Consistent with the Ricardian equivalence theorem, Ricardian households in NORA treat debt issuance and (non-distortionary) taxation as equivalent.
[83] In Section 4.3 we discuss the fiscal multipliers in more detail.

Figure 4.8 Temporary increase in government spending of 1 percent of mainland GDP under alternative financing schemes



Note: Responses to a temporary increase in government purchases of goods and services of 1 percent of mainland GDP. "pct" denotes percentage deviation from the steady state, and "pp" denotes a deviation from the steady state in percentage points.

original level after about five years.

The response of private consumption to the fiscal stimulus depends on how the stimulus is financed. This is because of the different dynamics of disposable income of liquidity-constrained households and, hence, their level of consumption. *Pre*-tax income of these households goes up, irrespective of the fiscal financing scheme. But the tax increases under VAT or labor surtax financing lower *after*-tax income for these households, and thus lower their consumption possibilities. This explains the different responses of aggregate consumption. In the absence of liquidity-constrained households, the government spending increase would always crowd out private consumption.

The fiscal expansion leads to inflation as firms gradually increase their prices in response to higher marginal costs. The spending increase is most inflationary when it is financed by the social security tax paid by firms, as they increase their prices more following the higher tax burden. To keep the inflation rate near the target, the central bank responds by raising its interest rate. As the interest rate increases, private investment falls, and it only recovers after several years.

The higher marginal costs for firms are driven by both higher wage and borrowing costs. The employment rate rises persistently in response to the spending increase. The peak effect is largest under lump-sum/deficit financing when it occurs after three quarters with an increase in the employment rate of 0.19

percentage points. The response of real wages depends on the financing scheme of the fiscal expansion. All financing schemes lower the unemployment rate, putting downward pressure on negotiated wages. However, if the government raises the social security tax on firms to pay for the spending increase, this results in a larger drop in manufacturing sector profits which counters the effect of unemployment on real wages. However, wage costs for firms including the social security tax increase in all cases. As government spending goes back to its previous level, it takes about four years for the labor market variables to return to their steady-state values.

The fiscal expansion generates a real appreciation of the currency and a deterioration of the trade balance. Exports decline as domestic firms lose competitiveness and imports rise as some of the increased domestic demand is met by buying from abroad.

4.3 Government spending multipliers

In this section we discuss the multiplier for mainland GDP in NORA following an 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. For comparison with the literature, our baseline scenario corresponds to an unanticipated temporary increase in government purchases of goods and services financed by lower lump-sum transfers to Ricardian households, as discussed in Section 4.2.3.

Our vector of interest is the present-value government spending multiplier for mainland GDP at various horizons. The present-value multiplier over a k-period horizon is calculated as

$$PV\left(\frac{\Delta Y}{\Delta G}\right) = \frac{\sum_{s=0}^{k}\left(1+\bar{r}\right)^{-s}\Delta Y_{t+s}}{\sum_{s=0}^{k}\left(1+\bar{r}\right)^{-s}\Delta G_{t+s}}, \tag{4.1}$$

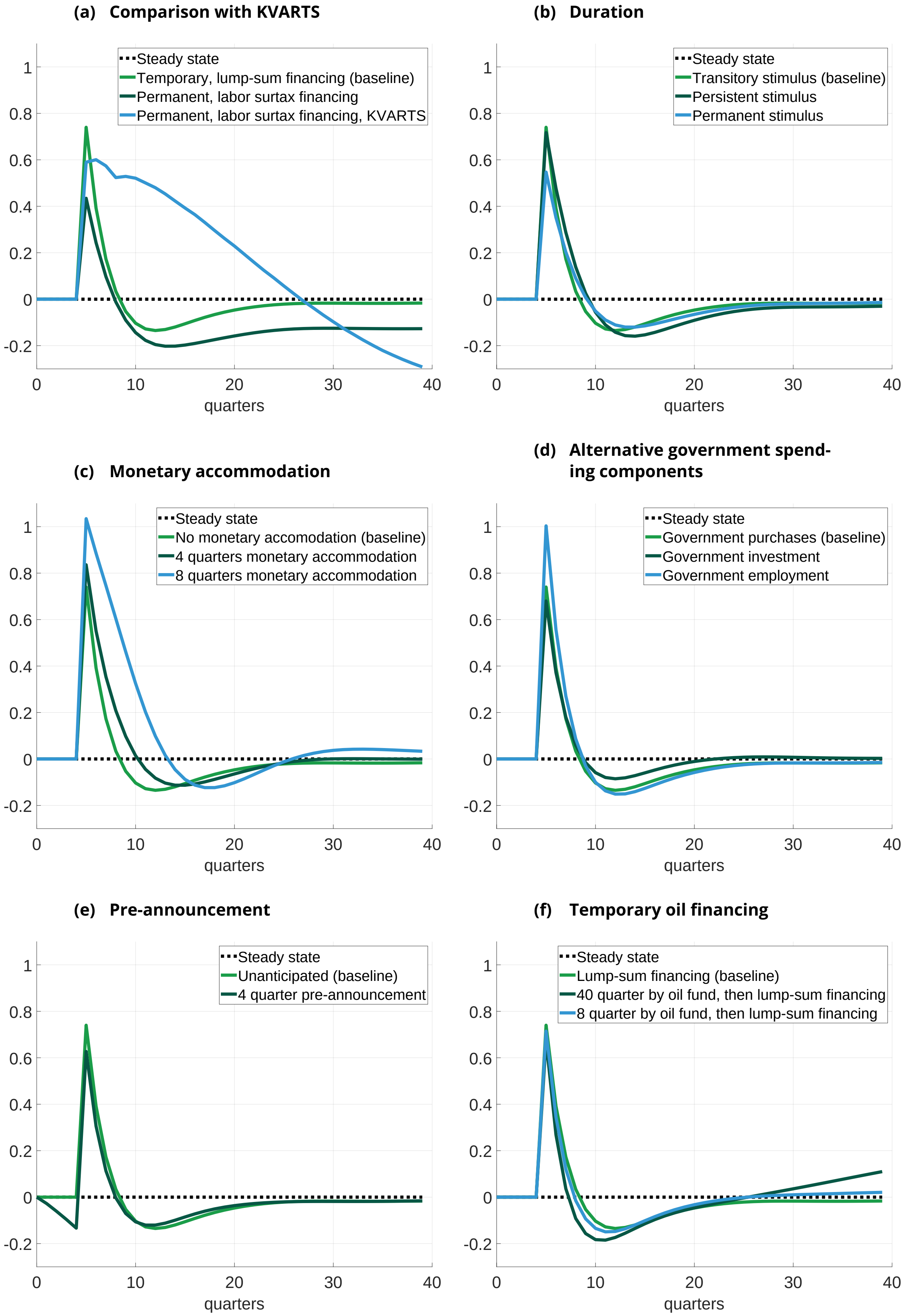
where Y_{t+s} is the response of mainland GDP at period $t+s$, G_{t+s} are government purchases at period $t+s$, and $\bar{r}$ is the steady-state real interest rate.

4.3.1 Government spending multipliers across different policy scenarios

Table 4.1 reports the present-value multipliers under a variety of policy scenarios. The corresponding responses of mainland GDP are presented in Figure 4.9.

Financing strategies The first rows in Table 4.1 present multipliers for alternative financing strategies, corresponding to the scenarios discussed in Section 4.2.3. The impact multiplier varies from 0.61 to 0.70, depending on the financing strategy. This range of values is in line with the multipliers reported in the literature. Based on a comprehensive literature review, Ramey (2019) finds that the majority of the government spending multipliers estimated for developed countries is between 0.6 to 1. Coenen et al. (2012) studied government spending multipliers in Europe and the US across various policy DSGE models and found that multipliers associated with a temporary increase in government consumption range between 0.7 to 1. Similar to the findings of Leeper et al. (2017), for example, the present-value multipliers in NORA trend down over longer horizons, approaching zero after 10 years or turn slightly negative in the cases of

Figure 4.9 Government purchases multiplier for mainland GDP across different policy scenarios



Note: The "baseline" scenario corresponds to a temporary increase in government purchases financed by a drop in lumps-sum transfers to Ricardian households, without monetary accommodation.

Table 4.1 Present-value government purchases multipliers for mainland GDP at various horizons across different policy scenarios

	Impact	1 year	5 years	10 years
Baseline	0.74	0.61	0.04	-0.09
Alternative financing strategies				
VAT financing	0.65	0.39	0.05	0.06
Firms' social security contribution financing	0.70	0.48	-0.09	-0.16
Labor surtax financing	0.61	0.45	-0.06	-0.17
Alternative duration				
Permanent stimulus	0.55	0.30	0.00	0.00
More persistent stimulus	0.72	0.57	0.00	-0.14
Monetary accommodation				
Monetary accommodation, 4 quarters	0.84	0.88	0.39	0.38
Monetary accommodation, 8 quarters	1.04	1.48	1.33	1.55
Alternative government spending components				
Government investment	0.68	0.59	0.27	0.31
Government wage bill	0.98	0.72	0.16	0.06
Temporary oil financing				
Financing by oil fund for 10 years	0.68	0.40	-0.25	0.31
Financing by oil fund for 2 years	0.72	0.53	-0.02	0.09

Note: The "baseline" scenario corresponds to an unanticipated temporary increase in government purchases financed by a drop in lumps-sum transfers to Ricardian households, without monetary accommodation.

labor surtax financing and social security contribution financing. At all horizons, the multiplier is largest when the fiscal expansion is financed by lower transfers to Ricardian households except for VAT financing for which the multipliers are slightly larger at the 5 and 10 year horizons. This financing strategy is equivalent to deficit financing and corresponds most closely 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.[84]

Comparison with KVARTS Figure 4.9a presents a comparison between the government spending multiplier in KVARTS and the equivalent multiplier in NORA. To allow a comparison between the two models, the figure plots the multiplier associated with a permanent spending increase financed with by an increase in the labor surtax. The impact multiplier of 0.43 in NORA (dark green line) is close to the value of 0.59 in KVARTS (blue line), but smaller than the NORA multiplier in the baseline scenario (green line), where the spending increase is temporary and financed by lump-sum transfers to Ricardian households. In both NORA and KVARTS the 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 lasting between 5-6 years in KVARTS compared to about 1 year in NORA.

[84] Holden and Sparrman (2018) find that approximately three-quarters of the changes in government spending in their cross-country sample are debt financed. Because lump-sum transfers to Ricardian households are non-distortionary this simulation is equivalent to a debt-financed increase in government spending and therefore resembles the analysis in Holden and Sparrman (2018).

Duration of the stimulus Figure 4.9b investigates the sensitivity of the multiplier to changes in the duration of the increase in government spending. We compare the baseline scenario with a permanent stimulus (blue line) and a 'persistent' stimulus (dark green line). In the latter case, the spending increase is twice as persistent as the baseline, with a half-life of about three years. As illustrated in Figure 4.9b and Table 4.1, longer expansions result in lower multipliers, both at impact and at longer horizons. This finding is consistent with the analysis of Coenen et al. (2012).

Monetary accommodation Figure 4.9c looks at how the fiscal multiplier is affected by the behavior of the central bank. Not surprisingly, the multiplier increases with the degree of monetary accommodation. The reported present-value multipliers in Table 4.1 are significantly larger, especially at longer horizons. As noted by Coenen et al. (2012) this is because, in the absence of monetary accommodation (green 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 enough 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 (dark green and blue lines), real interest rates will fall, reinforcing the positive effects on GDP resulting from the increase in government spending. When a fixed nominal interest rate accommodates the spending increase for two years, the multipliers are highest, with a one-year present-value multiplier of about 1.5.

Alternative government spending components Figure 4.9d and the last rows of Table 4.1 look at how the multiplier varies across different spending components. An increase in government employment (government wage bill) results in the highest GDP response in the first year, with a multiplier of 0.98 at impact. This reflects the fact that government employment is a direct component of GDP. The strength of the crowding-out effect at longer horizons is somewhat higher than for government purchases, however, given the impact of higher government employment on unemployment and the labor union's wage demands. The present-value multipliers for the government wage bill nevertheless remain significantly higher than for government purchases (baseline), at all horizons. 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, the direct impact on mainland GDP is somewhat smaller, but the present-multipliers over longer horizons are larger than when other government spending components are increased.

Pre-announcement Figure 4.9e shows how the fiscal multiplier is affected by a 4-quarter preannouncement of the increase in government spending (dark green line). Preannouncing the increase in government spending reduces output in the period leading up to the actual increase in spending. This is primarily due to the behavior 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 behavior of liquidity-constrained households and thus broadly similar. However, be-

Table 4.2 Present-value government purchases multipliers for mainland GDP at various horizons: sensitivity to parameter values

	Impact	1 year	5 years	10 years
Baseline	0.74	0.61	0.04	-0.09
Liquidity-constraint households 0%	0.68	0.53	0.03	-0.08
Liquidity-constraint households 50%	0.79	0.67	0.05	-0.10
Domestic intermediate goods prices: flexible	0.41	0.15	-0.14	-0.27
Domestic intermediate goods prices: rigid	0.78	0.75	0.42	0.35
Investment adjustment costs: low	0.79	0.53	-0.09	-0.26
Investment adjustment costs: high	0.75	0.64	0.23	0.20
Wage rigidity: low	0.77	0.63	0.13	0.00
Wage rigidity: high	0.76	0.68	0.23	-0.13
Home bias in government purchases: low	0.67	0.55	0.03	-0.10
Home bias in government purchases: high	0.81	0.66	0.05	-0.08
Unemployment sensitivity of negotiated wages: low	0.75	0.66	0.28	0.18
Unemployment sensitivity of negotiated wages: high	0.74	0.59	0.00	-0.13

Note: The "baseline" scenario corresponds to an unanticipated temporary increase in government purchases in the fifth quarter financed by a drop in lumps-sum transfers to Ricardian households, without monetary accommodation.

cause of the lower starting point, the increase in GDP relative to its initial starting point is smaller.

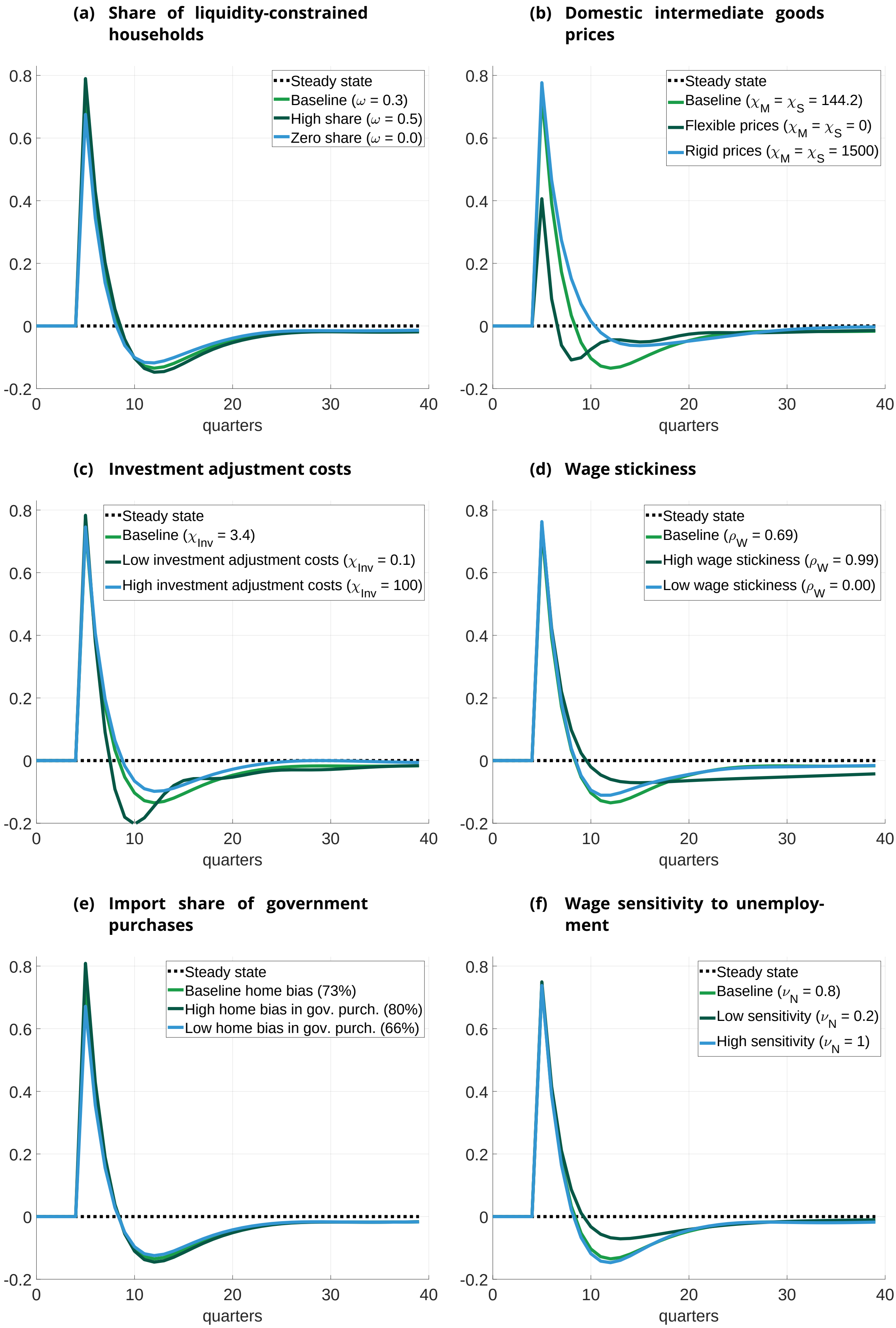
Temporary oil financing Figure 4.9f investigates how the fiscal multiplier is affected if the increase in government spending is, for a period of time, financed by larger withdrawals from the oil fund instead of lower transfers to Ricardian households (dark green and blue lines). The figure and the corresponding multipliers in Table 4.1 illustrate that these alternative financing strategies lead to very similar impacts on mainland GDP. It is important to note that after the temporary increase in oil fund withdrawals the value of the fund is permanently lower, which permanently lowers the sustainable amount of withdrawals. In the simulation it is assumed that the resulting gap is filled by lower lump-sum transfers to Ricardian households or, equivalently, debt. If distortionary taxes, such as the labor surtax, are used instead, mainland GDP would be affected negatively and the multipliers would become smaller (or negative), especially at longer horizons. A more protracted use of oil money in combination with distortionary taxes results in smaller (or negative) effects on mainland GDP, because a more depleted oil fund (and consequently a lower sustainable level of oil fund withdrawals) has to be met by higher tax rates.

