Essays on Business Cycles and Macroeconomic Policy

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Contents

Introduction

In this thesis my co-authors and I address questions related to the sources and consequences of business cycles and economic policy. First, I study how the Fiscal Rule[1] and the size of the Government Pension Fund Global[2] affect the propagation of domestic business cycle shocks. Second, we study how the zero lower bound on nominal interest rates and a lower limit on nominal wage growth affect fiscal multipliers in recessions. In the third paper we change focus and analyze how business cycles affect households' and grocery stores' behavior, and the consequences for transaction prices.

The two first papers answers questions relevant to policymakers. First, does the Fiscal Rule and the size of the sovereign wealth fund affect the Norwegian business cycle? The Fiscal Rule ties withdrawals from sovereign wealth to its value in Norwegian Krone. The fund has grown relative to the Norwegian economy since the Fiscal Rule was implemented in 2001. As a result, the government budget is increasingly exposed to exchange rate variation. Shocks that drive the business cycle might cause exchange rate fluctuations which lead to unfavorable adjustments to the government budget. That would be an argument in favor of adjusting the current policy framework. Second, interest rates have exhibited a secular decline over the past decades, limiting the opportunity for central banks to lower the policy rate in response to adverse economic shocks. The responsibility for stabilizing the business cycle is then increasingly seen to be a co-responsibility of the fiscal authority. One of the fiscal authority's policy tools is to purchase goods and services from the private sector. In the second paper we study how these purchases affect the economy when the zero lower bound on nominal interest rates and a lower bound on nominal wage growth are binding.

To answer these research questions, we have chosen to use dynamic stochastic general equilibrium (DSGE) models. This allows us to focus on the contribution of the fund's size and the constraints on prices on the economy, by holding the remaining aspects of the economy unchanged. The core theories we use are widely used in academia and policy institutions to analyze similar questions. However, we make several extensions to capture features of the Norwegian economy. In the first paper, I include the Fiscal Rule and the sovereign wealth fund in domestic currency in a DSGE model. In the second paper, we provide a novel model of the Norwegian labor market in a DSGE model and include a rich tax structure capturing the Norwegian tax system. In comparison to the first paper, we disregard the effect of exchange rate changes on the withdrawals from the fund.

In the first paper, I find that the interaction of the Fiscal Rule and the size of the fund matters for how domestic sources of business cycles affect the economy. A domestic shock to the economy will have an impact on both the real and the nominal exchange rates. The fund is invested abroad and the larger it is in foreign currency, the larger is the change in the Norwegian Krone value of the fund for a given change in the exchange rates. The Fiscal Rule implies that withdrawals from the fund will change more when the fund is larger, for same change in the exchange rates. I find that the effect of a larger fund on the fluctuations in output caused by a shock depends on two elements. First, whether the shock increases or decreases output, and second whether the exchange rate appreciates or depreciates. A larger fund reinforces the effect of a shock on output, if the shock increases output and depreciate the exchange rate as the government, behaving according to the Fiscal Rule, can spend more during the boom when the fund is larger.

[1] Handlingsregelen in Norwegian.

[2] Henceforth referred to as "the sovereign wealth fund", or simply "the fund".

If the shock reduces output and depreciates the exchange rate, the impact of the shock on the economy is reduced following the same logic. I consider technology, monetary policy, and government consumption shocks. The technology shock increases output and depreciates the real exchange rate. Hence, a larger fund increases the impact of technology shocks on output. The effect of a monetary policy shock is also amplified as it causes the same co-movement in output and the exchange rate. An increase in government consumption increases output and appreciates the exchange rate. The impact on output is then reduced by a larger fund, while the effect is small and dependent on the expected duration of the increase in spending. The more short-lived the increase is, the smaller is the effect of a larger fund.

In the second paper, we study how the zero lower bound on nominal interest rates and a lower bound on nominal wage growth affect fiscal multipliers in recessions. We find that recessions exhibit larger fiscal multipliers compared to normal times, if at least one constraint is binding. If one of the constraints is binding the multiplier is three times larger, and if both are binding the multiplier is two times larger. Thus, the two constraints interact to reduce the expansionary effects of fiscal stimulus during severe recessions. The result is driven by the effect of nominal wage growth on inflation. Suppose an adverse shock causes a recession in which the zero lower bound is binding. A government spending increase during the recession increases nominal wage growth and inflation, thereby reducing the real interest rate and stimulating consumption and output. If the lower bound on nominal wage growth is binding, the government spending increase does not affect nominal wage growth during the recession. Consequently, there is a smaller increase in firms' marginal cost and prices increase by less in response to the government spending increase. Consequently, the real interest rate falls by less and the expansionary effects on consumption and output are smaller compared to when only the zero lower bound on nominal interest rates is binding. We also show that the interaction of a zero lower bound on nominal interest rates and a lower bound on nominal wage growth alleviate the paradox of thrift. The paradox states that a labor tax reduction has adverse effects in recessions when the zero lower bound on nominal interest rates is binding, as it reduces wages and thereby inflation and increases the real interest rate. This then leads to lower consumption and output. The lower bound on nominal wage growth reduces the potential for lower wages and reduces the negative effects of the labor tax reduction at the zero lower bound on nominal interest rates.

In the third paper, we ask if households and grocery stores change their behavior over the business cycle. If so, which aspects of their behavior change, and how large are the effects on average prices and expenditure. A household can adjust its shopping along several dimensions. For example, the household can reduce the quality of goods or spend more time to purchase the same good at a lower price. As expenditures on food and beverages represent 12 percent of expenditures in the consumer price index, and close to 25 percent of variable consumption, these adjustments can play a significant role in households' responses to shocks over the business cycle. Furthermore, these adjustments might affect the price level, and hence is of interest to policymakers.

The methodological approach in this paper differs from the approach in the two first. We use panel data methods and rich data from Norway's biggest grocery chain to study how aspects of households' and grocery stores' behavior change with the local unemployment rate. This allows us to utilize variation in the data which would be challenging to capture in a structural model. Our results, however, can be useful in the parameterization of structural models as they provide evidence on the quantitative role of different sources of price variation at the household level.

We find that households shift their expenditures towards cheaper grocery stores and brands when the local unemployment rate increases. They take more advantage of sales and reduce the average price they pay for a product. Grocery stores reduce their prices when the local unemployment rate increases. By decomposing the price households pay for products, we find that the willingness to take advantage of sales and changes to the grocery stores' prices are the main drivers of product prices at the household level.

I Does size matter? The Norwegian sovereign wealth fund, the Fiscal Rule, and the business cycle

Does size matter?
The Norwegian sovereign wealth fund, the Fiscal Rule, and the business cycle*

Thor Andreas Aursland

Abstract

Does the size of the Norwegian sovereign wealth fund affect the propagation of business cycle shocks in Norway? To answer this question I calibrate a DSGE model to one small and one large steady-state value of the fund and study the impulse response functions to technology, monetary policy, and government consumption shocks. I conclude that while the effects on output of government consumption shocks are muted by a larger fund, the effects of technology and monetary policy shocks are amplified. The results are driven by the Fiscal Rule which ties the government's budget deficit to the fund's value measured in domestic currency. As the value of holdings in foreign currency increases, the impact of exchange rate changes on the budget deficit is exacerbated. Furthermore, a larger fund lead to more equal consumption outcomes for households following the shock.

1 Introduction

Does the size of the sovereign wealth fund affect the propagation of business cycle shocks in Norway? The Fiscal Rule[1] defines the behavior of withdrawals from the Government Pension Fund Global[2]. Over a business cycle, the withdrawal rate should average the expected long-run real return of the fund. From 2002 to 2018 the Norwegian Krone value of the withdrawal implied by the expected real rate of return grew from 5 to 22 percent of non-petroleum central government revenue. Hence, the fund plays an increasingly important role in financing the government's yearly budget. The increasing reliance on withdrawals exposes the budget to exchange rate variability. The spending capacity of the government over the business cycle increasingly depends on the exchange rate movements caused by the shocks driving the business cycle. For example, with a larger fund, an adverse shock depreciating the exchange rate will increase the potential for countercyclical policies.