4.3.2 Sensitivity analysis

In this section, we investigate the sensitivity of the government spending multipliers to alternative values of some key parameters. Table 4.2 reports the present-value multipliers for alternative parameter choices and Figure 4.10 plots the associated responses of mainland GDP.

Share of liquidity-constrained households The government spending multiplier is larger in the presence of liquidity-constrained households. The impact multiplier for mainland GDP rises from 0.70 to 0.89 when the fraction of liquidity-constrained households grows from 0.30 to 0.50, as illustrated in Figure 4.10a and the first rows of Table 4.2. The multiplier falls to 0.68 in the absence of liquidity-constrained households (blue line). Liquidity-constrained households respond to the fiscal expansion by consuming more as their

Figure 4.10 Sensitivity of the government purchases multiplier for mainland GDP



disposable income increases. Ricardian households, on the other hand, consume less as they take into account the negative wealth effect of lower lump-sum transfers used to finance the spending increase. The overall impact on aggregate private consumption is positive, as Ricardians represent only a share of the total population and reduce their consumption much more gradually due to consumption habits and their ability to access financial markets to smooth their consumption profile. It is well-understood that the presence of liquidity-constrained (or “rule-of-thumb”) households in new Keynesian DSGE models helps to generate a positive consumption response to a government spending increase, thereby accounting for the evidence from several empirical studies using structural vector autoregressive (SVAR) models (see Galí et al., 2007, for example).

Price rigidity Figures 4.10b, 4.10c, and 4.10d look at how the government spending multiplier is affected by the magnitude of the real and nominal rigidities in NORA. The corresponding present-value multipliers are presented in Table 4.2. 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 4.10b shows how the fiscal multiplier changes if we change the degree of price stickiness in the domestic intermediate goods sectors in NORA. If prices are fully flexible (dark green line), they increase rapidly in response to the increase in aggregate demand, accelerating the decline in private sector demand. The impact multiplier is smaller and the crowding-out of mainland GDP occurs more rapidly. Present-value multipliers turn negative five years after the initial spending increase. On the other hand, when prices are more rigid (blue line) than in the baseline scenario (green line), the impact multiplier is somewhat higher and present-value multipliers over longer horizons go up significantly.

Investment adjustment costs Figure 4.10c shows how the fiscal multiplier is affected by changes in the magnitude of investment adjustment costs. The impact of varying investment costs is relatively small in this simulation. Low investment adjustment costs (dark green line) magnify the negative adjustment of mainland GDP after the initial increase as they amplify the decline in investment due to higher interest rates. When investment adjustment costs are high (blue line), private investment declines only marginally. Overall, because the movement in investment itself is pretty modest in all scenarios, the effects of changing investment adjustment costs is also pretty small, in particular in the first years of the fiscal expansion.

Wage rigidity Figure 4.10d 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. The degree of wage stickiness does not affect the short-term multipliers much, but over the medium term (1-5 years) the present-value multipliers are somewhat smaller if wages are flexible, see Table 4.2. 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 and leads to a sharper decline in private investment. This amplifies the reduction in mainland GDP in the medium run.

Import share of government purchases Figure 4.10e illustrates the impact of the import share in government purchases on the fiscal multiplier. In the baseline specification, the national account input-output tables used to calibrate this part of NORA indicate that imported inputs make up as much as 27 percent of government purchases of goods and services. Put differently, the home bias in government purchases is 73 percent. The figure illustrates that increasing the home bias to 80 percent (dark green line) significantly increases the impact of the spending increase on mainland GDP. The impact multiplier of 0.81 is close to the value of Stähler and Thomas (2012), who assume a full home bias in public consumption. The multiplier remains high over longer horizons, as Table 4.2 illustrates. Analogously, a lower home bias—i.e. a higher import share—in government spending lowers the impact of the fiscal expansion on mainland GDP as the import leakage is larger.

Sensitivity of negotiated wages to unemployment Figure 4.10f explores the sensitivity of the government spending multiplier to ν_U, the weight of unemployment in the union's reference utility. This parameter determines the sensitivity of negotiated wages to the unemployment rate (see Section 2.4 on the wage bargaining setup in the model). The impact multiplier on mainland GDP is unaffected by the responsiveness of wages to the unemployment rate as wages adjust sluggishly. However, the parameter does influence the crowding-out effect of the fiscal expansion on mainland GDP in the medium term. When sensitivity is low (dark green line), wage growth in response to the drop in unemployment is weak, reducing the crowding-out effect. When sensitivity is high (blue line) negotiated wages increase more, leading to a stronger crowding-out effect. As a result, the present-value government spending multipliers over longer horizons are higher (lower) when negotiated wages are less (more) responsive to changes in unemployment, as the last rows of Table 4.2 illustrate.

5. Summary

This document presents NORA, a microfounded macroeconomic model for fiscal policy analysis in Norway. NORA was developed by a team of economists on behalf of the Ministry of Finance in collaboration with Statistics Norway and Norges Bank, and it is now part of Statistics Norway's portfolio of models. Unlike DSGE models developed to analyze 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. The standard framework is also modified significantly to account for features particular to the Norwegian economy. Most notably this includes the characterization of wage setting in the economy as the outcome of Nash bargaining between firms in the exposed sector of the economy and a labor union. 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. Model appendix

A.1 First-order conditions of the Ricardian household

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

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

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

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

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 $\frac{\partial \mathcal{L}}{\partial S_t^{R,M}} = 0$ is then given by

$$\beta^t \lambda_t P_t^{E,M}(1+F_t^S) = \beta^{t+1} E_t \left[\lambda_{t+1} \left(\frac{P_t^{E,M}}{\pi_{t+1}^{ATE}} + (1-\tau_{t+1}^D)(P_{t+1}^{E,M} - \frac{P_t^{E,M}}{\pi_{t+1}^{ATE}} + DIV_{t+1}^M) + RRA_{t+1} \frac{P_t^{E,M}}{\pi_{t+1}^{ATE}} \tau_{t+1}^D \right) \right]$$
$$\lambda_t(1+F_t^S) = \beta E_t \left[\lambda_{t+1} \left(\frac{1}{\pi_{t+1}^{ATE}} + (1-\tau_{t+1}^D)(P_{t+1}^{E,M} - \frac{P_t^{E,M}}{\pi_{t+1}^{ATE}} + DIV_{t+1}^M)/P_t^{E,M} + RRA_{t+1} \frac{1}{\pi_{t+1}^{ATE}} \tau_{t+1}^D \right) \right]$$
$$\lambda_t(1+F_t^S) = \beta E_t \left[\frac{\lambda_{t+1}}{\pi_{t+1}^{ATE}} \left(1 + \pi_{t+1}^{ATE}(1-\tau_{t+1}^D)(P_{t+1}^{E,M} - \frac{P_t^{E,M}}{\pi_{t+1}^{ATE}} + DIV_{t+1}^M)/P_t^{E,M} + RRA_{t+1}\tau_{t+1}^D \right) \right]$$
$$\lambda_t(1+F_t^S) = \beta E_t \left[\frac{\lambda_{t+1}}{\pi_{t+1}^{ATE}} R_t^S \right] \tag{A.2}$$

Subtracting equation (A.2) from equation (A.1) 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 (A.2) 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 Age-specific labor force participation rates

Building on Gjelsvik et al. (2013), the equations for the age-specific labor force participation rates are as follows.

Labor force participation rate for the 15-19 age group, total (L_t^{1519}):

$$\log\left(L_t^{1519}\right) = c_1^{1519} + c_2^{1519}\log\left(L_{t-1}^{1519}\right) + c_3^{1519}\log\left(L_{t-2}^{1519}\right) + c_4^{1519}\left[\log\left(\left(1-\tau_t^W\right)W_t\right) - \log\left(\left(1-\tau_{t-1}^W\right)W_{t-1}\right)\right] + c_5^{1519}\log\left(U_{t-1}+U_{t-2}+U_{t-3}+U_{t-4}\right) + c_6^{1519}\left[\log\left(L_{t-4}^{1519}\right) - \log\left(L_{t-5}^{1519}\right)\right]. \quad \text{(A.3)}$$

Labor force participation rate for the 20-24 age group, total (L_t^{2024}):

$$\log\left(L_t^{2024}\right) = c_1^{2024} + c_2^{2024}\log\left(L_{t-1}^{2024}\right) + c_3^{2024}\log\left(L_{t-3}^{2024}\right) + c_4^{2024}\log\left(U_{t-3}\right). \quad \text{(A.4)}$$

Labor force participation rate for the 25-61 age group, female (L_t^{K2561}):

$$\log\left(L_t^{K2561}\right) - \log\left(L_{t-1}^{K2561}\right) = c_1^{K2561} + c_2^{K2561}\left[\log\left(L_{t-4}^{K2561}\right) - \log\left(L_{t-5}^{K2561}\right)\right] + c_3^{K2561}\log\left(L_{t-1}^{K2561}\right) + c_4^{K2561}\log\left(U_{t-1}\right) + c_5^{K2561}\log\left(\left(1-\tau_{t-3}^W\right)W_{t-3}\right). \quad \text{(A.5)}$$

Labor force participation rate for the 62-66 age group, female (L_t^{K6266}):

$$\log\left(L_t^{K6266}\right) = c_1^{K6266} + c_2^{K6266}\log\left(L_{t-1}^{K6266}\right) + c_3^{K6266}\log\left(L_{t-4}^{K6266}\right) + c_4^{K6266}\log\left(\left(1-\tau_{t-2}^W\right)W_{t-2}\right) + c_5^{K6266}\log\left(\left(1-\tau_{t-5}^W\right)W_{t-5}\right). \quad \text{(A.6)}$$

Labor force for the 25-61 age group, male (L_t^{M2561}):

$$\log\left(L_t^{M2561}\right) = c_1^{M2561} + c_2^{M2561}\log\left(L_{t-1}^{M2561}\right) + c_3^{M2561}\log\left(L_{t-2}^{M2561}\right) + c_4^{M2561}\log\left(L_{t-3}^{M2561}\right) + c_5^{M2561}\log\left(L_{t-5}^{M2561}\right) + c_6^{M2561}\left[\log\left(U_{t-3}\right) - \log\left(U_{t-4}\right)\right]. \quad \text{(A.7)}$$

Labor force participation rate for the 62-66 age group, male (L_t^{M6266}):

$$\log\left(L_t^{M6266}\right) = c_1^{M6266} + c_2^{M6266}\log\left(L_{t-1}^{M6266}\right) + c_3^{M6266}\log\left(L_{t-3}^{M6266}\right) + c_4^{M6266}\log\left(L_{t-4}^{M6266}\right) + c_5^{M6266}\log\left(\left(1-\tau_{t-2}^W\right)W_{t-2}\right) + c_6^{M6266}\log\left(\left(1-\tau_{t-5}^W\right)W_{t-5}\right) + c_7^{M6266}\left[\log\left(U_{t-3}\right) - \log\left(U_{t-4}\right)\right]. \quad \text{(A.8)}$$

Labor force participation rate for the 67-74 age group, total (L_t^{6774}):

$$\log\left(L_t^{6774}\right) = c_1^{6774} + c_2^{6774}\log\left(L_{t-1}^{6774}\right) + c_3^{6774}\log\left(L_{t-4}^{6774}\right) + c_4^{6774}\log\left(\left(1-\tau_{t-2}^W\right)W_{t-2}\right). \quad \text{(A.9)}$$

Table A.1 Calibrated coefficients for labor force participation equations

Parameter	Note (if applicable)		Value
Weights in equation (2.12)			
w^{1519}			0.0860
w^{2024}			0.0884
w^{K2561}			0.3236
w^{K6266}			0.0371
w^{M2561}			0.3397
w^{M6266}			0.0375
w^{6774}	Defined as $1 - w^{1519} - w^{2024} - w^{K2561} - w^{K6266} - w^{M2561} - w^{M6266}$		0.0877
Steady-state			
L^{1519}			0.4064
L^{2024}			0.7202
L^{K2561}			0.8269
L^{K6266}			0.4232
L^{M2661}			0.8815
L^{M6266}			0.5462
L^{6774}			0.1245
c_1^{6774}	Calibrated to make SS-equation hold		-0.2686
c_1^{1519}	Calibrated to make SS-equation hold		-0.9274
c_1^{2024}	Calibrated to make SS-equation hold		-0.1851
c_1^{K2561}	Calibrated to make SS-equation hold		0.1804
c_1^{K6266}	Calibrated to make SS-equation hold		-0.0758
c_1^{M2661}	Calibrated to make SS-equation hold		0.2241
c_1^{M6266}	Calibrated to make SS-equation hold		0.0256
c_1^{6774}	Calibrated to make SS-equation hold		-0.2686
Other dynamic parameters grouped by age and gender			
c_2^{1519}	0.6178	c_3^{1519}	-0.1947
c_4^{1519}	0.1421	c_5^{1519}	-0.4061
c_6^{1519}	0.5254		
c_2^{2024}	0.3894	c_3^{2024}	0.1661
c_4^{2024}	-0.1933		
c_2^{K2561}	0.3324	c_3^{K2561}	-0.2511
c_4^{K2561}	-0.0694	c_5^{K2561}	0.0769
c_2^{K6266}	0.3902	c_3^{K6266}	0.3266
c_4^{K6266}	0.5024	c_5^{K6266}	-0.3227

c_2^{M2561}	0.5682	c_3^{M2561}	0.2667
c_4^{M2561}	0.2319	c_5^{M2561}	-0.1784
c_6^{M2561}	-0.2002		
c_2^{M6266}	0.3245	c_3^{M6266}	0.1791
c_4^{M6266}	0.4018	c_5^{M6266}	0.4917
c_6^{M6266}	-0.3696	c_7^{M6266}	-0.1759
c_2^{6774}	0.3805	c_3^{6774}	0.4739
c_4^{6774}	0.2308		

A.3 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

$$\frac{\partial}{\partial W}\Phi^{NP}(W) = \gamma\frac{\frac{\partial V}{\partial W}}{V - V_t^0} + (1-\gamma)\frac{\frac{\partial}{\partial W}\Pi_t^M}{\Pi_t^M} = 0 \tag{A.10}$$

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.[85]

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

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

[85] 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

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

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

Equation (A.10) 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.

$$\frac{\partial^2}{\partial W^2}\Phi^{NP}(W) < 0. \tag{A.11}$$

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 (A.10) holds again. This is because $\frac{\partial}{\partial W}\Phi^{NP}(W)$ falls with the wage, see equation (A.11).

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.[86]

A.4 Final good sector cost minimization

In the following, we will solve the cost minimization problem for the second stage of the final good sector for $Z_t \in \{I_t, G_t^C\}$. The cost minimization for the first stage in all the final good sectors 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 Lagrangian

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

Note, that the Lagrange multiplier is identified to be P_t^Z since the marginal cost (which is the economic interpretation of the Lagrange multiplier) equals the final good price due to perfect competition.

[86] 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.

1. $\frac{\partial \mathcal{L}}{\partial Z_t^M} = 0$ implies

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

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 firms (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.5 Export sector price setting

The Lagrangian of the problem of firm i in the export sector is

$$\mathcal{L}_t^X(i) = \sum_{\tau=t}^{\infty} \Delta_{t,\tau} \left\{ \left[\left(P_\tau^X(i) RER_\tau - MC_\tau^X \right) X_\tau(i) - AC_\tau^X(i) \right] + \lambda_\tau^X \left[\left(\frac{P_\tau^X(i)}{P_\tau^X} \right)^{-\epsilon_\tau^X} X_\tau - X_\tau(i) \right] \right\}$$

The first-order conditions with respect to the choice variables are then as follows:

1. $\frac{\partial \mathcal{L}_t^X(i)}{\partial X_t(i)} = 0$:

$$P_t^X(i) RER_t - MC_t^X = \lambda_t^X$$

2. $\frac{\partial \mathcal{L}_t^X(i)}{\partial P_t^X(i)} = 0$:

$$\Delta_{t,t}\left\{RER_t X_t(i) - \frac{\partial AC_t^X(i)}{\partial P_t^X(i)} + \lambda_t^X(-\epsilon_t^X)\left(\frac{P_t^X(i)}{P_t^X}\right)^{-\epsilon_t^X}\frac{P_t^X}{P_t^X(i)}\frac{1}{P_t^X}X_t\right\} - \Delta_{t,t+1}\frac{\partial AC_{t+1}^X(i)}{\partial P_t^X(i)} = 0$$

$$\Rightarrow \frac{\partial AC_t^X(i)}{\partial P_t^X(i)} = RER_t X_t(i) - \epsilon_t^X\left(P_t^X(i)RER_t - MC_t^X\right)\left(\frac{P_t^X(i)}{P_t^X}\right)^{-\epsilon_t^X}\frac{X_t}{P_t^X(i)} - \frac{\Delta_{t,t+1}}{\Delta_{t,t}}\frac{\partial AC_{t+1}^X(i)}{\partial P_t^X(i)}$$

$$\Rightarrow \frac{\partial AC_t^X(i)}{\partial P_t^X(i)} = RER_t X_t(i) - \epsilon_t^X\left(P_t^X(i)RER_t - MC_t^X\right)\frac{X_t(i)}{P_t^X(i)} - \frac{\Delta_{t,t+1}}{\Delta_{t,t}}\frac{\partial AC_{t+1}^X(i)}{\partial P_t^X(i)}$$

$$\Rightarrow DAC_t^X(i)X_t RER_t = (1-\epsilon_t^X)RER_t X_t(i) + \epsilon_t^X MC_t^X\frac{X_t(i)}{P_t^X(i)} + \frac{\Delta_{t,t+1}}{\Delta_{t,t}}DAC_{t+1}^X(i)\frac{P_{t+1}^X(i)}{P_t^X(i)}X_{t+1}RER_{t+1}$$

where

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

Since all firms arrive at this same optimal pricing equation, we can drop the firm index i to obtain:

$$DAC_t^X = 1 - \epsilon_t^X + \epsilon_t^X\frac{MC_t^X}{P_t^X RER_t} + \frac{\Delta_{t,t+1}}{\Delta_{t,t}}\frac{P_{t+1}^X X_{t+1}RER_{t+1}}{P_t^X X_t RER_t}DAC_{t+1}^X \tag{A.12}$$

A.6 The first-order conditions of firms in the manufacturing sector

The problem of firm i is given by the Lagrangian:

$$\begin{aligned}\mathcal{L}^M(i) = \sum_{t=0}^{\infty}\frac{1}{R_t^e}\Bigg\{&\Big[P_t^M(i)Y_t^M(i) - (1+\tau_t^{SSF})W_t N_t^M(i) - (R_{t-1}^L RP_{t-1}^{B,M} - 1)\frac{B_{t-1}^M(i)}{\pi_t^{ATE}}\\ &- \Big(AC_t^M(i) + AC_t^{Inv,M}(i) + AC_t^{BN,M}(i)\Big)\Big](1-\tau_t^{OIF})\\ &+ \delta_\tau P_t^I K_t^M(i)\tau_t^{OIF} + TD^{OIF}\tau_t^{OIF} - P_t^I Inv_t^M(i) + BN_t(i)\\ \\ &+ \lambda_t^{K,M}(i)\left[Inv_t^M(i)\exp\left(Z_t^{MEI}\right) + (1-\delta_{KP})K_t^M(i) - K_{t+1}^M(i)\right]\\ &+ \lambda_t^{B,M}(i)\left[BN_t^M(i) + \frac{1}{\pi_t^{ATE}}B_{t-1}^M(i) - B_t^M(i)\right]\\ &+ \lambda_t^{Y,M}(i)\left[\left(\frac{P_t^M(i)}{P_t^M}\right)^{-\epsilon_t^M}Y_t^M - Y_t^M(i)\right]\\ &+ \lambda_t^{Q,M}(i)\left[\left(\exp\left(Z_t^{Y^M}\right)\left(K_t^G\right)^{\kappa_M}\left(K_t^M(i)\right)^{\alpha_M}\left(N_t^M(i)\right)^{1-\alpha_M} - FC^M\right) - Y_t^M(i)\right]\Bigg\}\end{aligned}$$

1. $\frac{\partial \mathcal{L}^M(i)}{\partial N_t^M(i)} = 0$ yields

$$\frac{1}{R_t^e}\left\{-(1-\tau_t^{OIF})(1+\tau_t^{SSF})W_t + \lambda_t^{Q,M}(i)\frac{\partial Y_t^M(i)}{\partial N_t^M(i)}\right\} = 0$$

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

2. $\frac{\partial \mathcal{L}^M(i)}{\partial Inv_t^M(i)} = 0$ yields

$$-\frac{(1-\tau_t^{OIF})}{R_t^e}\frac{\partial AC_t^{Inv,M}(i)}{\partial Inv_t^M(i)} - \frac{P_t^I}{R_t^e} + \frac{\lambda_t^{K,M}(i)}{R_t^e}\exp\left(Z_t^{MEI}\right) - \frac{(1-\tau_{t+1}^{OIF})}{R_{t+1}^e}\frac{\partial AC_{t+1}^{Inv,M}(i)}{\partial Inv_t^M(i)} = 0$$

$$\Rightarrow\ \frac{\partial AC_t^{Inv,M}(i)}{\partial Inv_t^M(i)} = \frac{\lambda_t^{K,M}(i)\exp\left(Z_t^{MEI}\right) - P_t^I}{1-\tau_t^{OIF}} - \frac{1}{DF_{t+1}^{DIV}}\frac{(1-\tau_{t+1}^{OIF})}{(1-\tau_t^{OIF})}\frac{\partial AC_{t+1}^{Inv,M}(i)}{\partial Inv_t^M(i)}$$

$$\Rightarrow\ DAC_t^{Inv,M}(i)P_t^I = \frac{\lambda_t^{K,M}(i)\exp\left(Z_t^{MEI}\right) - P_t^I}{1-\tau_t^{OIF}} + \frac{1}{DF_{t+1}^{DIV}}\frac{(1-\tau_{t+1}^{OIF})Inv_{t+1}^M(i)}{(1-\tau_t^{OIF})Inv_t^M(i)}DAC_{t+1}^{Inv,M}(i)P_{t+1}^I$$

where the variable $DAC_t^{Inv,M}(i)$ is defined by:

$$DAC_t^{Inv,M}(i) = \frac{1}{P_t^I}\frac{\partial AC_t^{Inv,M}(i)}{\partial Inv_t^M(i)} = \chi_{Inv}\left(\frac{Inv_t^M(i)}{Inv_{t-1}^M(i)} - 1\right)\frac{Inv_t^M}{Inv_{t-1}^M(i)}$$

All firms choose the same investment, so we can drop the i's and write in terms of aggregate variables:

$$DAC_t^{Inv,M} = \frac{\lambda_t^{K,M}\exp\left(Z_t^{MEI}\right) - P_t^I}{(1-\tau_t^{OIF})P_t^I} + \frac{1}{DF_{t+1}^{DIV}}\frac{(1-\tau_{t+1}^{OIF})P_{t+1}^I Inv_{t+1}^M}{(1-\tau_t^{OIF})P_t^I Inv_t^M}DAC_{t+1}^{Inv,M} \tag{A.13}$$

3. $\frac{\partial \mathcal{L}^M(i)}{\partial K_{t+1}^M(i)} = 0$ yields

$$-\frac{\lambda_t^{K,M}(i)}{R_t^e} + \frac{\delta_\tau}{R_{t+1}^e}P_{t+1}^I\tau_{t+1}^{OIF} + \frac{\lambda_{t+1}^{K,M}(i)}{R_{t+1}^e}(1-\delta_{KP}) + \frac{\lambda_{t+1}^{Q,M}(i)}{R_{t+1}^e}\frac{\partial Y_{t+1}^M(i)}{\partial K_{t+1}^M(i)} = 0$$

$$\Rightarrow\ \lambda_t^{K,M}(i)DF_{t+1}^{DIV} = \delta_\tau P_{t+1}^I\tau_{t+1}^{OIF} + \lambda_{t+1}^{K,M}(i)(1-\delta_{KP}) + \lambda_{t+1}^{Q,M}(i)\alpha_M\frac{Y_{t+1}^M(i)+FC^M}{K_{t+1}^M(i)} = 0 \tag{A.14}$$

4. $\frac{\partial \mathcal{L}^M(i)}{\partial BN_t^M(i)} = 0$ yields

$$-\frac{(1-\tau_t^{OIF})}{R_t^e}\frac{\partial AC_t^{BN,M}(i)}{\partial BN_t^M(i)} + \frac{1}{R_t^e} + \frac{\lambda_t^{B,M}(i)}{R_t^e} - \frac{(1-\tau_{t+1}^{OIF})}{R_{t+1}^e}\frac{\partial AC_{t+1}^{BN,M}(i)}{\partial BN_t^M(i)} = 0$$

$$\Rightarrow\ \lambda_t^{B,M}(i) = -1 + (1-\tau_t^{OIF})DAC_t^{BN,M}(i) - \frac{(1-\tau_{t+1}^{OIF})}{DF_{t+1}^{DIV}}DAC_{t+1}^{BN,M}(i)\frac{BN_{t+1}^M(i)}{BN_t^M(i)}$$

$$\Rightarrow\ DAC_t^{BN,M}(i) = \frac{\lambda_t^{B,M}(i)+1}{(1-\tau_t^{OIF})} + \frac{1}{DF_{t+1}^{DIV}}\frac{(1-\tau_{t+1}^{OIF})}{(1-\tau_t^{OIF})}\frac{BN_{t+1}^M(i)}{BN_t^M(i)}DAC_{t+1}^{BN,M}(i) \tag{A.15}$$

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

5. $\frac{\partial \mathcal{L}^M(i)}{\partial B_t^M(i)} = 0$ yields

$$\begin{aligned} -\frac{\lambda_t^{B,M}(i)}{R_t^e} - \frac{(1-\tau_{t+1}^{OIF})}{R_{t+1}^e}(R_t^L RP_t^{B,M}-1)\frac{1}{\pi_{t+1}^{ATE}} + \frac{\lambda_{t+1}^{B,M}(i)}{R_{t+1}^e}\frac{1}{\pi_{t+1}^{ATE}} = 0 \\ \Rightarrow\ \lambda_t^{B,M}(i) = \frac{1}{DF_{t+1}^{DIV}\pi_{t+1}^{ATE}}\left(\lambda_{t+1}^{B,M}(i) - (1-\tau_{t+1}^{OIF})(R_t^L RP_t^{B,M}-1)\right) \end{aligned}$$

In the absence of new borrowing adjustment costs ($\lambda_t^{B,M}(i) = -1$ from equation (A.15)) it holds that

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

which is equation (2.47).

6. $\frac{\partial \mathcal{L}^M(i)}{\partial P_t^M(i)} = 0$:

$$\frac{Y_t^M(i)(1-\tau_t^{OIF})}{R_t^e} - \frac{(1-\tau_t^{OIF})}{R_t^e}\frac{\partial AC_t^M(i)}{\partial P_t^M(i)} + \frac{\lambda_t^{Y,M}(i)}{R_t^e}(-\epsilon_t^M)\left(\frac{P_t^M(i)}{P_t^M}\right)^{-\epsilon_t^M-1}\frac{Y_t^M}{P_t^M} - \frac{(1-\tau_{t+1}^{OIF})}{R_{t+1}^e}\frac{\partial AC_{t+1}^M(i)}{\partial P_t^M(i)} = 0$$

$$\begin{aligned} \Rightarrow\ & Y_t^M(i)(1-\tau_t^{OIF}) - (1-\tau_t^{OIF})\frac{\partial AC_t^M(i)}{\partial P_t^M(i)} \\ & + \lambda_t^{Y,M}(i)(-\epsilon_t^M)Y_t^M(i)\left(\frac{P_t^M(i)}{P_t^M}\right)^{-1}\frac{1}{P_t^M} - \frac{(1-\tau_{t+1}^{OIF})}{DF_{t+1}^{DIV}}\frac{\partial AC_{t+1}^M(i)}{\partial P_t^M(i)} = 0 \end{aligned}$$

$$\Rightarrow\ \lambda_t^{Y,M}(i) = \frac{P_t^M(i)}{\epsilon_t^M Y_t^M(i)}\left(Y_t^M(i)(1-\tau_t^{OIF}) - (1-\tau_t^{OIF})\frac{\partial AC_t^M(i)}{\partial P_t^M(i)} - \frac{(1-\tau_{t+1}^{OIF})}{DF_{t+1}^{DIV}}\frac{\partial AC_{t+1}^M(i)}{\partial P_t^M(i)}\right) \tag{A.16}$$

7. $\frac{\partial \mathcal{L}^M(i)}{\partial Y_t^M(i)} = 0$:

$$\begin{aligned} \frac{1}{R_t^e}\left(P_t^M(i)(1-\tau_t^{OIF}) - \lambda_t^{Y,M}(i) - \lambda_t^{Q,M}(i)\right) = 0 \\ \Rightarrow\ \lambda_t^{Y,M}(i) = P_t^M(i)(1-\tau_t^{OIF}) - \lambda_t^{Q,M}(i) \end{aligned} \tag{A.17}$$

8. The pricing equation — Combining equations (A.16) and (A.17) we get:

$$P_t^M(i)(1-\tau_t^{OIF}) - \lambda_t^{Q,M}(i) = \frac{P_t^M(i)(1-\tau_t^{OIF})}{\epsilon_t^M} - \frac{P_t^M(i)}{\epsilon_t^M Y_t^M(i)}(1-\tau_t^{OIF})\frac{\partial AC_t^M(i)}{\partial P_t^M(i)} - \frac{P_t^M(i)}{\epsilon_t^M Y_t^M(i)}\frac{(1-\tau_{t+1}^{OIF})}{DF_{t+1}^{DIV}}\frac{\partial AC_{t+1}^M(i)}{\partial P_t^M(i)}$$

$$\Rightarrow \quad \frac{1}{Y_t^M(i)}\frac{\partial AC_t^M(i)}{\partial P_t^M(i)} = 1 - \epsilon_t^M + \frac{\epsilon_t^M}{P_t^M(i)(1-\tau_t^{OIF})}\lambda_t^{Q,M}(i) - \frac{1}{DF_{t+1}^{DIV}}\frac{1-\tau_{t+1}^{OIF}}{1-\tau_t^{OIF}}\frac{1}{Y_t^M(i)}\frac{\partial AC_{t+1}^M(i)}{\partial P_t^M(i)}$$

For simplicity we introduce

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

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

$$DAC_t^M = 1 - \epsilon_t^M + \frac{\epsilon_t^M}{P_t^M(1-\tau_t^{OIF})}\lambda_t^{Q,M} + \frac{1}{DF_{t+1}^{DIV}}\frac{1-\tau_{t+1}^{OIF}}{1-\tau_t^{OIF}}\frac{P_{t+1}^M Y_{t+1}^M}{P_t^M Y_t^M}DAC_{t+1}^M \tag{A.18}$$

9. Finally, we can derive an expression for the implied (after-tax) rental rate on capital as in Sandmo (1974). To do so, we set investment and price adjustment costs to zero and assume a constant price of the investment good.[87] Equation (A.13) then implies that the marginal value of capital equals the price of the investment good, so that $\lambda_t^{K,M} = P_t^I = P^I$. From equation (A.18) we obtain the expression $\lambda_t^{Q,M} = \frac{\epsilon_t^M - 1}{\epsilon_t^M}P_t^M(1-\tau_t^{OIF})$. Inserting these expressions into equation (A.14), we obtain:

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

which is equation (2.46).

A.7 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

[87] These are the same simplifying assumptions as in Sandmo (1974).