The current situation resembles historic periods in which the budget has been exposed to variable income streams. Petroleum-related revenue has historically varied between 8 and 20 percent of non-petroleum central government revenue. In response the government in 1990 passed the law which established the sovereign wealth fund and started to transfer the revenue into the fund. Given the current size of the fund, withdrawals based on a strict interpretation of the Fiscal Rule replaces petroleum-related revenue as a source of variable income on the budget.

I study whether the size of the sovereign wealth fund and the Fiscal Rule affect the propagation of domestic business cycle shocks to macroeconomic aggregates (such as output, consumption, and government expenditure components) and consumption outcomes between different types of households. I capture

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[1] Fiscal Rule with capitalized letters refers to "Handlingsregelen" in Norwegian.

[2] Henceforth referred to as "the sovereign wealth fund", or simply "the fund".

the consequences of a larger sovereign wealth fund by embedding the Fiscal Rule and the sovereign wealth fund in a New-Keynesian small open economy model of the Norwegian economy, and study the impulse response functions around two steady states. The two steady states correspond to the time periods 2002 - 2006 and 2014 - 2018, respectively. The initial period corresponds to the period after the Fiscal Rule was implemented and value of the fund was 70 percent of annual GDP, on average, while the second period reflects a period in which the value of the fund was 267 percent of annual GDP, on average.

The Fiscal Rule and sovereign wealth fund implementation allows a decomposition of fund withdrawals into two components. First, a short-term component reflects business cycle variation in tax revenue and automatic stabilizers. Second, a medium-term component reflects changes in the domestic-currency value of the fund due to exchange rate variation, as well as the previous short-term component. The medium-term component captures two objectives of the Fiscal Rule; withdrawing the long-run real return of the fund, and smoothing withdrawals from the fund. The larger is the foreign-currency value of the fund, the larger is the contribution of the exchange rate to the medium-term component, which consequently is reflected in government consumption and transfers to households.

I find that the effect of a larger fund on shock propagation depends on the shock. A positive technology shock depreciates the exchange rate and, through the Fiscal Rule, increases government consumption and transfers to households. Hence, a larger fund implies higher spending following the shock. Higher government consumption implies a mechanical effect on output and employment which increase relative to the small-fund steady state. The effect on households' consumption differs across households which save (savers) and those who do not (non-savers). Higher government consumption crowds out consumption by savers, but higher labor income and transfers relative to the small-fund steady state increases consumption by non-savers. The effect on aggregate consumption is small in the short-term, but leads to lower aggregate consumption in the medium-term. Because consumption by savers increase after the shock, and consumption by non-savers fall, irrespective of steady state, a larger fund reduces the differences in consumption outcomes between the two types of households following the shock.

A positive monetary policy shock increases the nominal (and real) interest rate and triggers a contraction in output and employment, and an appreciation of the exchange rate. A larger fund held in foreign currency leads to a larger reduction in the domestic-currency value of the fund following the appreciation. This amplifies the decline in government expenditures implied by the medium-term component, and therefore amplifies the movements in output and employment following a monetary policy shock. Consumption by non-savers declines following the shock due to lower labor income, and the reduction is amplified by the fall in government transfers due to the larger exchange rate effect on the medium-term component. Consumption by savers decline in response to the shock, but is relatively unaffected by the size of the fund. Thus, a larger fund amplifies the transmission of the monetary policy shock to aggregate consumption. Because the interest rate increase leads to a larger decline in savers' consumption than non-savers', irrespective of steady state, the effects from a larger fund reduce differences in consumption outcomes between savers and non-savers following the monetary policy shock.

A positive shock to government consumption increases output and employment, and triggers an appreciation of the exchange rate. Because the exchange rate appreciates, a larger fund reduces the medium-term component of the withdrawal from the fund, and leads to a more rapid decline in government consumption following the initial expansion. Hence, the impact on output and employment is muted by a larger fund. Because the increase in output, employment, and government consumption is large irrespective of the size of the fund, the reduction in amplification is small relative to the technology shock. Consumption by savers declines after the shock, with the effect muted by a larger fund due to crowding-in from lower government consumption following the real exchange rate appreciation. Non-savers' consumption response to the shock is muted by a smaller increase in labor income and and transfers due to the larger exchange rate effect on the medium-term component. Because the shock, irrespecive of the fund's size, crowds out consumption by savers and increases consumption by non-savers, these effects imply a smaller difference in consumption outcomes between savers and non-savers following the shock in the large-fund steady state than in the small-fund steady state.

The results are robust to assumptions regarding the degree of real and nominal rigidities in the economy, as they do not change the correlation between output and the exchange rate caused by the shocks. The same holds true with respect to the degree of persistence of the shocks. However, a more persistent government consumption shock increases the exchange rate appreciation and therefore gives a clearer illustration of the consequence of a larger fund.

The shocks I consider in this paper are not the only potential drivers of the business cycle. However, the qualitative effect of a larger sovereign wealth fund might be informative of its role in the propagation of other shocks. For example, Bergholt et al. (2019) find that, similar to a government consumption shock, oil price shocks increase output and appreciate the real exchange rate. While the fund itself shields the budget from a volatile petroleum-related revenue stream, the Fiscal Rule and the size of the fund provides a second channel which reduce the impact of oil price shocks.

My results follow from the fiscal authority strictly following a fiscal rule, and do not reflect optimal policy. The results, however, indicate that the fiscal authority can reduce variation in output and employment by deciding whether to allow exchange rate changes to affect spending, conditional on the level of output and the real exchange rate. This can be done by taking into account exchange rate effects when the level output and the real exchange rate, are above and below their long-term levels, respectively. The advice is simple in theory, however, identifying the long-term level of output and the real exchange rate is a challenging task.

I study the consequences of following a fiscal rule and a changing size of the government balance sheet, for the propagation of the business cycle shocks studied by Cochrane (1994) and Ramey (2016). Since Taylor (1993) policy rules have had a central role in economic policy analysis. Kumhof and Laxton (2013) analyze the welfare consequences of different fiscal rules when a country produces natural resources. In the terminology of Kumhof and Laxton (2013), I consider a counter-cyclical rule fiscal rule which they find to improve welfare of non-saving households. While they show that the response of fiscal instruments to debt matter little for welfare, I show that a large increase in government assets cause feedback effects which matter for the positive behavior of the economy.

Beyond their use in economic policy analysis, fiscal rules are adopted by governments to alleviate deficit biases. Wyplosz (2013) reviews historical experiences with fiscal rules. In the Norwegian context Gjedrem and Thøgersen (2017) motivate the Fiscal Rule as the practical implementation of the normative implications that derive from the permanent income hypothesis taking into account growth and uncertainty in petroleum income. In this paper I show that strictly following a fiscal rule might cause the budget deficit to increase in booms, contrary to its intended effect. NOU 2015:9 (2015) argue that the implementation of the Fiscal Rule has been flexible, which has been a key factor to its success. This suggests that the government has made appropriate, discretionary, adjustments to fund withdrawals and prevented the adverse effects from a strict interpretation of the Fiscal Rule.

Eichengreen et al. (2005) argue that foreign currency denominated liabilities, both in the private and public sector, is a typical characteristic of emerging market economies and is a potential source of economic instability. The Norwegian situation with a large sovereign wealth fund invested in a global portfolio offers an interesting counterexample. In this paper I show that, in some cases, strict adherence to a fiscal rule can create larger fluctuations in output with a larger fund. However, the results depends on the type of fluctuations.