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, returns on equity are then double-taxed, whereas the return on other financial assets in form of deposits is only taxed once, at the ordinary income tax rate.[88] 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:

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

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.[89] The second component equals the rate of return on deposits. The set-up of the ordinary income tax base, see equation (2.4) 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 $\tau_t^{OIF}=\tau_t^{OIH}$, then

- The stream of dividends is discounted at the same rate as the stream of other income of households. Hence, firms discount the future in the same way as households.
- The blow-up factor 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

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

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

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

Using the first-order condition for deposits, equation (A.1), 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 (2.47), 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.8 Import sector price setting

The Lagrangian of the problem for individual importing firm i:

$$
\mathcal{L}_t^{IM}(i) = \sum_{\tau=t}^{\infty} \Delta_{t,\tau} \Big\{ \left[\left(P_\tau^{IM}(i) - RER_\tau\right) IM_\tau(i) - AC_\tau^{IM}(i) \right] + \lambda_\tau^{IM} \left[\left(\frac{P_\tau^{IM}(i)}{P_\tau^{IM}} \right)^{-\epsilon_\tau^{IM}} IM_\tau - IM_\tau(i) \right] \Big\}
$$

The first-order conditions with respect to the choice variables are then as follows:

1. $\frac{\partial \mathcal{L}_t^{IM}(i)}{\partial IM_t(i)} = 0$:

$$
P_t^{IM}(i) - RER_t = \lambda_t^{IM}
$$

2. $\frac{\partial \mathcal{L}_t^{IM}(i)}{\partial P_t^{IM}(i)} = 0$:

$$\Delta_{t,t}\left\{IM_t(i) - \frac{\partial AC_t^{IM}(i)}{\partial P_t^{IM}(i)} + \lambda_t^{IM}(-\epsilon_t^{IM})\left(\frac{P_t^{IM}(i)}{P_t^{IM}}\right)^{-\epsilon_t^{IM}}\frac{P_t^{IM}}{P_t^{IM}(i)}\frac{1}{P_t^{IM}}IM_t\right\} - \Delta_{t,t+1}\frac{\partial AC_{t+1}^{IM}(i)}{\partial P_t^{IM}(i)} = 0$$

$$\Rightarrow \frac{\partial AC_t^{IM}(i)}{\partial P_t^{IM}(i)} = IM_t(i) - \epsilon_t^{IM}(P_t^{IM}(i) - RER_t)\left(\frac{P_t^{IM}(i)}{P_t^{IM}}\right)^{-\epsilon_t^{IM}}\frac{IM_t}{P_t^{IM}(i)} - \frac{\Delta_{t,t+1}}{\Delta_{t,t}}\frac{\partial AC_{t+1}^{IM}(i)}{\partial P_t^{IM}(i)}$$

$$\Rightarrow \frac{\partial AC_t^{IM}(i)}{\partial P_t^{IM}(i)} = IM_t(i) - \epsilon_t^{IM}(P_t^{IM}(i) - RER_t)\frac{IM_t(i)}{P_t^{IM}(i)} - \frac{\Delta_{t,t+1}}{\Delta_{t,t}}\frac{\partial AC_{t+1}^{IM}(i)}{\partial P_t^{IM}(i)}$$

$$\Rightarrow DAC_t^{IM}(i)IM_t = (1-\epsilon_t^{IM})IM_t(i) + \epsilon_t^{IM}RER_t\frac{IM_t(i)}{P_t^{IM}(i)} + \frac{\Delta_{t,t+1}}{\Delta_{t,t}}DAC_{t+1}^{IM}(i)\frac{P_{t+1}^{IM}(i)}{P_t^{IM}(i)}IM_{t+1}$$

where

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

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

$$DAC_t^{IM} = 1 - \epsilon_t^{IM} + \epsilon_t^{IM}\frac{RER_t}{P_t^{IM}} + \frac{\Delta_{t,t+1}}{\Delta_{t,t}}\frac{P_{t+1}^{IM}IM_{t+1}}{P_t^{IM}IM_t}DAC_{t+1}^{IM} \tag{A.19}$$

A.9 Törnqvist index

The total value of domestic production is given by

$$\begin{aligned} P_t^{Nom,Y}Y_t^D &= P_t^{Nom,M}Y_t^M + P_t^{Nom,S}Y_t^S + P_tVA_t^XX_t, \text{ or equivalently} \\ P_t^YY_t^D &= P_t^MY_t^M + P_t^SY_t^S + VA_t^XX_t \end{aligned}$$

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

$$\begin{aligned} P_t^{Nom,Y} &= \left(P_t^{Nom,M}/P_{0,ss}^{Nom,M}\right)^{\left(\left[\frac{VAM_t}{TVA_t}+\frac{VAM_{0,ss}}{TVA_{0,ss}}\right]/2\right)}\left(P_t^{Nom,S}/P_{0,ss}^{Nom,S}\right)^{\left(\left[\frac{VAS_t}{TVA_t}+\frac{VAS_{0,ss}}{TVA_{0,ss}}\right]/2\right)} \\ &\quad \times\left(P_tVA_t^X/(P_{0,ss}VA_{0,ss}^X)\right)^{\left(\left[s_t^X+s_{0,ss}^X\right]/2\right)} \end{aligned}$$

where $\frac{VAM_t}{TVA_t}$ denotes the share of value added in the manufacturing sector, i.e. $\frac{VAM_t}{TVA_t} = (P_t^MY_t^M)/(P^YY_t^D)$, and $\frac{VAS_t}{TVA_t}$ the share of value added in the service sector, i.e. $\frac{VAS_t}{TVA_t} = (P_t^SY_t^S)/(P^YY_t^D)$.[90] Consequently,

[90]The expression can equivalently be expressed as

$$\Delta\log(P_t^Y) = \left(\left[\frac{VAM_t}{TVA_t}+\frac{VAM_{0,ss}}{TVA_{0,ss}}\right]/2\right)\Delta\log(P_t^M) + \left(\left[\frac{VAS_t}{TVA_t}+\frac{VAS_{0,ss}}{TVA_{0,ss}}\right]/2\right)\Delta\log(P_t^S) + \left(\left[s_t^X+s_{0,ss}^X\right]/2\right)\Delta\log(P_tVA_t^X)$$

where $\Delta log(X_t) = log(X_t) - log(X_{0,ss})$.

$s_t^X = 1 - \frac{VAM_t}{TVA_t} - \frac{VAS_t}{TVA_t}$. The notation $X_{0,ss}$ denotes the base-year value of X. We set the base year to the initial steady state, and this is kept fixed even if a policy change leads to a new steady state. It can be easily verified, that the relationship also holds for real prices (under the assumption that $P_{0,ss} = 1$), i.e:

$$P_t^Y = \left(P_t^M / P_{0,ss}^M\right)^{\left(\left[\frac{VAM_t}{TVA_t} + \frac{VAM_{0,ss}}{TVA_{0,ss}}\right]/2\right)} \left(P_t^S / P_{0,ss}^S\right)^{\left(\left[\frac{VAS_t}{TVA_t} + \frac{VAS_{0,ss}}{TVA_{0,ss}}\right]/2\right)} \left(VA_t^X / VA_{0,ss}^X\right)^{\left(\left[s_t^X + s_{0,ss}^X\right]/2\right)}.$$

A.10 Derivation of the market clearing condition

In the following we derive the goods market clearing, starting from the budget constraint of Ricardian households given by equation (2.5), expressed in real terms. Note, that we drop the expectation operator everywhere to simplify notation.

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

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 (2.10), we obtain

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

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 (2.9), which yields

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

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

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

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 (2.54), which yields

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

We now use definition of T_t in (2.52) 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 (2.53) and obtain

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

Using the definition of Π_t^C from (2.36) we obtain

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

Using the relationship between dividends and profits given in equation (2.42), as well as the definition of profits in equation (2.41), yields

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

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 (2.17) to derive

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

Cancelling the government debt terms as well as using the definition of retained profits in (2.43), as well as the new borrowing equation in (2.39), we obtain

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

Ignoring the expectation in equation (2.19), we use $R_t^L = R_t$ and can simplify to

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

Using the definition of Π_t^B ($\Pi_t^B = \frac{B_{t-1}^M}{\pi_t^{ATE}} R_{t-1}^L (RP_{t-1}^{B,M} - 1) + \frac{B_{t-1}^S}{\pi_t^{ATE}} R_{t-1}^L (RP_{t-1}^{B,S} - 1)$) we obtain

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

Using the definition of Π_t^X in equation (2.34) and the definition of total output from equation (2.65) yields

$$\begin{aligned}-RER_t B_t^F &= 1/\pi_t^{ATE}(-RER_{t-1}B_{t-1}^F)R_{t-1}^L + P_t^Y Y_t^D \\ &-P_t^I(Inv_t^M + Inv_t^S + Inv_t^H + G_t^I) + OFW_t - P_t^{G^C} G_t^C - P_t^{IM} IM_t^{Res} - C_t - AC_t\end{aligned}$$

where $AC_t = AC_t^M + AC_t^S + AC_t^{Inv} + AC_t^{BN} + AC_t^X + AC_t^C$ captures the entirety of adjustment costs in the model economy. We now use the balance of payments equation (2.67) as well as the UIP condition in equation (2.20) which yields

$$\begin{aligned}NX_t + OFW_t + P_t^I Inv_t^{Oil} = P_t^Y Y_t^D - P_t^I(Inv_t^M + Inv_t^S + Inv_t^H + G_t^I) + OFW_t \\ - P_t^{G^C} G_t^C - P_t^{IM} IM_t^{Res} - C_t - AC_t\end{aligned}$$

which after rearranging gives

$$P_t^Y Y_t^D = C_t + NX_t + P_t^I I_t + P_t^{G^C} G_t^C + AC_t + P_t^{IM} IM_t^{Res}.$$

A.11 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

$$\pi^{ATE} = \pi_{ss}^{ATE}$$
$$\pi^{TP} = \pi_{ss}^{TP}$$

   where π_{ss}^{ATE} and π_{ss}^{TP} are given by empirical targets described in Section 3.

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

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

   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 (2.31)

for the final consumption good sector yields (remembering that $MC_t^C = 1$ 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 (2.32), 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 (2.21), 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 equation (2.22), 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, (A.19), that

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

Using the optimal home good pricing equation, (A.18), we derive the steady-state shadow value of production as

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

and the steady-state value of capital using equation (A.13) 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 (A.12), we obtain

$$P_x = \frac{\epsilon_X}{\epsilon_X - 1}\frac{MC^x}{RER}$$

where $MC^x = 1$ as follows from equation (2.33). 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 (A.1) 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 (2.20) 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 (2.19) 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 (2.38), 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 (2.47), 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 (2.40) 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.[91] Using equation (A.14), we then obtain in steady state that

$$\begin{aligned} \lambda_t^{K,M} DF^{DIV} &= \tau^{OIF}\delta_\tau P^I + \lambda_t^{K,M}(1 - \delta_{KP}) + \lambda^{Y,M}\alpha_M \frac{Y^M + FC^M}{K^M} \\ \lambda_t^{K,M}(DF^{DIV} - 1 + \delta_{KP}) - \tau^{OIF}\delta_\tau P^I &= \lambda^{Y,M}\alpha_M \frac{Y^M + FC^M}{K^M} \\ \underbrace{\lambda_t^{K,M}(DF^{DIV} - 1 + \delta_{KP}) - \tau^{OIF}\delta_\tau P^I}_{=\theta_{K,M}} &= \lambda^{Y,M}\alpha_M \frac{Y^M}{K^M}(1 + \frac{FC^M}{Y^M}) \end{aligned} \tag{A.20}$$

Rearranging the first-order condition for labor demand, equation (2.45), 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 (A.20) 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 (A.20). This choice of the parameters then ensures that manufacturing firms have the capital to output ratio as well as labor

[91] 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.

share as found in the data. Since we assume the same capital to output ratio in the service sector and the same markup it holds that $\alpha_M = \alpha_S$.

Dividing the steady-state version of equation (2.45) by equation (A.20), we obtain

$$\frac{W}{\theta_{K,M}} = \frac{1}{(1-\tau^{OIF})(1+\tau^{SSF})} \frac{(1-\alpha_M)}{\alpha_M} \frac{K^M}{N^M} \tag{A.21}$$

From the steady-state version of equation (2.37), we obtain

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

Using this and equation (A.21) 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.[92] 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 Section 3, 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 (2.45), 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 (2.45) 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 manufacturing 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 $X = \frac{P^X RERX}{Y^{CPI}} Y^{CPI} / (P^X RER)$. Using equation (2.30), 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

[92]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.

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 (2.7), 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 (2.15) holds in steady state.

15. **Liquidity-constraint budget constraint:** As mentioned above, we are assuming that $C = C^L = C^R$ (in the steady state only). To ensure this is the case, we choose lump-sum transfers to liquidity-constraint households, TR^L, in such a way, that $C^L = C$. Following the aggregation rules, it then follows $C^R = C^L = C$. Using an empirical aggregate transfer to GDP-ratio, TR/Y^{CPI}, we set $TR = (TR/Y^{CPI})Y^{CPI}$. Using the aggregation equation (2.10), 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 (2.67) 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 (2.54) can then be resolved to obtain T^L, since all other components of the budget constraint are known at this point.

B. Calibration

This section lists data used in the calibration exercise. In particular, Table B.1 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 B.2 and B.3. 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 B.1, the second column of Table B.2 provide the formula to calculate the empirical ratio in the first column. Table B.3 describe how to obtain the empirical counterpart to the model's tax revenues and tax bases.

Table B.1 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		

Table B.1 Data sources

Category/Units	Variable description	Variable code
	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		
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 B.1 Data sources

Category/Units	Variable description	Variable code
Table 10644 Foreign assets and liabilities		
Foreign assets, stock		
	Sum total	$FA3$
	Portfolio investment, general government (GG)	$FA32101RS3$
	Investment Fund shares, GG	$FA32102RS3$
	Debt securities, short-term, GG	$FA322SRS3$
	Debt securities, long-term, GG	$FA322LRS3$
	Currency and deposits, GG	$FA342RS3$
	Loans, GG	$FA343RS3$
	Other accounts recievable/payable, GG	$FA346RS3$
	Reserve assets (IMF breakdown), GG	$FA35$
Liabilities, stock		
	Sum total	$FL3$
	Debt securities, short-term, GG	$FL322SRS3$
	Debt securities, long-term, GG	$FL322LRS3$
	Loans, GG	$FL343RS3$
	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		

Table B.1 Data sources

Category/Units	Variable description	Variable code
	Gross public debt in total	C_OFF999

Table B.2 Empirical great ratios.

Ratio	Formula
$P^C C/P^Y Y$	$koh.nrpriv/bnpb.nr23\_9fn$
$P^H C^H/P^Y Y$	$nr62bolig/bnpb.nr23\_9fn$
$P^{NH} C^{NH}/P^Y Y$	$(koh.nrpriv - nr62bolig)/bnpb.nr23\_9fn$
$P^I I^P/P^Y Y$	$bif.nr83\_6fnxof/bnpb.nr23\_9fn$
$P^I I^G/P^Y Y$	$bif.nr84\_5/bnpb.nr23\_9fn$
$P^I I^{Oil}/P^Y Y$	$bif.nr83oljroer/bnpb.nr23\_9fn$
$\delta_{KG} P^I K^G/P^Y Y$	$W3/bnpb.nr23\_9fn$
$P^{G^C} G^C/P^Y Y$	$(koo.nroff - B1 - W3)/bnpb.nr23\_9fn$
$(1+\tau^{SSF}) W^G N^G/P^Y Y$	$B1/bnpb.nr23\_9fn$
$P^X RERX/P^Y Y$	$(x.nrtradvare + x.puboljdiv + x.pubreise + x.nratjen)/bnpb.nr23\_9fn$
$P^{IM} IM/P^Y Y$	$im.nrtot/bnpb.nr23\_9fn$
$D/P^Y Y$	$C\_OFF999/bnpb.nr23\_9fn$
$B/P^Y Y$	$\left[\left(FA3 - \sum_{j\neq 3} FAj\right) - \left(FL3 - \sum_{i\neq 3} FLi\right)\right]/bnpb.nr23\_9fn$
$UB/P^Y Y$	$COF\_105/bnpb.nr23\_9fn$
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 B.3 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	$Z40$	$Z01$

B.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 3.1 describes how elasticities are set according to existing studies. To determine the share parameters, we have received significant assistance from colleagues in the KVARTS model team 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[93]

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.

[93]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.

B.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.[94] 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 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.[95,96] 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.

[94] 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.

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

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

C. Data series used in estimation

This section provides details on the data sources and the construction of the data series used in the estimation of the model.

C.1 Foreign variables

In order for the data to reflect the model structure, we implement a trade-weighting of relevant foreign variables. These are the ouput, interest rate and inflation rate of Norway's trading partners. To carry out this weighting, we get data derived from the Norwegian National Accounts on relative export shares from the KVARTS database. In KVARTS, these weights are used to construct an indicator, "Markedsindikatoren" (MI), that measures foreign demand for Norwegian goods and services. To work with the best data availability, we focus on the six largest trading partners, who account for 80–95 per cent of the total exports going into MI depending on the time-period.[97] The quarterly variation in the weights is noisy and we thus use fixed weights set to be the average across the 1999Q1–2019Q4 sample. These weights are reported in Table C.1.

[97] The countries included in the MI indicator in KVARTS are the Eurozone, the USA, the UK, Sweden, Denmark, Poland, Russia, China, Japan, and Korea. We exclude the last four of these countries in our trade-weighted series.

Figure C.1 Data and trends used to construct estimation data for the foreign block.

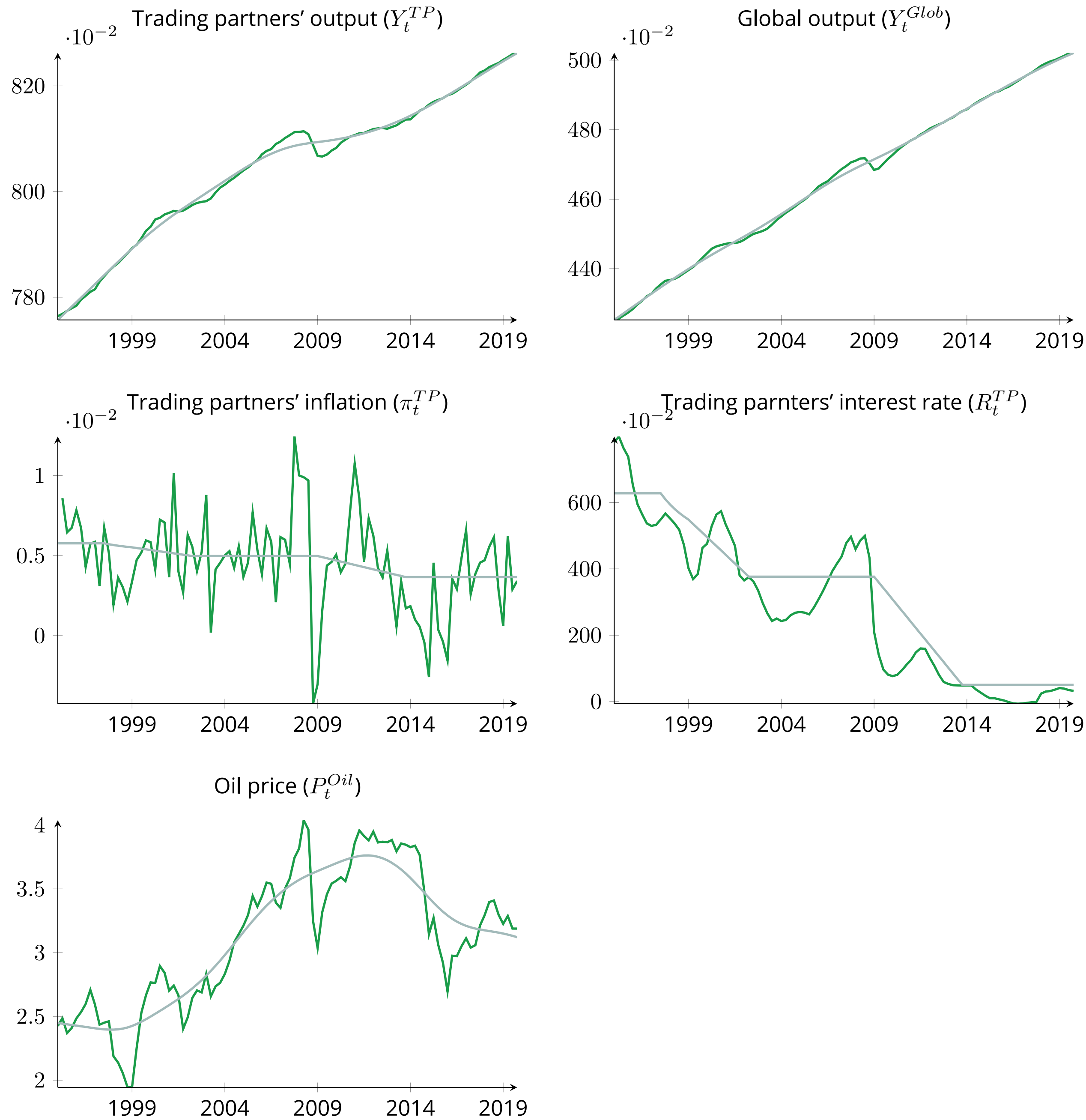
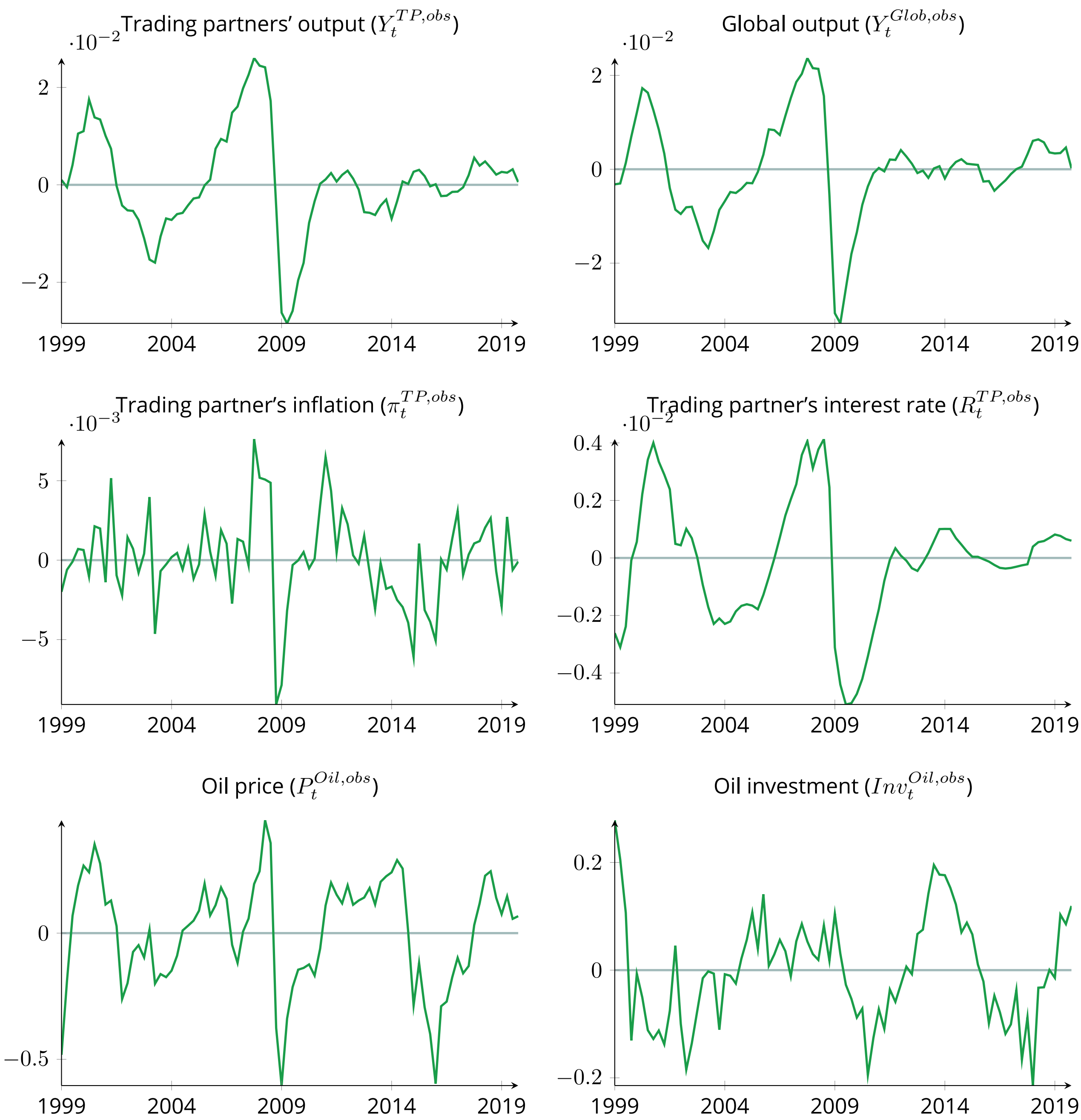


Figure C.2 Gap-variables used in the estimation of the foreign block.



Generally, the real foreign observables are constructed by detrending the log of the data series by a two-sided Hodrick Prescott (HP) filter with smoothing parameter $\lambda = 1600$ and then demeaning the detrended series. The nominal variables are detrended by subtracting the means, but we allow for breakpoints on 1998Q1 and 2009Q3. The main reason for this is that different time periods are characterized by very different means in series such as the interest rate and inflation. This is particularly true for the periods before and after the financial crisis in 2008. To smooth out the breakpoints, we apply a moving average transformation using a 4 year window. The real price of oil is detrended using the HP-filter. All gaps are demeaned before estimation. The series we use to estimate the foreign block are:

- *Trading partners' output* ($Y_t^{TP,obs}$): Seasonally adjusted total gross domestic product constant prices (2015 as base year) in local currencies from the OECD Main Economic Indicators (MEI) national accounts database. To get in common currency, we use the purchasing power parities (PPP) for GDP measured in national currency per U.S. dollar for 2015. Series are then trade-weighted according to Table C.1.

- *Global output* ($Y_t^{Glob,obs}$): Our starting point is the Index for global GDP (excl. U.S. and Norway) constructed by the Federal Reserve Bank of Dallas' Database of Global Economic Indicators (DGEI) project. We obtain a global index that includes the United States by re-weighting this index using the separate indices for the United States and advanced economies as well as the weights in the DGEI documentation.

- *Trading partners' inflation* ($\pi_t^{TP,obs}$): CPI inflation series for trading partner countries from the latest OECD Economic Outlook publication (harmonized CPI for the United Kingdom). Trade-weighted according to Table C.1.

- *Trading partners' short-term nominal interest rate* ($R_t^{TP,obs}$): Short-term nominal interest rate from the latest OECD Economic Outlook publication. Trade-weighted according to Table C.1.

- *Oil price* ($P_t^{Oil,obs}$): The Brent Crude oil price (`POILBREUSDQ`) from the Federal Reserve Economic Data database at the Federal Reserve Bank of St.Louis. The series is deflated by U.S. CPI (`CPIAUCSL`) from the same source.

- *Oil investment* ($Inv_t^{Oil,obs}$): 'Extraction and transport via pipelines (GFCF)' series of gross fixed capital formation in Table 09190 'Final expenditure and gross domestic product' of the Norwegian quarterly national accounts. Seasonally adjusted at constant prices. Retrieved from the website of Statistics Norway.

Table C.1 Export weights

Country	Weight	Share of MI	Country	Weight	Share of MI
Eurozone	0.50	0.44	United States	0.11	0.10
Sweden	0.15	0.13	Denmark	0.08	0.07
United Kingdom	0.12	0.11	Poland	0.03	0.03

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

Figure C.3 **Data and trends used to construct estimation data for the domestic block.**

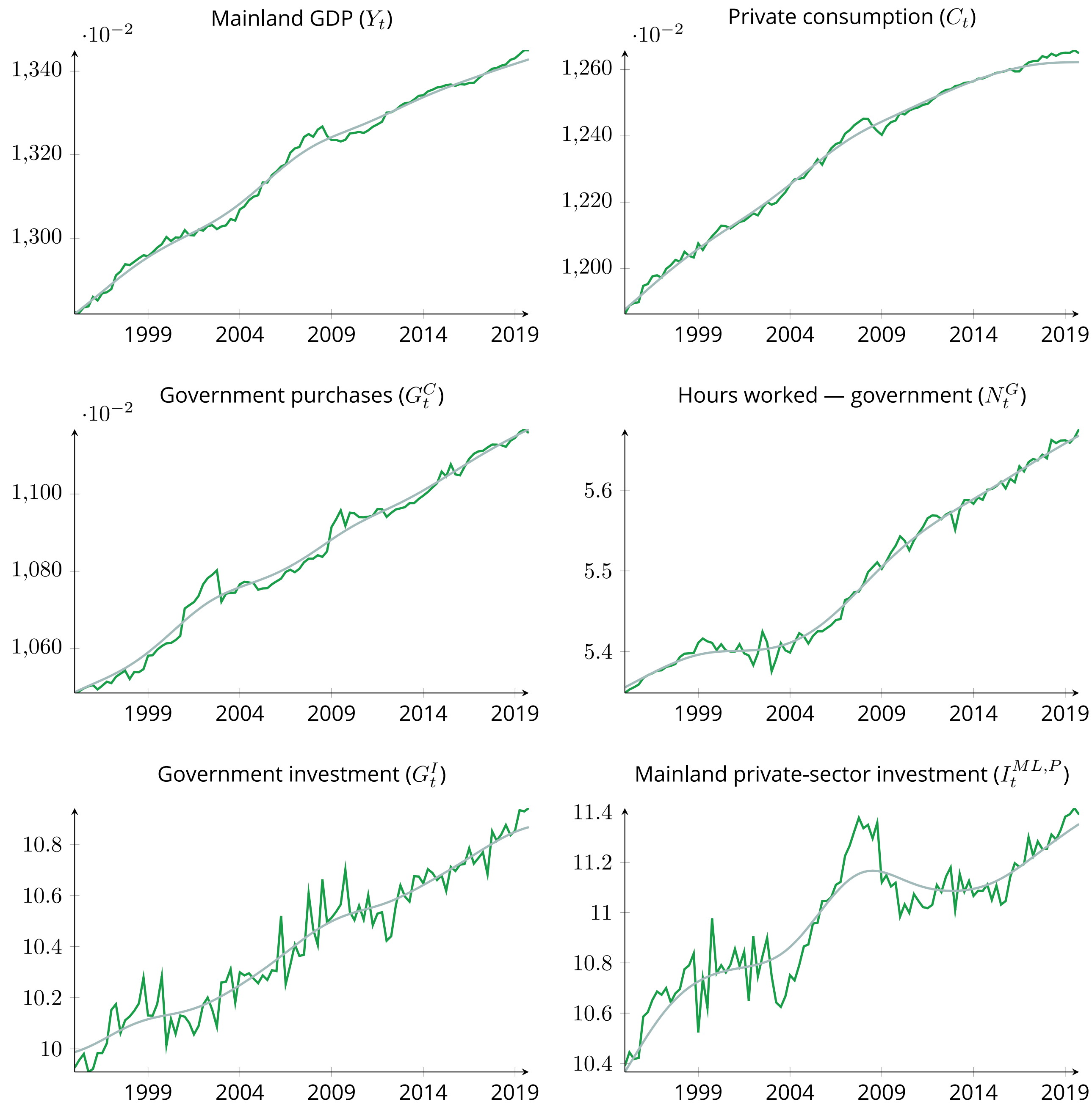


Figure C.3 **Data and trends used to construct estimation data for the domestic block. (continued)**

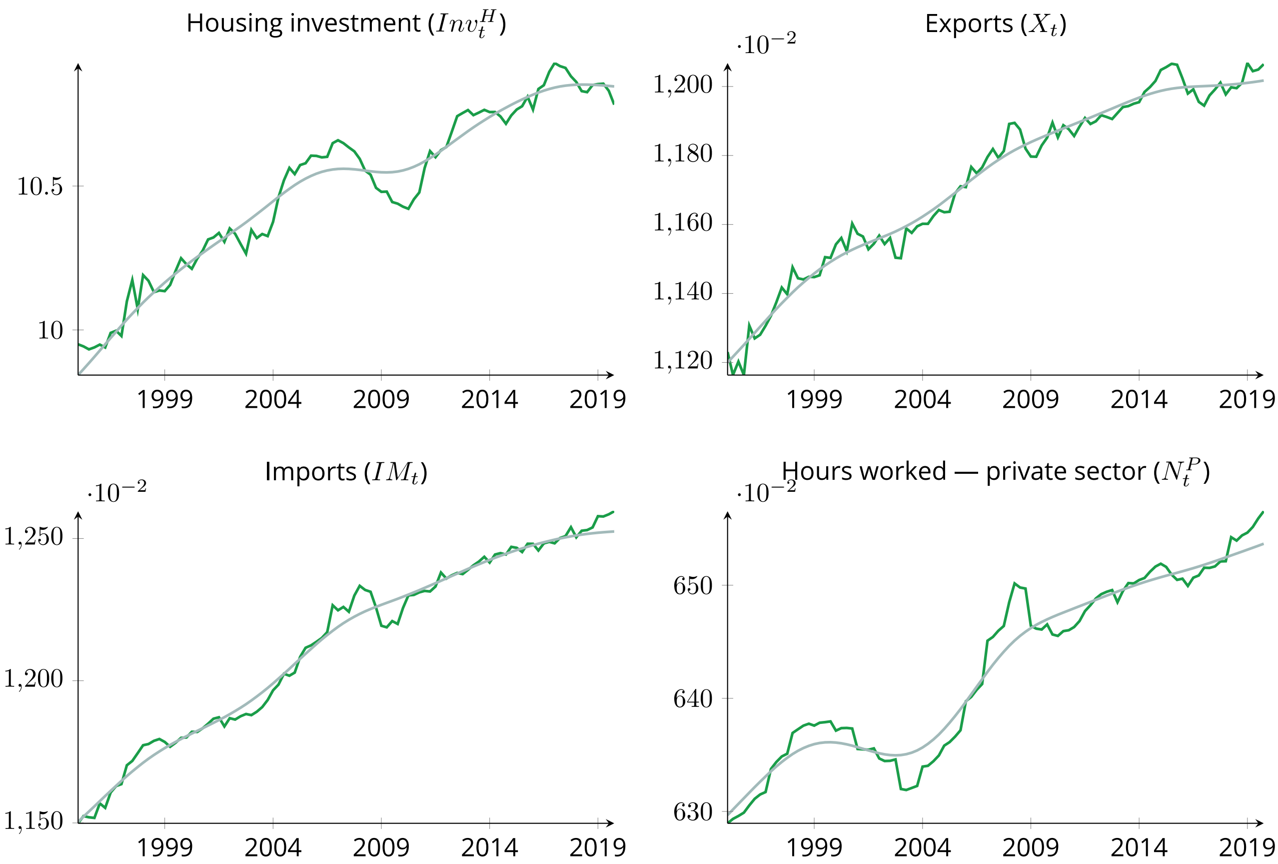


Figure C.3 **Data and trends used to construct estimation data for the domestic block. (continued)**