Finally, several authors focus on the role of the fiscal framework in Norway, and the fiscal rule in the propagation of oil price shocks in Norway. Kjelsrud (2017) and Berisha and Helle (2017) are the studies closest in scope to the current analysis. Kjelsrud (2017) finds that the response of the structural oil-adjusted budget deficit to an oil price shock changes from 2011 to 2017, using the large-scale macroeconometric model KVARTS. Berisha and Helle (2017) interpret a larger sovereign wealth fund as an additional impulse to the IS-equation following oil price and risk premium shocks in the model by Røisland and Sveen (2005), and find that a larger fund stabilizes the economy's response to oil price shocks and destabilizes the economy in response to risk premium shocks. Bergholt et al. (2019) estimate a large-scale DSGE model of Norway with a detailed oil production sector. Their results show that the sovereign wealth fund combined with the Fiscal Rule reduce the impact of oil price shocks on the mainland economy compared to spending the resource revenue as it accrues. Given the qualitative similarity between on output and the real exchange rate of the government consumption shock in this paper, and that of oil price shocks in Bergholt et al. (2019), the current analysis suggest that the size of the fund also stabilizes variation in output in response to oil price shocks. Pieschacón (2012) finds that the Norwegian fiscal framework reduces the impact of oil price shocks on the Norwegian economy relative to other oil producing countries. Compared to the papers which focus on oil price shocks, I focus on a a set of domestic shocks. As in Pieschacón (2012), Bjørnland and Thorsrud (2019) study the effect of oil prices on fiscal policy. By separating between demand and supply factors in driving the oil price, Bjørnland and Thorsrud (2019) conclude that fiscal policy in Norway is more sensitive to the oil price since the introduction of the Fiscal Rule.

The remainder of the paper is structured as follows. Section 2 describes the current fiscal policy framework, section 3 presents the dynamic stochastic general equilibrium model used to answer the research question, section 4 describes the calibration of the model, section 5 contains the empirical predictions of a larger sovereign wealth fund and changed policy rule, section 6 examines the robustness of the results to assumptions regarding rigidities and shock persistence, and section 7 concludes.

2 The fiscal framework in Norway

In this section, I review the elements of the fiscal policy framework which are captured in the model, and are the most relevant to the research questions. A full description can be found in the annual budget Meld. St. 1 (2019 -2020) (2019).[3]

The government receives a net cash flow from petroleum related activities due to the extraction of oil and gas on the continental shelf. The cash-flow is volatile and is closely related to oil and gas prices. To avoid large fluctuations in fiscal policy instruments in response to short-term variation in resource prices, the cash flow is transferred to the Government Pension Fund Global. Consequently, the policy-relevant budget balance is the oil adjusted budget deficit; the budget deficit ignoring petroleum-related revenues accruing to the government. By law, the fund is invested in a global portfolio consisting of bonds, equities, and real estate. Cash flows accruing to the fund are reinvested in the portfolio.

The Fiscal Rule describes the behavior of withdrawals from the sovereign wealth fund. The withdrawal rate should average the expected long-run real return of the fund over the business cycle. The expected long-run real return was four percent in 2002 and revised to three percent in 2017. In a given budget year the degree of "spending" (out of the value of the fund) is measured by the structural oil-adjusted budget deficit. The structural oil-adjusted budget deficit adjusts revenue and spending components of the budget for business cycle variations and the effects of petroleum activities. Panel A of figure 1 displays the development of the structural oil adjusted budget deficit as a share of mainland trend GDP, as estimated by the Meld. St. 1 (2019 -2020) (2019). Consistent with spending the expected long-run real return on the fund value, the structural oil-adjusted budget deficit has increased with the size of the fund. In the first year the fiscal rule was operative in 2002 the structural oil-adjusted deficit was three percent of mainland GDP and grew to seven percent in 2018.

The oil adjusted budget deficit corresponds to the actual withdrawal, or cash flow, from the sovereign wealth fund to the budget. By law (Meld. St. 1 (2019 -2020), 2019, p. 44), central government budget deficits must be financed by withdrawals from the sovereign wealth fund; i.e. debt financing is not feasible. Hence, withdrawals from the sovereign wealth fund are equal to the primary budget deficit and contain a component due to business cycle variation. The cyclical component of the budget deficit is plotted in

[3] See in particular box 3.2.

panel B of figure 1. On average a 1 percent output gap corresponds to a 0.5 percentage point deviation of the oil adjusted, cyclical, budget deficit to trend GDP ratio.

In the long-run the fiscal framework should maintain the real value of the sovereign wealth fund (Meld. St. 1 (2019 -2020), 2019, p. 44) to the benefit of future generations. The objective of, on average, spending the (expected) long-run real return of the fund and maintaining the real value of the fund raises a potential trade-off for the central government, as temporary shocks will have permanent effects on the value of the fund.

Finally, large changes in the value of the fund (e.g. due to nominal exchange rate changes or portfolio returns) should be reflected in spending over time.

3 Model

This section presents the model used to analyze the research questions. The model is closely related to Justiniano and Preston (2010), and extended with a non-traded sector to match the low import-content of public consumption. In order to generate realistic effects of fiscal policy the model features non-Ricardian households as in Galí et al. (2007), henceforth referred to as non-savers as in Leeper et al. (2017). The government collects revenues from consumption, labor and corporate taxes, and spends on government consumption and transfers to households. The fiscal rule is implemented as a feedback rule from the fund's value to government spending, a mechanism similar to that in Corsetti et al. (2012).

3.1 Firms

3.1.1 Sectoral and final goods

There are three sectoral goods: the non-traded good, $z_{N,t}$, the domestic traded good, $z_{H,t}$, and the foreign traded good $z_{F,t}$. The sectoral goods are produced by a representative firm in a perfectly competitive market, using a CES-production technology

$$z_{j,t} = \left[\int_0^1 z_{j,t}(i)^{(\epsilon_j - 1)/\epsilon_j} di \right]^{\epsilon_j/(\epsilon_j - 1)}, \quad i \in [0, 1]. \tag{1}$$

where i is the continuum of intermediate good producers, ϵ_j is the elasticity of substitution between intermediate goods in sector $j = N, H, F$. Profit maximization by firms in these industries gives rise to well-known demand functions and price indices

$$z_{j,t}(i) = \left(\frac{P_{j,t}(i)}{P_{j,t}} \right)^{-\epsilon_j} z_{j,t}, \quad \forall i, \quad j = N, H, F \tag{2}$$

$$P_{j,t} = \left[\int_0^1 P_{j,t}(i)^{1-\epsilon_j} di \right]^{1/(1-\epsilon_j)}, \quad j = N, H, F. \tag{3}$$

A representative firm, operating in a perfectly competitive market, produces the traded good, $z_{T,t}$, combining the domestic and foreign sectoral goods using a CES production function with elasticity of substitution η and share parameter α

$$z_{T,t} = \left[\alpha^{1/\eta} z_{H,t}^{\frac{\eta-1}{\eta}} + (1-\alpha)^{1/\eta} z_{F,t}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}. \tag{4}$$

Profit mazimization by the representative firm gives the following demand functions and price index

$$z_{H,t} = \left(\frac{P_{H,t}}{P_{T,t}}\right)^{-\eta} z_{T,t} \tag{5}$$

$$z_{F,t} = \left(\frac{P_{F,t}}{P_{T,t}}\right)^{-\eta} z_{T,t} \tag{6}$$

$$P_{T,t} = \left[\alpha P_{H,t}^{1-\eta} + (1-\alpha) P_{F,t}^{1-\eta}\right]^{1/(1-\eta)} \tag{7}$$

The final private consumption good, z_t, is produced by a representative firm operating in a perfectly competitive market. The firm combines the non-traded and traded good according to a CES production function with share parameter γ and elasticity of substitution θ_c

$$c_t = \left[\gamma^{1/\theta_c} c_{N,t}^{\frac{\theta_c - 1}{\theta_c}} + (1-\gamma)^{1/\theta_c} c_{T,t}^{\frac{\theta_c - 1}{\theta_c}}\right]^{\frac{\theta_c}{\theta_c - 1}}. \tag{8}$$

Profit maximizing by the representative firm yields the following demand functions and price index

$$z_{N,t} = \gamma \left(\frac{P_{N,t}}{P_t}\right)^{-\theta_c} z_t \tag{9}$$

$$z_{H,t} = (1-\gamma) \left(\frac{P_{H,t}}{P_t}\right)^{-\theta_c} z_t \tag{10}$$

$$P_t = \left[\gamma P_{N,t}^{1-\theta_c} + (1-\gamma) P_{H,t}^{1-\theta_c}\right]^{1/(1-\theta_c)}. \tag{11}$$

The final public consumption good is equal to the non-traded sectoral good.