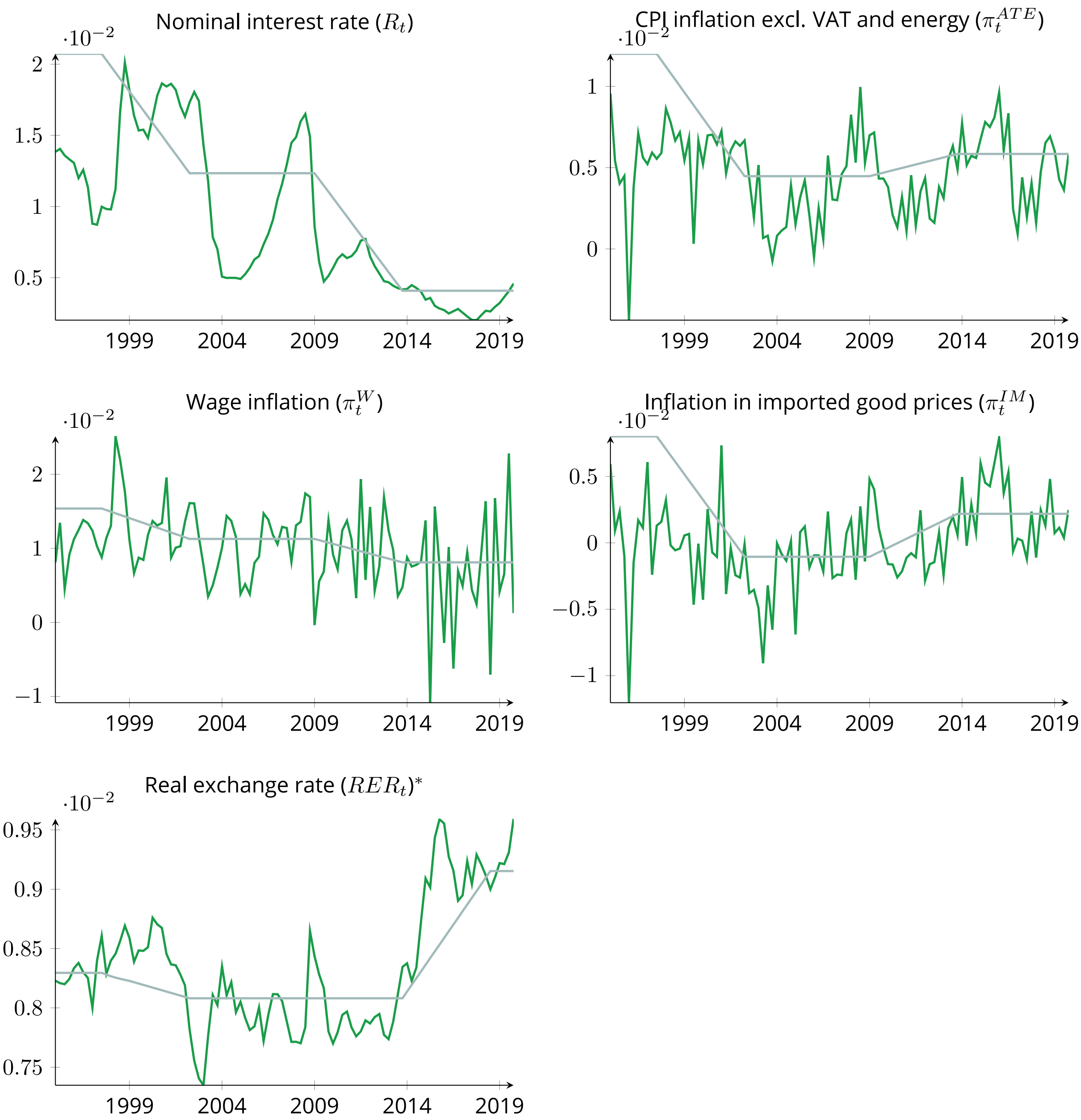


Figure C.4 Gap-variables used in the estimation of the domestic block.

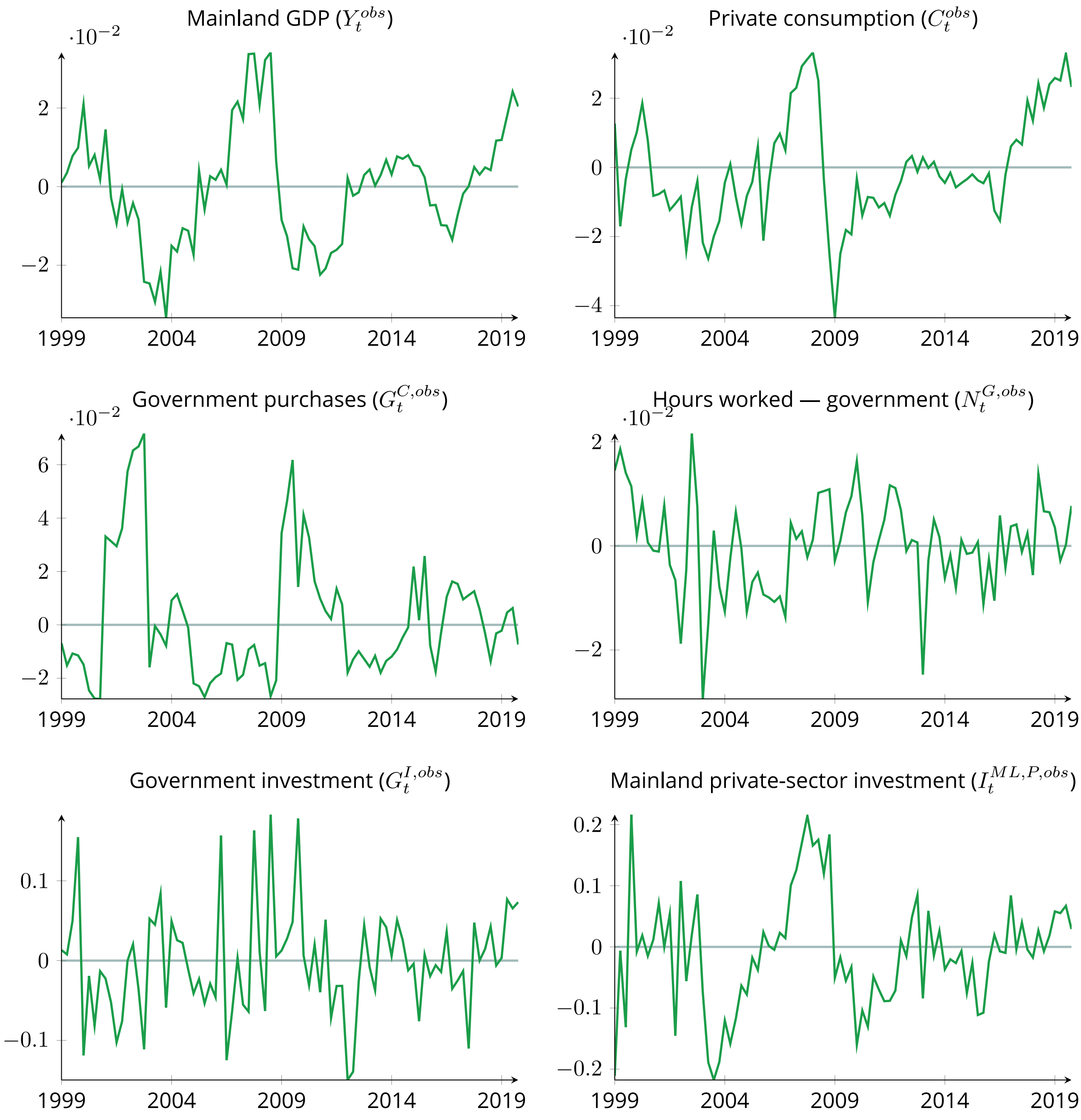
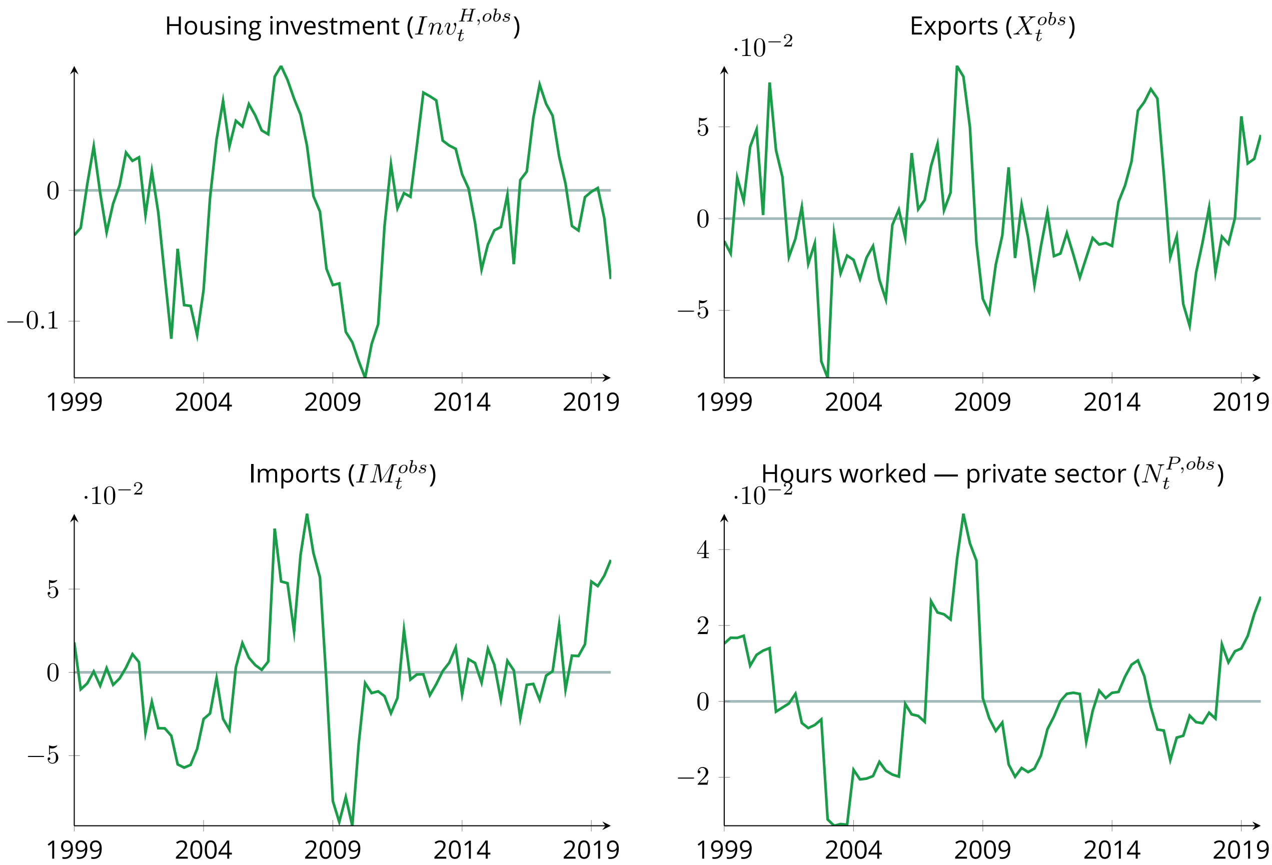


Figure C.4 Gap-variables used in the estimation of the domestic block. (continued)

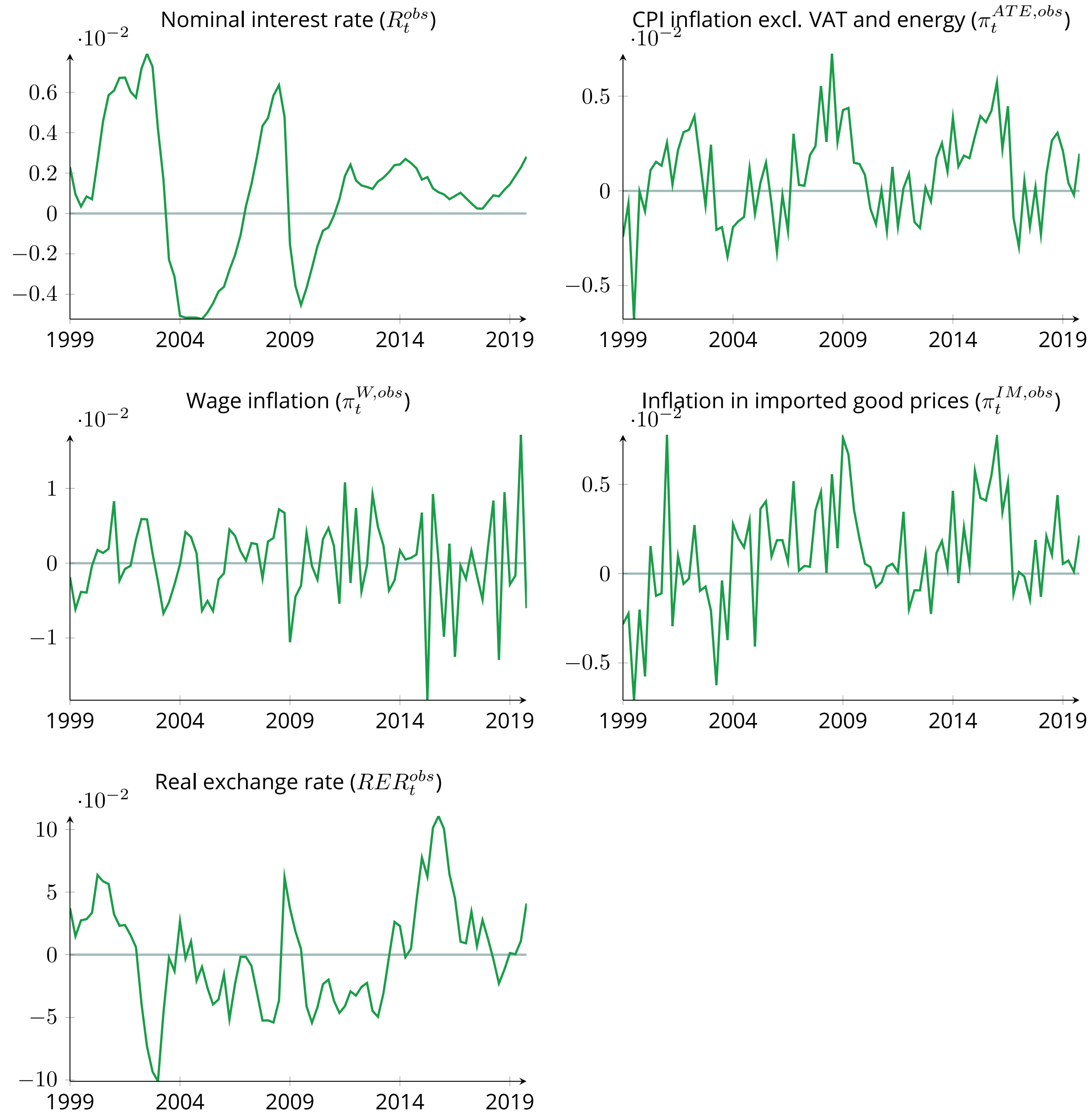


C.2 Domestic variables

The real domestic observables are constructed by detrending the log of the data series by a two-sided Hodrick-Prescott filter with smoothing parameter $\lambda = 1600$ and then demeaning the detrended series. To alleviate the end-point problem and because of the COVID pandemic we use the Economic Survey 2019/4 projections ("Konjunkturtendensene") to construct data points for the period 2020Q1–2022Q4. This approach is used for the following series:

- *Mainland GDP* (Y_t^{obs}): Gross domestic product Mainland Norway, basic prices, measured in constant prices, seasonally adjusted, in Table 09190 'Final expenditure and gross domestic product' of the Norwegian quarterly national accounts, retrieved from the website of Statistics Norway.
- *Private consumption* (C_t^{obs}): $nr61 - nr61bolig$, where $nr61$ is 'final consumption expenditure of households' and $nr61bolig$ is 'dwelling services' measured in constant prices, seasonally adjusted, in Table 09173 'Final consumption expenditure of households' of the Norwegian quarterly national accounts, retrieved from the website of Statistics Norway.
- *Government purchases of goods and services* ($G_t^{C,obs}$): Seasonally adjusted series of $h90$ variable from the KVARTS database.
- *Hours worked in the government sector* ($N_t^{G,obs}$): Total hours worked for employees and self-employed, seasonally adjusted series (million workhours) for the 'general government' industry in Table 09175

Figure C.4 Gap-variables used in the estimation of the domestic block. (continued)



'Wages and employment, by industry, contents and quarter' of the Norwegian quarterly national accounts, retrieved from the website of Statistics Norway.

- *Government investment* ($G_t^{I,obs}$): Gross fixed capital formation of 'General government' in Table 09190 'Final expenditure and gross domestic product' of the Norwegian quarterly national accounts, retrieved from the website of Statistics Norway.
- *Mainland private-sector investment* ($I_t^{ML,P,obs}$): $bif.nr83\_6fnxof - bif.nr8368$ where $bif.nr83\_6fnxof$ is the 'Mainland Norway excluding general government' series and $bif.nr8368$ is the 'Dwelling service (households)' series of gross fixed capital formation in Table 09190 'Final expenditure and gross domestic product' of the Norwegian quarterly national accounts, retrieved from the website of Statistics Norway.
- *Housing investment* ($Inv_t^{H,obs}$): 'Dwelling service (households)' series of gross fixed capital formation in Table 09190 'Final expenditure and gross domestic product' of the Norwegian quarterly national accounts, retrieved from the website of Statistics Norway.
- *Exports* (X_t^{obs}): Sum of data series for exports of 'other goods', 'petroleum activities, various services', 'travel', and 'other services', measured in constant prices, seasonally adjusted, in Table 09177 'Exports of goods and services' of the Norwegian quarterly national accounts, retrieved from the website of Statistics Norway.
- *Imports* (IM_t^{obs}): Sum of data series for imports of 'other goods', 'petroleum activities, various services', 'travel', and 'other services', measured in constant prices, seasonally adjusted, in Table 09178 'Imports of goods and services' of the Norwegian quarterly national accounts, retrieved from the website of Statistics Norway.
- *Hours worked in the private sector* ($N_t^{P,obs}$): Difference between the 'mainland Norway' and the 'general government' series of total hours worked for employees and self-employed, seasonally adjusted series (million workhours) in Table 09175 'Wages and employment, by industry, contents and quarter' of the Norwegian quarterly national accounts, retrieved from the website of Statistics Norway.

The data source for the *short-term nominal interest rate* (R_t^{obs}), *CPI inflation excluding VAT and energy* ($\pi_t^{ATE,obs}$), *wage inflation* ($\pi_t^{W,obs}$), and *inflation in imported good prices* ($\pi_t^{IM,obs}$) is the KVARTS database. The KVARTS series are seasonally adjusted and detrended using averages before and after 1998Q1 and 2009Q3. To smooth out the breakpoint, a moving average filter with a 4 year window is applied. The resulting series are demeaned before being used in the estimation.

For the *real exchange rate* (RER_t^{obs}) the broad real effective exchange rate index for Norway from the website of the Bank for International Settlements is used. We apply the exact same procedure as e.g. the domestic short-term nominal interest rate, but set the breakpoint to coincide with the rapid decline of oil prices starting in 2014Q2.

D. Shocks and shock decompositions

This appendix lists all the shocks used in NORA. The shocks are sorted into different groups and presented in Appendix D.1. Then shock decompositions of the estimated model using these groups of shocks are presented in Appendix D.2.

D.1 Shocks

In the following we provide a list of all shocks occurring in NORA. Note that only 20 of these shocks are used in the estimation, and those are listed in Section 3.2.2.

Foreign shocks:

Trading partners' output shock

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

Trading partners' inflation shock

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

Trading partners' monetary policy shock

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

Non-trading partners' output shock

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

Oil price shock

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

Export demand shock

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

Consumption:

Consumption preferences shock

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

Monetary policy:

Monetary policy shock

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

Technology:

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

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

Investment:

Marginal efficiency of investment (MEI) shock

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

Housing investment shock

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

Oil sector investment shock

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

Markup:

Price markup shock in the manufacturing sector

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

Price markup shock in the service sector

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

Price markup shock in the import sector

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

Price markup shock in the export sector

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

Labor market:

Labor force participation shock

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

Nash reference utility shock

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

Risk premium/Home bias:

Risk premium shock

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

Import share shock

$$Z_t^{IM,\alpha} = \theta_{IM,\alpha} Z_{t-1}^{IM,\alpha} + \sigma_{IM,\alpha} E_t^{IM,\alpha}$$

Government policy:

Government purchases shock

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

Government employment shock

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

Government authorized investment shock

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

Transfers to Ricardian households shock

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

Transfers to liquidity-constrained households shock

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

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

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

Lump-sum tax shock

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

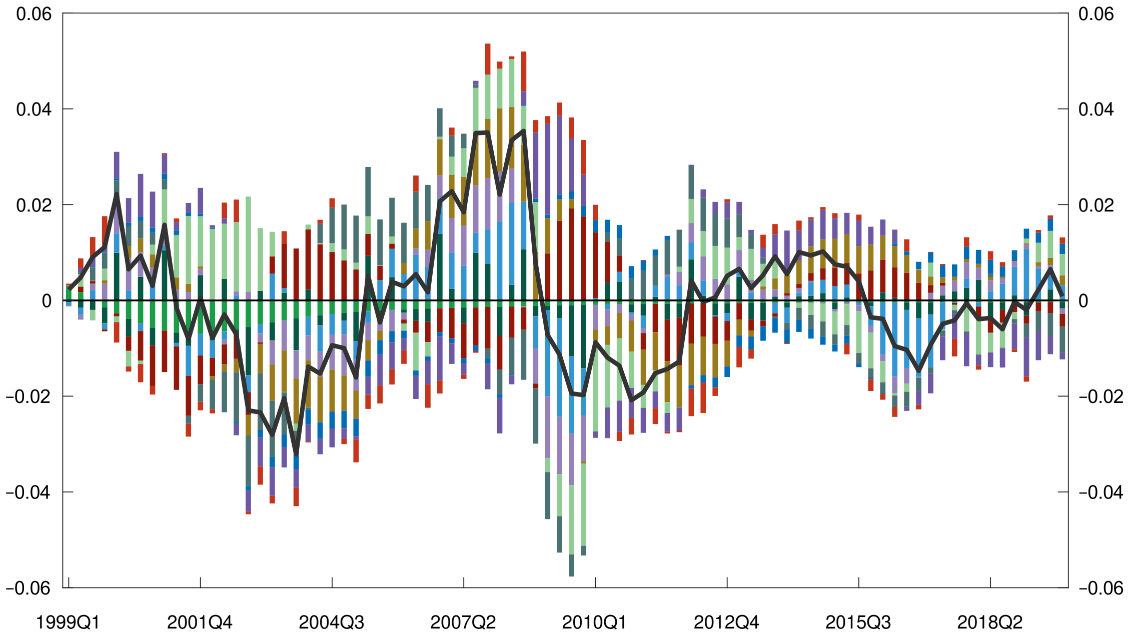
Oil fund withdrawals shock

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

D.2 Shock decompositions

Figure D.1 Shock decompositions

(a) Mainland GDP



(b) Consumption

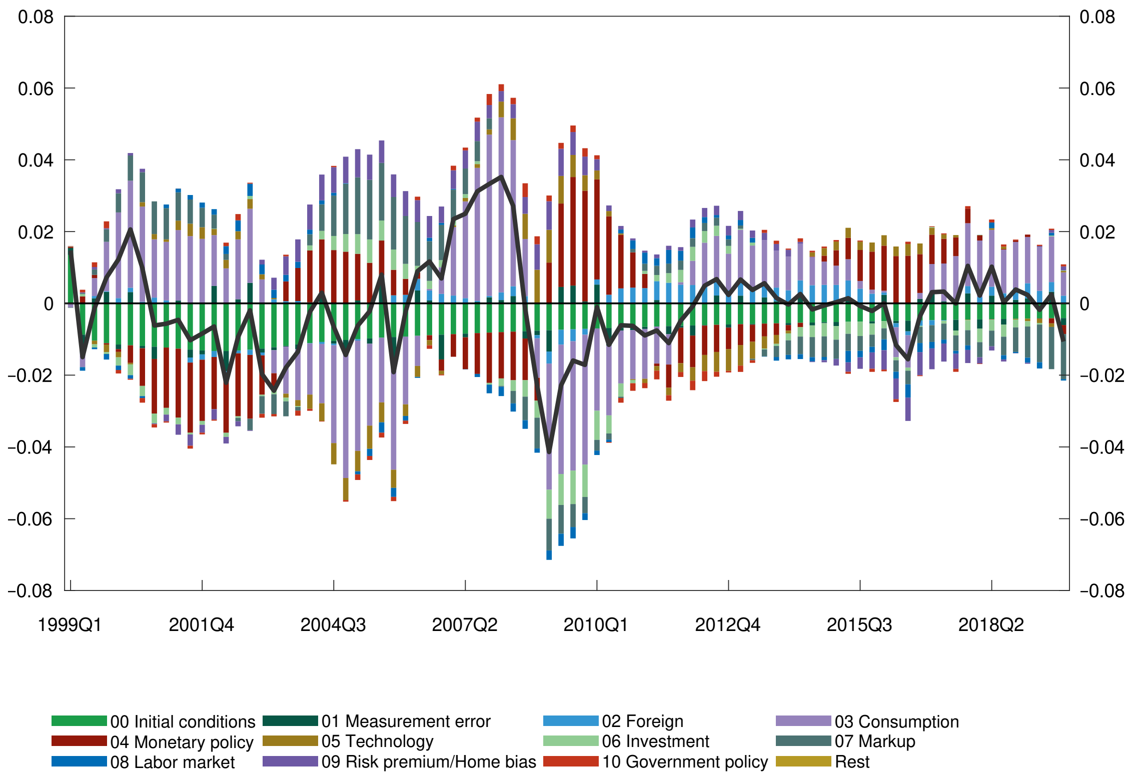
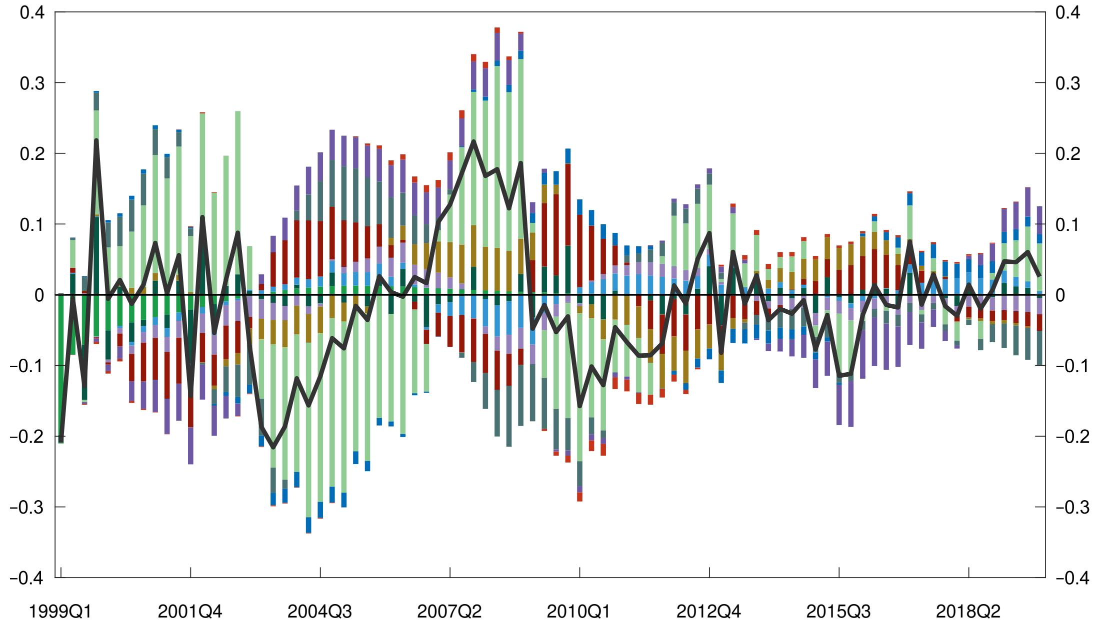


Figure D.1 Shock decompositions (continued)

(c) Private, mainland investment (excl. housing)



(d) Private sector hours worked

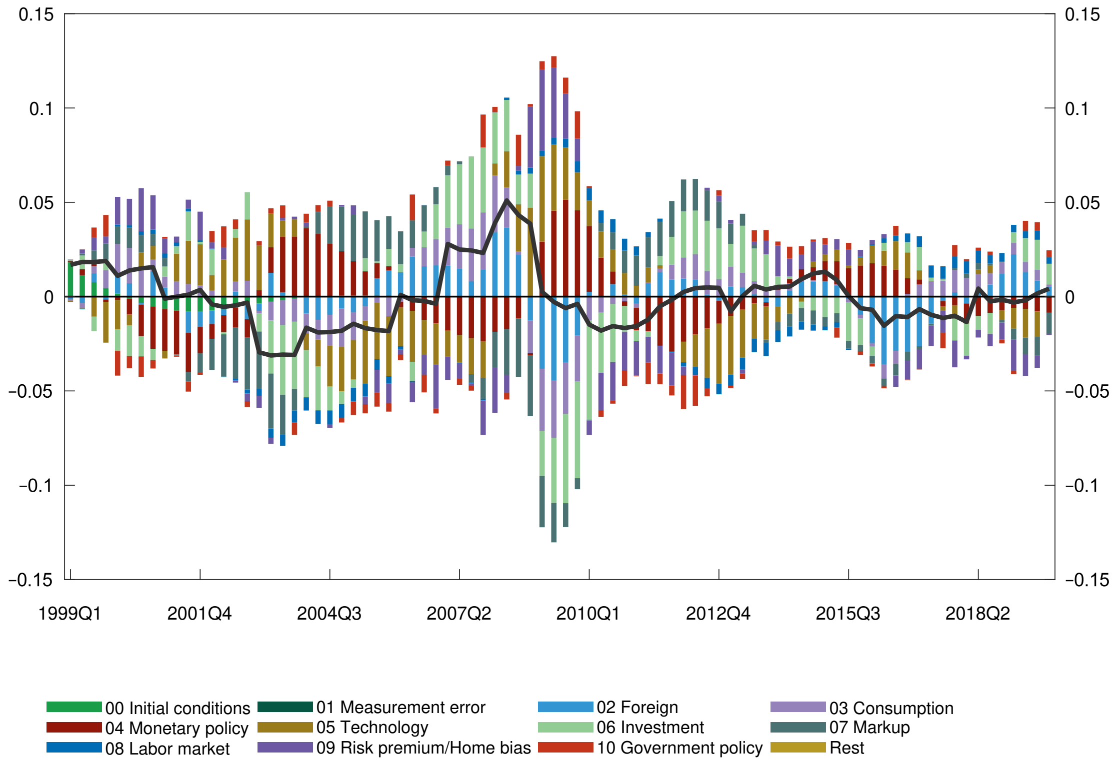
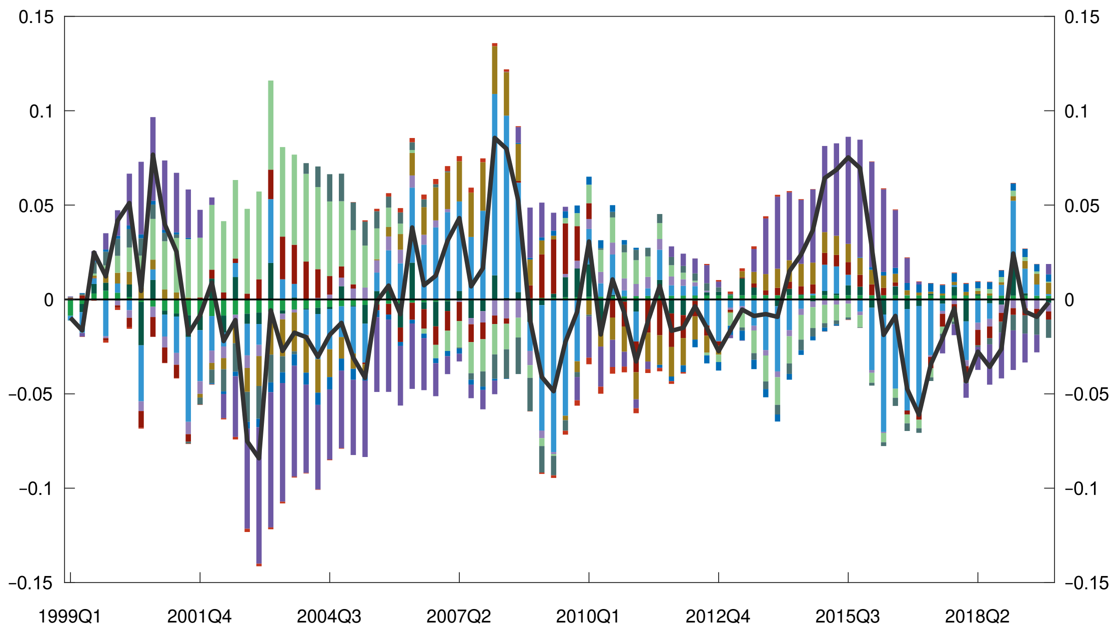


Figure D.1 Shock decompositions (continued)