3.1.2 Intermediate good producers

Intermediate good producers operate with a decreasing returns to scale technology using labor, $n_j(i)$, as the only input

$$y_{j,t}(i) = A_j Z_t n_{j,t}(i)^{\alpha_j} \quad, \forall i \in [0,1], \quad j = N, H \tag{12}$$

where A_j is the technology level in each sector, Z_t is an exogenous productivity shifter common across sectors, and α_j is the elasticity of output with respect to labor used by the firm. Given the firm's price, $P_{j,t}(i)$, and the unit cost of labor, W_t, the surplus from production, $DIV_{j,t}(i) = P_{j,t}(i) y_{j,t} - W_t n_{j,t}(i)$, is paid out as dividends to savers (who own the firms). Firms maximize the discounted value of dividends using savers' discount factor. Intermediate good firms have monopoly power, and every period the firm has a probability of $1-\theta_j$ to freely set its price as in Calvo (1983). If the firm is not allowed to set its price, the price is updated according to a geometric average of lagged and steady-state inflation with weight χ_j as in Leeper et al. (2017)

$$\mathbb{P}_{j,t} = \Pi_{t+k}^{\chi_j} \Pi_{ss}^{1-\chi_j} \mathbb{P}_{j,t-1}, \quad j = N, H. \tag{13}$$

where $\Pi_t \equiv P_t / P_{t-1}$ is consumer price inflation. Firms which set prices in period t maximize the expected discounted value of dividends using savers' (nominal) discount factor, $\beta^k \tilde{\lambda}_{t+k}$, subject to satisfying demand at the chosen price

$$\begin{aligned}
\max_{P_j^{\#}(i)} \quad & \mathbb{E}_t \left[\sum_{k=0}^{\infty} (\beta \theta_j)^k \frac{\tilde{\lambda}_{t+k}}{\tilde{\lambda}_t} \left[\mathbb{P}_{j,t+k} P_{j,t}^{\#}(i) y_{j,t+k|t}(i) - \Psi(y_{j,t+k|t}(i)) \right] \right] \\
s.t. \quad & y_{j,t+k|t}(i) = \left(\frac{\mathbb{P}_{j,t+k} P_{j,t}^{\#}(i)}{P_{j,t+k}} \right)^{-\epsilon_j} z_{j,t+k} \\
& \Psi(y_{j,t+k|t}(i)) = W_t \left(\frac{y_{j,t+k|t}(i)}{A_j Z_t} \right)^{1/\alpha_j},
\end{aligned}$$

where $\mathbb{E}_t$ denotes the expectation operator conditional on information available to the firm at date t, Ψ is the cost of production and W_t the nominal wage. The optimal price, $P_j^{\#}(i)$, satisfies the first order condition

$$\mathbb{E}_t \left[\sum_{k=0}^{\infty} (\theta_j \beta)^k \tilde{\lambda}_{t+k} y_{j,t+k|t}(i) \left[\mathbb{P}_{j,t+k} P_{j,t}^{\#}(i) - \frac{\epsilon_j}{\epsilon_j - 1} \psi_{j,t+k|t}(i) \right] \right] = 0 \tag{14}$$

where $y_{j,t+k|t}(i)$ and $\psi_{j,t+k|t}$ are demand and nominal marginal cost of firms setting prices in period t.

Production of the final imported good follows Kollmann (2002) in which producers of the imported good, $z_{F,t}$, are located abroad and re-brand the foreign final good and to sell it in Home. Similar to domestic intermediate good produdcers, exporters to Home have monopoly power and are subject to a pricing friction. They solve the following maximization problem

$$\begin{aligned}
\max_{P_{F,t}^{\#}(i)} \quad & \mathbb{E}_t \left[\sum_{k=0}^{\infty} \theta_F^k R^{*-k} E_{t+k}^{-1} \left[\mathbb{P}_{F,t+k} P_{F,t}^{\#}(i) - E_{t+k} P_{F,t+k}^{*} \right] y_{F,t+k|t}(i) \right] \\
s.t. \quad & y_{F,t+k|t}(i) = \left(\frac{\mathbb{P}_{F,t+k} P_{F,t}^{\#}(i)}{P_{F,t+k}} \right)^{-\epsilon_F} z_{F,t+k}, \quad \forall k,
\end{aligned}$$

where R^* is the foreign nominal interest rate, E_t is the nominal exchange rate, θ_F is the probability foreign exporters are not allowed to adjust their price, and $P_{F,t}^*$ is the price of the nominal price of the Foreign good (i.e. the price level in Foreign), $P_{F,t}^{\#}$ is the optimal price set by foreign exporters. Indexation is defined similar to (13). The first order condition is similar to (14).

3.2 Labor market

3.2.1 Labor agency

A price-taking labor agency packages a continuum of differentiated labor services (professions), indexed by $m \in [0, 1]$, into a composite labor input using a CES production technology with elasticity of substitution ϵ_W and sells it to domestic producers of intermediate goods. Cost minimization by the labor agency gives the following demand function for each labor type and nominal wage index respectively

$$n_t(m) = \left(\frac{W_t(m)}{W_t} \right)^{-\epsilon_W} (n_{N,t} + n_{H,t}) \tag{15}$$

$$W_t = \left[\int_0^1 W_t(m)^{1-\epsilon_W} dm \right]^{1/(1-\epsilon_W)} \tag{16}$$

where $W_t(m)$ and W_t are the nominal wage in profession m and the wage index, respectively, and $n_t(m)$ is demand for labor service m given total labor demand n_t. Labor demand for each labor service is homogeneously distributed towards each household.

3.2.2 Labor unions

Each profession is organized in a union which sets the nominal wage on behalf of its members. Every period there is a probability $1-\theta_W$ that the profession is allowed to set its wage. Unions which are not allowed to set their wage, index wage growth in the same way as intermediate good producers, with weight χ_W on lagged inflation. As in Leeper et al. (2017) and Forni et al. (2009), labor demand is assumed to be uniformly distributed across households, and that all households receive the same wage. This implies that all households work the same amount of hours in each profession. The per period pay-off of the union is

$$\begin{aligned} &\int_0^1 \left[W_t(m)n_t(h,m)\tilde{\lambda}_t - v(n_t(h))\right] dh \\ &\quad = W_t(m)n_t(m)\tilde{\lambda}_t - v(n_t) \end{aligned} \tag{17}$$

where $n_t(h,m)$ is labor supply by household h to profession m, and $n_t(h) = \int_0^1 n_t(h,m)dm$ is labor supply by household h, $h \in [0,1]$. Nominal labor income is valued using savers marginal utility of nominal wealth and disutility from working by household i is given by $v(n_t(h))$. Professions which set their wage in period t maximize the discounted sum of expected pay-offs with respect to the profession's wage subject to satisfying labor demand

$$\begin{aligned} &\max_{W_t^{\#}(m)} \mathbb{E}_t \left[\sum_{k=0}^{\infty} (\theta_W \beta)^k \left[\mathbb{P}_{W,t+k} W_t^{\#}(m) n_{t+k}(m)\tilde{\lambda}_{t+k} - v(n_{t+k})\right]\right] \\ \text{s.t. } & n_{t+k|t}(m) = \left(\frac{\mathbb{P}_{W,t+k}W_t^{\#}(m)}{W_{t+k}}\right)^{-\epsilon_W} (n_{N,t+k} + n_{H,t+k}) \\ & n_{j,t+k} = \int_0^1 n_{j,t+k}(m)dm \quad j = N, H \end{aligned}$$

where $n_{t+k|t}(m)$ is labor supplied by professions setting wages in period t at date $t+k$, $W_t^{\#}$ is the optimal wage set by professions setting wages in period t, $\mathbb{P}_{W,t+k}$ is wage indexation and follows the recursion in equation (13) with indexation parameter χ_W. Optimal wage-setting results in the following first order condition

$$\mathbb{E}_t \left[\sum_{k=0}^{\infty} (\beta\theta_W)\, \tilde{\lambda}_{t+k} n_{t+k|t} \left[\mathbb{P}_{W,t+k}W_t^{\#} - \frac{\epsilon_W}{\epsilon_W - 1}\frac{v'(n_{t+k})}{\tilde{\lambda}_{t+k}}\right]\right] = 0$$

where the profession index is omitted as all professions setting wages choose the same wage.