(e) Exports



(f) Imports

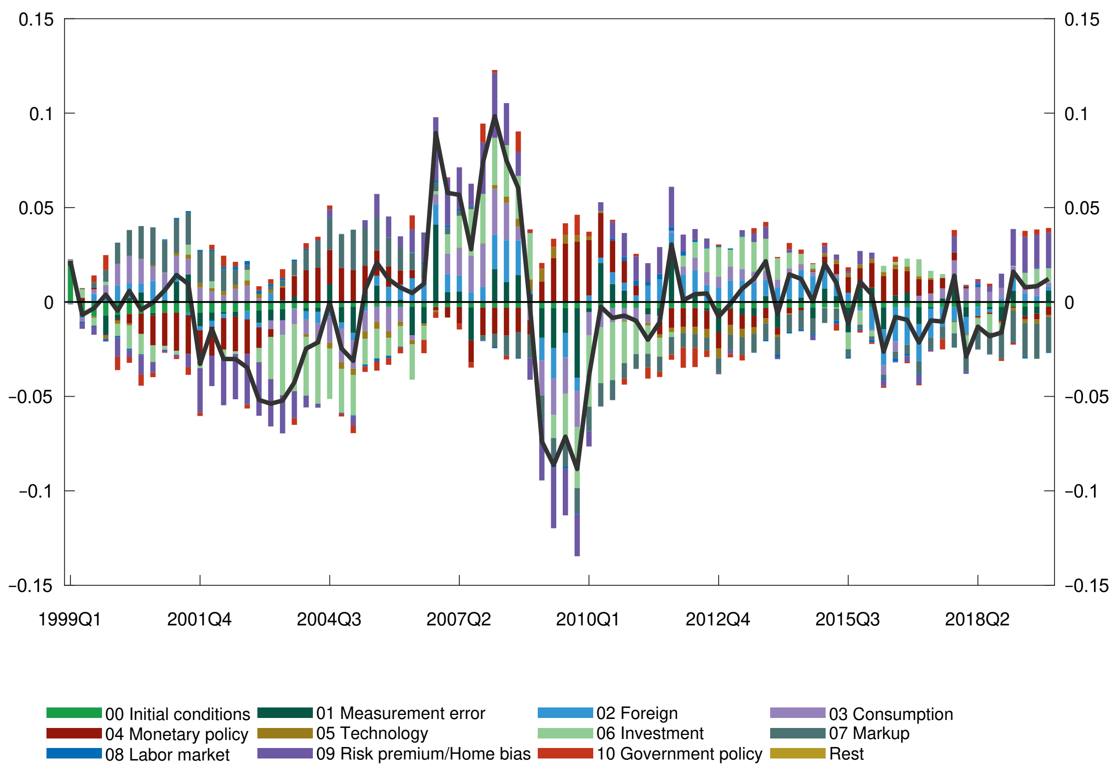
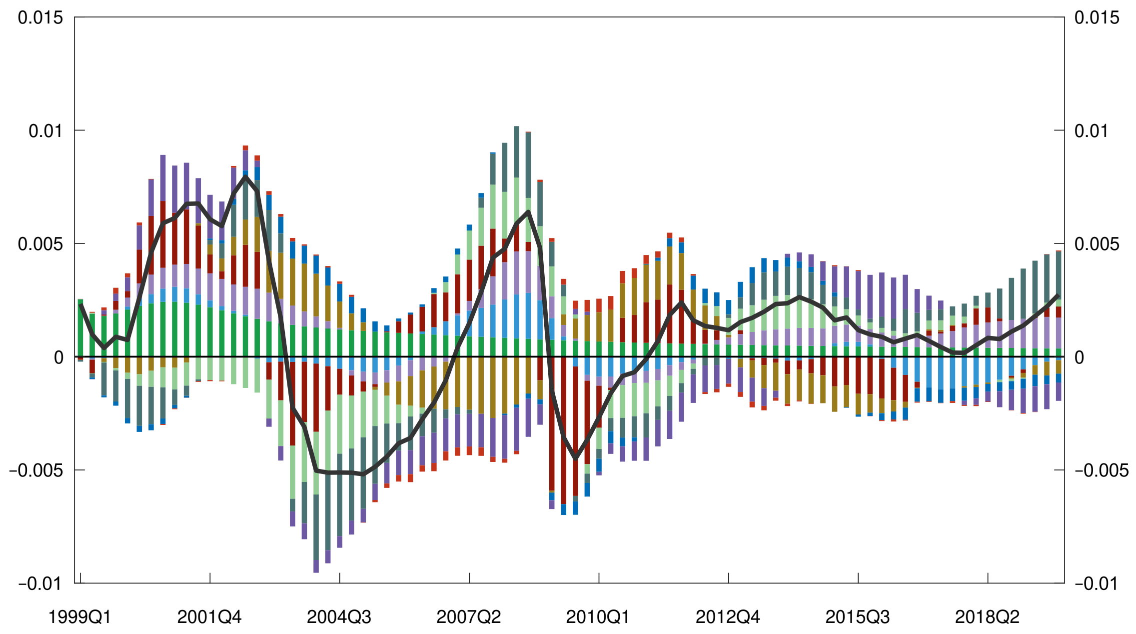


Figure D.1 Shock decompositions (continued)

(g) Interest rate



(h) Inflation (ATE)

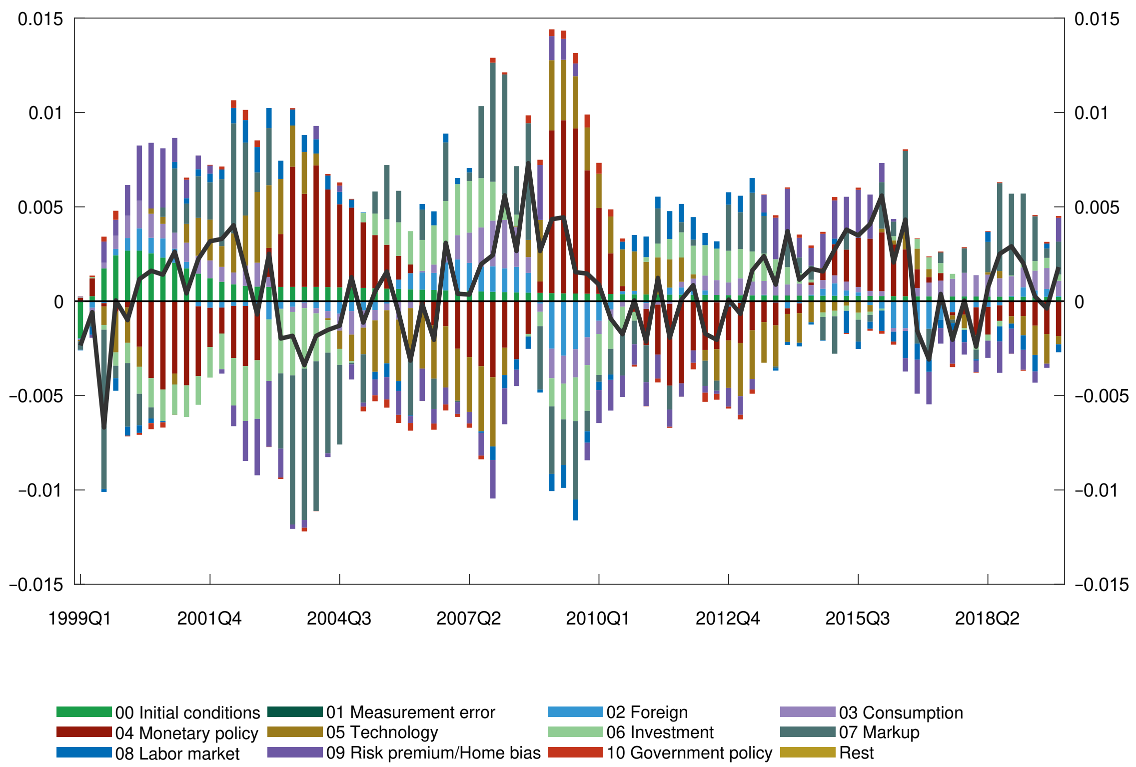
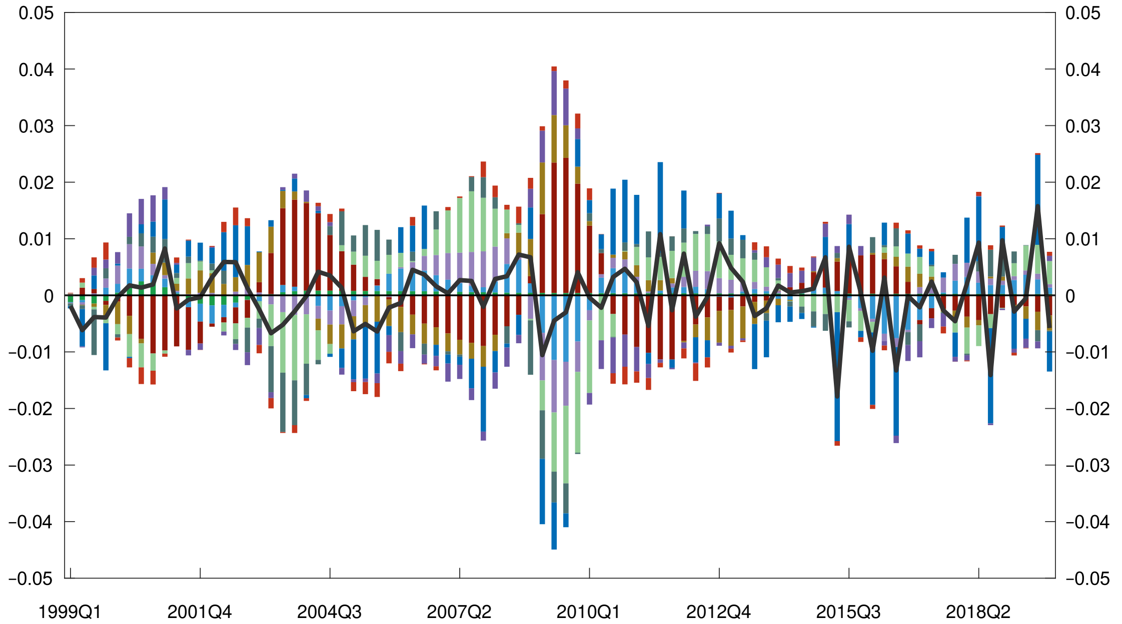


Figure D.1 Shock decompositions (continued)

(i) Wage inflation



(j) Import prices

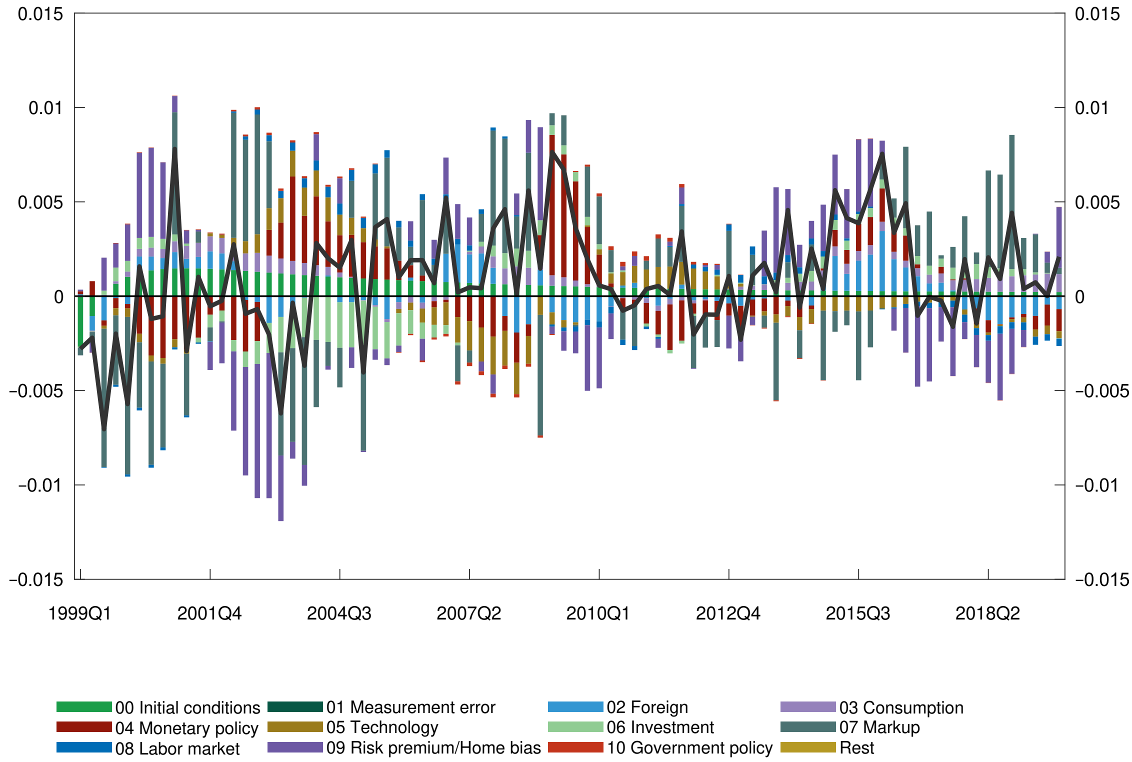
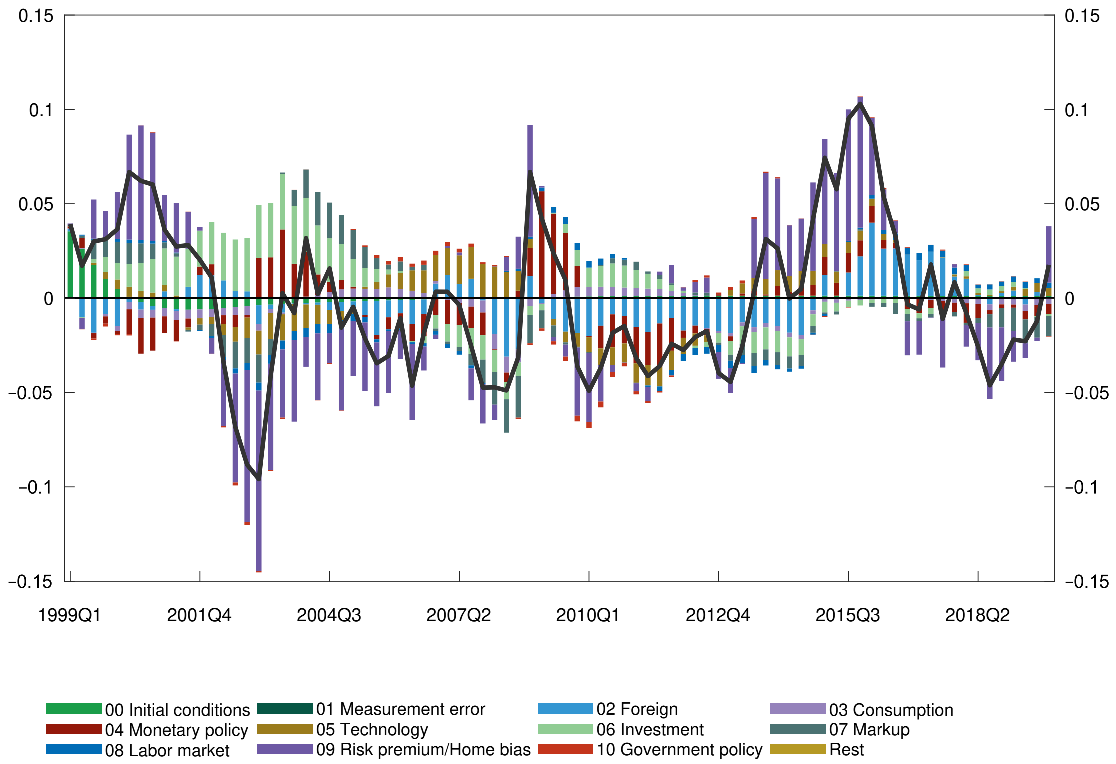


Figure D.1 Shock decompositions (continued)

(k) Real exchange rate



E. Variable overview

Table E.1 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
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

Table E.1 Variable Names

Variable name	Variable description
$\lambda_t^{K,M}$	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
$Y_t^{M,I}$	Domestically-produced manufacturing sector good used for final investment good

Table E.1 Variable Names

Variable name	Variable description
$IM_t^{M,I}$	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

Table E.1 Variable Names

Variable name	Variable description
$IM_t^{S,X}$	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
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)
π_t^{IM}	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
$\tilde{R}_t$	Target nominal interest rate
R_t^{Ann}	Nominal domestic interest rate, yearly
$\tilde{Y}_t$	Target GDP in monetary policy rule
$\widetilde{RER}_t$	Target real exchange rate in monetary policy rule
T_t	Total government revenue

Table E.1 Variable Names

Variable name	Variable description
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
$T_t^{\Pi,M}$	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
$G_t^{C,CPI}$	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
$G_t^{I,Auth}$	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

Table E.1 Variable Names

Variable name	Variable description
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
OBU_t	Oil-corrected deficit ("oljekorrigert budsjettunderskudd")
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
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

Table E.1 Variable Names

Variable name	Variable description
$Z_t^{T^{OILR}}$	Shock: Oil fund withdrawals
$Z_t^{N^G}$	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 goods sectors
$Z_t^{IM,\alpha}$	Shock: Import share in final good production
$Z_t^{\eta_{TP}}$	Shock: Export demand
$Z_t^{MEI,M}$	Shock: Marginal efficiency of investment in manufacturing sector
$Z_t^{MEI,S}$	Shock: Marginal efficiency of investment in service sector

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