3.3 Households

3.3.1 Savers

Savers in the model consume the final consumption good and save in domestic and foreign bonds. They receive income from supplying their labor, and ownership of bonds and domestic firms. Saving in foreign bonds is subject to a risk premium, rp_t, which depends on the households' foreign net assets, as in Schmitt-Grohé and Uribe (2003). The risk premium determines the steady-state level of net foreign assets and ensures stationarity of net foreign assets. The households' budget constraint is given by

$$\begin{aligned} (1+\tau^c)\, P_t c_t^s(h) + B_{H,t}^s(h) + B_{F,t}^s E_t(h) &= R_{t-1}B_{H,t-1}^s(h) + R^* rp_{t-1} B_{F,t-1}^s(h) E_t \\ &+ (1-\tau^w)\int_0^1 W_t(m) n_t^s(h,m)dm + \left(1-\tau^K\right) DIV_t^s(h) + P_t trnf_t^s(h) \end{aligned} \tag{18}$$

where $h \in (\gamma_{ns}, 1]$ and γ_{ns} is the fraction of non-savers in the economy and superscript s denotes choice variables, or incomes, of savers. $P_t c_t^s$ $B_{H,t}^s$ and $B_{F,t}^s$ are nominal purchases of the final consumption good, domestic and foreign bonds, respectively. DIV_t^s is the nominal value of dividends received from firm ownership, $trnf_t^s$ is the real value of transfers received from the government, and $\tau^j, j = c, w, K$ are tax rates on consumption, labor income, and firm profits, respectively. Finally, the risk premium on foreign investments is given by

$$rp_t = e^{-\phi_b \left(E_t B_{F,t}^{Agg} / P_t - \bar{b}_F \right)} \tag{19}$$

where ϕ_b determines the risk premium's sensitivity to the deviation of the country's real net foreign assets from its steady-state value $\bar{b}_F$. Savers maximize the expected value of discounted utility. Utility in each period is a function of consumption, c_t^s, and labor effort, n_t^s

$$u(c_t^s(h), c_{t-1}^s, n_t^s(h)) = \frac{\sigma - 1}{\sigma (1 - h_c)} \left(c_t^s(h) - h_c c_t^s \right)^{1 - 1/\sigma} - \frac{\chi}{1 + \psi} n_t^s(h)^{1+\psi} \tag{20}$$

where σ is the intertemporal elasticity of substitution, ψ the Frisch elasticity, h_c the degree of consumption habits, and χ the disutility of working. Habits depend on the aggregate level of consumption by savers, c_t^s. Hence, savers solve the optimization problem

$$\max_{\{c_{t+k}^s(h), B_{H,t+k}^s(h), B_{F,t+k}^s(h)\}_{k=0}^{\infty}} \quad \mathbb{E}_t \left[\sum_{k=0}^{\infty} u(c_{t+k}^s(h), c_{t+k-1}^s, n_{t+k}^s(h)) \right]$$

$$\begin{aligned}
\text{s.t.} \quad (1 + \tau^c) P_{t+k} c_{t+k}^s(h) + B_{H,t}^s(h) + E_{t+k} B_{F,t}^s(h) = {} & R_{t+k-1} B_{H,t-1}^s(h) \\
& + R_{t+k-1}^* rp_{t+k-1} E_{t+k} B_{F,t+k-1}^s(h) \\
& + (1 - \tau^w) \int_0^1 W_{t+k}(m) n_{t+k}^s(h, m) dm \\
& + \left(1 - \tau^K\right) DIV_{t+k}^s(h) + P_{t+k} trnf_{t+k}^s(h), \quad \forall k
\end{aligned}$$

The optimality conditions are

$$\frac{\partial u}{\partial c_t^s} = (1 + \tau^c) P_t \tilde{\lambda}_t \tag{21}$$

$$\tilde{\lambda}_t = \beta R_t \mathbb{E}_t \left[\tilde{\lambda}_{t+1} \right] \tag{22}$$

$$E_t \tilde{\lambda}_t = \beta R^* rp_t \mathbb{E}_t \left[E_{t+1} \tilde{\lambda}_{t+1} \right] \tag{23}$$

where $\tilde{\lambda}$ is the marginal utility of (nominal) wealth. The household index is omitted as savers work in all professions and face the same wages and prices, and therefore choose the same consumption and investment path.

3.3.2 Non-Savers

Non-savers consume their disposable income each period. Similarly to savers, non-savers receive labor income, transfers from the government, and pay taxes on their consumption expenditures and labor income. However, they do not have any source of capital income. To compensate for this, transfers from the government contain a constant lump-sum transfer from savers to non-savers to ensure equal steady-state consumption. Hence, γ_{ns} corresponds to the share of non-savers in aggregate consumption (and not simply the share of households in the economy). As in Leeper et al. (2017) non-savers set their wage equal to the average wage rate of savers. Consequently, non-savers have the same wage rate and hours worked as savers. Consumption by non-savers is given by

$$(1 + \tau^c) P_t c_t^{ns}(h) = (1 - \tau^w) W_t n_t^{ns}(h) + P_t trnf_t^{ns}(h) \tag{24}$$

where $h \in [0, \gamma_{ns}]$.

3.4 Government

3.4.1 Monetary policy

I define output as the value of output at constant, steady-state, prices

$$y_{FP,t} \equiv p_{H,ss} y_{H,t} + p_{N,ss} y_{N,t}$$

Monetary policy follows the Taylor rule

$$\frac{R_t}{R_{ss}} = \left(\frac{R_{t-1}}{R_{ss}}\right)^{\rho_R} \left[\left(\frac{\Pi_t}{\bar{\Pi}}\right)^{\phi_{R,\Pi}} \left(\frac{y_{FP,t}}{y_{FP,ss}}\right)^{\phi_{R,y}}\right]^{1-\rho_R} e^{z_{R,t}}$$

where $\phi_{R,\Pi}$ and $\phi_{R,y}$ are the long-term responses of monetary policy to the inflation gap and the output gap, respectively. The degree of interest rate smoothing is given by ρ_R, and $z_{R,t}$ represents a monetary policy shock and follows an AR(1) process.

3.4.2 Fiscal policy

3.4.2.1 Asset accumulation and the budget balance

The fiscal authority levies taxes on households, provides transfers to households, and purchases goods from the non-traded sector, g_t. In nominal terms, the primary oil-adjusted budget deficit of the government is given by

$$PBD_t = P_{N,t} g_t + P_t trnf_t - \tau^c P_t c_t - \tau^w W_t n_t - \tau^K DIV_t$$

where DIV_t is total profits/dividends from intermediate good producers, and $trnf_t$ is total transfers to savers and non-savers. Government debt, D_t, accumulates according to

$$D_t = R_{t-1} D_{t-1} + PBD_t - FR_t$$

where FR_t is the value of the withdrawal from the sovereign wealth fund in domestic currency. Due to offshore petroleum activity, the government receives a (net) cash flow from petroleum related activities in every period. This cash flow is transferred directly into the sovereign wealth fund. The objective of the paper is not to explain variation in the cash flow from petroleum related activities, and so it is assumed constant and denominated in domestic currency. Hence, the value of the sovereign wealth fund in foreign currency, Ω_t, evolves according to

$$\Omega_t = R_{SWF,t-1} \Omega_{t-1} + (OilRev - FR_t) / E_t.$$

3.4.2.2 Fiscal rules

Closing the fiscal sector requires specifying the behavior of tax rates, government spending, transfers, and the model of the fiscal rule withdrawal. Historically tax changes following tax reforms have not been motivated by business cycle variation and hence marginal tax rates are assumed constant [4] and only expenditures adjust to fluctuations in the fund's value. In the following I refer to fluctuations in expenditure variables due to fluctuations in the fund value as medium term. This follows the terminology

[4] Since the introduction of the fiscal rule, there have been three major reforms. First, the reform in 2006 was motivated by increased compliance to EU rules and reducing the opportunities for tax avoidance (Alstadsæter et al., 2006, p. 56 paragraph 4.2)). Second, the pension reform was motivated by sustainability of the pension system. Finally, the tax reform in 2014 was motivated by global developments in business taxation (NOU 2014:13, 2014)).

in Corsetti et al. (2012) in which feedback from debt to government consumption is referred to as medium-term movements in government consumption.

Real government consumption expenditure is determined by two components reflecting the short- and medium-term components, respectively,

$$g_t^{ST} = \overline{g}e^{z_{g,t}} \tag{25}$$

$$g_t^{MT} = \psi_{g,FR}\frac{FR_t^{MT} - FR_{ss}^{MT}}{P_{N,t}} \tag{26}$$

$$g_t = g_t^{ST} + g_t^{MT}. \tag{27}$$

where $z_{g,t}$ represents discretionary expenditure changes, and follows an AR(1) process. The parameter $\psi_{g,FR}$ determines the sensitivity of government consumption to variations in the withdrawals from the fund.

The fiscal policy framework requires all deficits to be financed by withdrawals from the sovereign wealth fund. To ensure this property of the fiscal framework, transfers to households adjust to ensure zero debt. This implies that the primary budget deficit is financed by the transfer from the sovereign wealth fund

$$PBD_t = FR_t \tag{28}$$

and the withdrawal is equal to the budget deficit.

The fiscal rule withdrawal is specified according to the government's objectives of spending a fraction of the fund equal to the expected long-run real rate of return every year, avoiding large year-to-year withdrawals, and yielding a counter-cyclical level of transfers to households.

The withdrawal from the sovereign wealth fund is separated in two components to capture these effects; a component due to short-term concerns, FR^{ST}, and one due to medium-term concerns FR^{MT}

$$FR_t = FR_t^{ST} + FR_t^{MT}. \tag{29}$$

The short-term component is driven by business cycle developments domestically, e.g. variation in tax revenue, whereas the medium-term component captures the Fiscal Rule and how the withdrawal depends on the fund value.

First, the medium-term component of the withdrawal from the fund depends on the deviation of the size of the fund from it's steady-state value according to

$$\frac{FR_t^{MT}}{P_t} = \rho_{FR}\frac{FR_{t-1}^{MT}}{P_{t-1}} + (1-\rho_{FR})\,\overline{fr} + \gamma_{FR}\left(\frac{\Omega_{t-1}E_{t-1}}{P_{t-1}}\frac{P_{t-1}}{P_t} - \omega_{ss}\right) \tag{30}$$

where $\overline{fr}$ is the steady-state level of the withdrawal from the fund in consumption units, and determines the model-equivalent of the structural oil adjusted budget deficit, and ω_{ss} is the steady-state value of the fund in domestic consumption units. The parameter γ_{FR} determines the pass-through of changes to the fund value to the size of the withdrawal (the Fiscal Rule), and ρ_{FR} determines the degree of smoothing. A higher value of ρ_{FR} implies a higher degree of smoothing of government expenditure. There are several reasons to smooth withdrawals. First, it prevents sharp adjustments of government consumption and transfers. Second, the political process may give rise to "sluggish" behavior; an initial increase in the fund value is difficult to reverse in the next quarter, or year. The value of the fund at the start of the year is the baseline for the budget year's withdrawal. Hence, it is the value of the fund given last period's real exchange rate which is the determinant of the medium-term component of the withdrawal. This also ensures that exchange rate fluctuations do not immediately affect spending.

To understand how the medium-term component of the withdrawal from the fund matters for transfers to households (the balancing item of the debt accumulation equation), assume that the economy is at steady state, but the medium-term component differs from its steady state value. Substitute for the primary budget deficit, and the fund withdrawal in equation (28) to obtain

$$P_t\left(trnf_t - trnf_{ss}\right) = \left(1-\psi_{g,FR}\right)\left(FR_t^{MT} - P_t\overline{fr}\right) \tag{31}$$

Hence, $1-\psi_{g,FR}$ determines the sensitivity of transfers to changes in the fund value.

The short-term withdrawal depends on business cycle variation in tax revenue, discretionary government consumption, and employment from their respective steady-state values in the following way

$$\frac{FR_t^{ST}}{P_t} = -\phi_{FR,tr}\left(tr_t - tr_{ss}\right) + \phi_{FR,g}\left(p_{N,t}g_t^{ST} - p_{N,ss}\overline{g}\right) - \phi_{FR,n}w_{ss}\left(n_t - n_{ss}\right) \tag{32}$$

where $tr_t \equiv \tau^c c_t + \tau^w w_t n_t + \tau^K div_t$ is real tax revenue, where $w_t = W_t/P_t$ and $div_t = DIV_t/P_t$ are real wages and dividends, respectively. Depending on coefficients in the rule, this allows the model-equivalent of the cyclical oil adjusted budget deficit in figure 1 to deviate from zero in response to domestic business cycle developments. To interpret the consequences of this rule, it is useful to substitute for the sovereign wealth fund withdrawal, and the primary budget deficit in equation (28). Assume that the fund is at its steady-state value such that the medium-term component of the withdrawal is zero. Then we have that

$$trnf_t - trnf_{ss} = \left(1-\phi_{FR,tr}\right)\left(tr_t - tr_{ss}\right) - \left(1-\phi_{FR,g}\right)\left(p_{N,t}g_t^{ST} - p_{N,ss}\overline{g}\right) - \phi_{FR,n}w_{ss}\left(n_t - n_{ss}\right) \tag{33}$$

This specification nests multiple potential assumptions about how transfers to households adjust to shocks in the economy. Assume first, at odds wit with the Fiscal Rule, that $\phi_{FR,tr} = \phi_{FR,g} = \phi_{FR,n} = 0$. From equation (32), this captures a situation in which the fiscal authority does not withdraw resources from the fund to make up for below steady-state tax revenue, and employment, or above steady-state government consumption expenditure. To ensure that there is no debt (in line with the Fiscal Rule), the fiscal authority reduces transfers to household. Hence, the coefficient on the tax revenue and government consumption expenditure gaps in equation (33) are one. Second, assume $\phi_{FR,tr} = \phi_{FR,g} = 1$. In this case, the government finances short-term fluctuations in tax revenue and government consumption expenditures with withdrawals from the sovereign wealth fund, and thereby avoids fluctuations in transfers to households over the business cycle. This is in line with the intentions in the Fiscal Rule, as the government uses the fund to smooth variations in revenue. Finally, the rule generates counter-cyclical transfer to households, when $\phi_{FR,tr} = \phi_{FR,g} = 1$ and $\phi_{FR,n} > 0$. This corresponds to the baseline calibration.

We can summarize the consequences of a zero-debt policy for transfers to households in a similar way as the decomposition of government consumption

$$\begin{aligned}
trnf_t^{ST} &= \left(1-\phi_{FR,tr}\right)\left(tr_t - tr_{ss}\right) - \left(1-\phi_{FR,g}\right)\left(p_{N,t}g_t^{ST} - \overline{g}\right) - \phi_{FR,n}w_{ss}\left(n_t - n_{ss}\right) \\
trnf_t^{MT} &= trnf_{ss} + \left(1-\psi_{g,FR}\right)\left(\frac{FR_t^{MT}}{P_t} - \overline{fr}\right) \\
trnf_t &= trnf_t^{ST} + trnf_t^{MT}
\end{aligned}$$

3.5 Market clearing and aggregation

Market clearing in intermediate goods and labor markets yield

$$A_N Z_t n_{N,t}^{\alpha_N} = v_{N,t} \left(c_{N,t}^{Agg} + g_t \right) \tag{34}$$

$$A_H Z_t n_{H,t}^{\alpha_H} = v_{H,t} \left(c_{H,t}^{Agg} + c_{H,t}^{*} \right) \tag{35}$$

$$n_t = v_{W,t} \left(n_{N,t} + n_{H,t} \right) \tag{36}$$

where

$$c_{H,t}^{*} = \left(\frac{P_{H,t}/E_t}{P_t^{*}} \right)^{-\eta_H^{*}} \bar{c}_H^{*} \tag{37}$$

$$v_{j,t}^{1/\alpha_j} = \theta_j \left(\iota_{j,t}/\Pi_{j,t} \right)^{-\epsilon_j/\alpha_j} v_{j,t-1}^{1/\alpha_j} + (1-\theta_j) \left(p_{j,t}^{\#}/p_{j,t} \right)^{-\epsilon_j/\alpha_j}, \quad j = N, H \tag{38}$$

$$v_{W,t} = \theta_W \left(\iota_{W,t}/\Pi_{W,t} \right)^{-\epsilon_W} v_{W,t-1} + (1-\theta_W) \left(w_t^{\#}/w_t \right)^{-\epsilon_W} \tag{39}$$

$$\iota_{j,t} = \Pi_{j,t-1}^{\chi_j} \Pi_{ss}^{1-\chi_j}, \quad j = N, H, W \tag{40}$$

where $c_{H,t}^{*}$ is foreign demand for domestic export goods, $v_{j,t}$ are price, and wage dispersion due to Calvo frictions, and lower-case letters refer to prices relative to the consumer price index. Aggregate consumption demand and transfers are given by $x_t^{Agg} = \gamma_{ns} x_t^{ns} + (1-\gamma_{ns}) x_t^{s}$, $x = c_N, c_H, c_F, c, trnf$. Labor effort is identical across households implying $n_t^{Agg} = n_t^{ns} = n_t^{s}$. Only savers have assets and receive dividends, implying $x_t = (1-\gamma_{ns}) x_t^{s}$, $x = DIV_N$, DIV_H, B_F. Domestic bonds are in zero net supply

$$B_{H,t} = 0 \tag{41}$$

3.5.1 Exogenous AR(1) processes

The exogenous AR(1) processes driving the productivity shifter, the monetary policy shock, and the government consumption shock are given by

$$\log(Z_t) = \rho_Z \log(Z_{t-1}) + u_{Z,t} \tag{42}$$

$$z_{R,t} = \rho_{z,R} z_{R,t-1} + u_{R,t} \tag{43}$$

$$z_{g,t} = \rho_{z,g} z_{g,t-1} + u_{g,t}, \tag{44}$$

respectively, where the ρ's are the persistence of the shocks.

4 Model calibration

This section describes the calibration of the model. I first describe the parameters which determine the steady state, and next the remaining parameters of the model. The steady state of the baseline calibration is calibrated to match shares in consumer price index, the size of the non-petroleum trade balance and the size of government variables relative to mainland GDP, and effective marginal tax rates in the period from 2014Q1 to 2018Q4. This reflects a period with a large sovereign wealth fund relative to GDP. Dynamic parameters are chosen to match parameter estimates in estimated DSGE models of Norway, and microeconomic estimates where feasible.

National accounts and consumer price index data are collected from Statistics Norway, the market value of the fund is taken from Macrobond, and data used to calculate effective marginal tax rates are collected from the OECD.

Parameter	Description	Value
Households		
γ_{ns}	Share of non-savers in the economy	0.3
ϕ_b	Risk premium sensitivity to NFA	0.0001
σ	Intertemporal elasticity of substitution	1
h_c	Habit persistence	0.85
ψ	Inverse of the Frisch elasticity	3
β	Utility discount factor	0.9975
γ	Expenditure share of non-traded goods	0.489
α	Share of exports in traded basket	0.393
θ_c	Elasticity of subst. T-NT goods	0.5
η	Elasticity of subst. H-F goods	0.5
ϵ_j	Intermediate goods substitution, $k = N, H, F$	6
Firms		
α_N	Labor-intensity in N-sector	0.754
α_H	Labor-intensity in H-sector	0.718
θ_N	Calvo parameter in N-sector	0.87
θ_H, θ_F	Calvo parameter in H,F-sector	0.75
χ_j	Degree of indexation to lagged CPI inflation, $k = N, H, F$	1
Foreign sector		
η_H^*	Export demand elasticity	0.5
Labor market		
ϵ_W	Elasticity of substitution between professions	2.5
θ_W	Calvo parameter in wage setting	0.82
χ_W	Degree of indexation to lagged wage inflation	1
Monetary policy rule		
ρ_R	Monetary policy smoothing	0.85
$\phi_{R,\Pi}$	Monetary policy long-run inflation response	2
$\phi_{R,y}$	Monetary policy long-run output response	0.125
$\log\left(\bar{\Pi}\right)$	Steady-state inflation rate	0.5%
Exogenous processes AR(1), shock persistence		
ρ_Z	Technology shock	0.7
$\rho_{z,R}$	Monetary policy	0
$\rho_{z,g}$	Government consumption	0.7
Fiscal policy rules		
Medium-term component		
ρ_{FR}	Medium-term withdrawal smoothing	0.9
γ_{FR}	Withdrawal rate (quarterly)	1%
Short-term component		
$\phi_{FR,tr}$	Tax revenue replacement	1
$\phi_{FR,g}$	Government consumption replacement	1
$\phi_{FR,n}$	Transfer response to employment	0.6
Government consumption		
$\psi_{g,FR}$	Sensitivity to medium-term component	0.45
Tax rates		
τ^c	Effective tax rate on consumption	0.263
τ^w	Effective tax rate on labor income	0.419
τ^K	Effective tax rate on capital income	0.193

Table 1: Overview of calibrated parameters. See text for details.

Variables relative to GDP	Value
Household consumption	0.82
Exports	0.16
Imports	0.25
Government consumption	0.28
Government transfers to households	0.34
Tax revenue	0.55
Fiscal rule transfer	0.07
NFA of households	2.55
Sovereign wealth fund	2.67
Government debt	0.00
Employment, sectoral ratios and prices	
Labor income share	0.62
Employment rate	0.96
Relative employment (NT-T)	2.23
Relative production value (NT-T)	2.12
Annual real interest rate	1.0%
Annual inflation rate	2.2%
Annual, nominal, SWF return	6.2%

Table 2: Calibration targets and steady-state values in the model.

4.1 Steady-state parameters

The share of wage costs in value added in the two intermediate goods producing sectors is given by $\alpha_j/\mu_j, j = H, N$. Following (Kravik and Mimir, 2019) and Aursland et al. (2020), the markup in all sectors is set to 1.2. This implies an elasticity of substitution between intermediate goods in the three sectors of 6. The elasticity of value added with respect to labor, α_j, is set to match the share of wage costs in value added in the two sectors. The wage share in the traded sector is 59.9 percent and 62.9 in the non-traded sector. This gives an α_H of 0.718 and an α_N of 0.754. Following Kravik and Mimir (2019) the elasticity of substitution among labor services, ϵ_W, is set to 2.5.

The share parameters of the consumption aggregates are chosen to match the import share in the consumer price index, and the share of service expenditure in household expenditures.[5] Over the sample period, the average share of imports in the CPI is 31.0 percent and the expenditure share of services in household consumption is 48.9 percent, yielding a γ of 0.489 and α of 0.393. The steady-state level of households' net foreign assets, $\bar{b}_F$, is set to match the sample non-petroleum trade balance to mainland GDP ratio of minus 9.8 percent.

The utility discount factor is set to obtain a steady-state real interest rate of one percent annually, yielding a β of 0.9975.[6] Steady-state inflation, $\bar{\Pi}$, is set to 1.005 to match an average inflation rate of the calibration period of 2.2 percent annually. The steady-state real rate of return of the fund is calibrated to four percent annually to match the expected real return in the early part of the calibration period. Hence, the steady-state nominal return is 6.2 percent given the assumption of no steady-state nominal exchange rate changes, and equal real interest rates domestically and abroad.

The steady-state level of government consumption, and the sovereign wealth fund are set to match the average value of government consumption, and the sovereign wealth fund to mainland GDP ratio

[5] Service and goods consumption expenditures are used as proxies for the consumption of non-tradable and tradable goods.

[6] The average real interest rate of the sample is negative, and a real interest rate of one is chosen to achieve a discount factor lower than one.

of 27.9 percent, and 10.7 percent, respectively. Finally, the steady-state level of fiscal transfers is set to match the average size of the oil adjusted budget deficit to GDP ratio of 7.3 percent. Because the consequences of oil extraction and oil price variation is not the focus of analysis in this paper, the ratio of oil revenue to mainland GDP is determined residually to allow the model to match the budget surplus, and the sovereign wealth to GDP ratio.

The effective marginal tax rates are determined following the method outlined in Mendoza et al. (1994). For the calibration period this gives $\tau^c = 0.263$, $\tau^w = 0.419$, and $\tau^K = 0.193$.

4.2 Dynamic parameters

As in Kravik and Mimir (2019) and Aursland et al. (2020), the inverse of the Frisch elasticity, ψ, is set to 3 and the intertemporal elasticity of substitution, σ, is set to 1. These are common values in the literature. The labor disutility parameter is set to match the employment rate of 0.96. The habit persistence parameter, h_c, is set to 0.85 which is a typical value in the literature, and in line with the results in Bergholt et al. (2019).

The elasticity of substitution between traded and non-traded goods, θ_c, is set to 0.5. Akinci (2011) summarizes empirical estimates and find ranges below one for this parameter. Estimated DSGE models tend to find low elasticities of substitution between tradable goods, see Bodenstein (2010). DSGE-models of Norway such as Kravik and Mimir (2019) and Bergholt et al. (2019) use a value of one half, and one respectively. Due to the nested CES structure of the current model, a similar value could (ceteris paribus) result in a lower elasticity of the share of foreign traded goods in the consumption basket. In order to obtain a similar level of substitutability as in Kravik and Mimir (2019), η is set to 0.5[7]. Preferences in Home and Foreign are similar with η^* equal to 0.5.

Wulfsberg (2016) finds that the average duration of a price spell for services is approximately eight quarters, while two to three quarters for goods. Bergholt et al. (2019) find the same qualitative difference in pricing behavior between the two sectors, but a higher level of price rigidity in the manufacturing sector. In line with these studies, θ_N and θ_H are set to 0.87 and 0.75 respectively. Bergholt et al. (2019) find that nominal wages are more sticky than the price of manufacturing goods, but adjusted more frequently than prices in the service sector. Based on their results, I set θ_W to 0.82.

The degree of price indexation varies considerably across DSGE-models of the Norwegian economy. Kravik and Mimir (2019) assume full indexation to lagged inflation. Bergholt et al. (2019) estimate a low weight to lagged inflation and a high weight on steady-state inflation for prices, and an approximately equal weight for nominal wages. As in Kravik and Mimir (2019), all prices and wages are assumed to be fully indexed to lagged inflation. Hence, $\chi_j, j = N, H, F, W$ is set to 1.

There is significant smoothing in the key policy rate with a coefficient on the lagged interest rate, ρ_R, of 0.85, and a long-run response to inflation of 2. The output response, $\phi_{R,y}$, is set to 0.125. Under the baseline calibration, this is the highest value which avoids deflation in response to a persistent government consumption shock.

The withdrawal rate, γ_{FR}, from the sovereign wealth fund is set to 0.01, which corresponds to a four percent annual withdrawal rate. This is line with the long-term concerns of the fiscal rule (the Fiscal Rule) to spend the expected real return on the fund. Furthermore, the medium-term component of the withdrawal from the sovereign wealth fund is smooth with a ρ_{FR} of 0.9. A smooth medium-term component is consistent with the government's concern of smoothing large fluctuations in the fund value, as described in section 2. Real government consumption and transfers to households adjust to the medium-term component of withdrawals with rates $\psi_{g,FR}$ and $1 - \psi_{g,FR}$, respectively. The parameter $\psi_{g,FR}$ is set to 0.45 reflecting the steady-state share of government consumption expenditures in government spending[8].

[7] If the price of foreign goods increases by one percent in the current model, demand falls by $(1-\alpha)\,\theta + \alpha\eta$. η is chosen such that this expression is 0.5 as in Kravik and Mimir (2019). Because θ is 0.5, the solution is $\eta = 0.5$.

[8] I am indebted to Svein Gjedrem for suggesting this calibration.

Fluctuations in tax revenue are fully smoothed by withdrawals from the sovereign wealth fund, as described in section 2. Hence, $\phi_{fr,tr} = 1$. Furthermore, changes in nominal government consumption spending, are financed by withdrawals from the fund in the short-term, i.e. $\phi_{fr,g} = 1$. In models with government debt, these assumptions are akin to assuming debt-financing of the government deficit. Finally, transfers to households depend on employment status (e.g. unemployment insurance). Hence, the short-term component of the budget surplus depends on the use of labor with $\phi_{fr,n} = 0.6$. This value is close to the replacement rate of unemployment benefits [9]. Furthermore, the model does not separate between the extensive and intensive margin of labor supply. However, the deviation of total hours from trend can be decomposed into a gap reflecting the number of employed persons and a gap reflecting hours per person. Panel B of figure 2 shows that the gap is mostly driven by the number of persons working. Hence, $\phi_{fr,n}$ is set to capture how transfers depend on the employment in the economy.

5 Results

5.1 Impulse response functions

In this section, I consider a shock to the level of technology, monetary policy, and government consumption. The shock size is set to yield a peak effect on output of one percent. The sign of the shock is chosen to increase the budget deficit. The impulse response functions are generated by linearizing the model around the steady state using the DYNARE software (Adjemian et al., 2011).

5.1.1 Technology

Figure 3 displays the economy's response to the technology shock. Increased productivity reduces intermediate goods firms' marginal cost and firms reduce price growth. At lower prices output expands in both sectors. The expansion in output is smaller than the increase in productivity, due to rigidities in price setting. Hence, demand for labor falls in both sectors. Falling inflation dominates the effect of lower output, inducing the central bank to reduce the nominal interest rate. The real interest rate increases in the short-run but falls below its steady state value as the policy rate fully incorporates the fall in inflation. Savers expecting higher real interest rates increase consumption growth. Savers in the economy are wealthier following the productivity shock; at unchanged prices the quantity of production increases. Hence, savers increase consumption on impact and thereafter. Wealthier savers desire to work less and would increase the real wage. However, lower labor demand outweighs the wealth effect, and the real wage falls. Lower employment and real wages reduce consumption by non-savers, ceteris paribus. Transfers from the government mute the decline in labor income, and also the reduction in consumption by non-savers relative to labor income. The real exchange rate depreciates on impact for two reasons. First, the technology shock, ceteris paribus, increases the relative supply of domestic goods. To clear the market for domestic tradable and non-tradable goods the relative price of domestic goods in units of foreign goods (the inverse of the real exchange rate) falls. Second, temporarily higher productivity, ceteris paribus, raises the supply of domestic consumption goods today relative to the future and triggers a decline in the (expected) real interest rate to induce current consumption. A low expected return on domestic assets require an expected appreciation of the nominal exchange rate due to uncovered interest rate parity. To generate an expected appreciation, the real and nominal exchange rates depreciate on impact. Falling inflation after the shock lead to a hump-shape in the response of the real exchange rate. Furthermore, as the nominal interest rate is slow to adjust, the real interest rate increases in the first periods after the shock.

The exchange rate depreciation increases the value of the fund in domestic currency and thereby the medium-term component of the withdrawal from the fund. Hence, the technology shock leads to

[9] https://www.nav.no/arbeid/no/arbeidsledig/

increased government expenditure in the future through the medium-term component. While output increases, tax revenue raised by the government declines following the technology shock. The increase in output and decline of labor income implies a lower labor income share in the economy, and thereby a lower average tax rate. In response to lower tax revenue and higher transfers to households, the government draws on the resources in the sovereign wealth fund to finance the budget deficit. Over time the deficits reduce the fund value, exacerbated by the exchange rate depreciation. Hence, the fund value in domestic currency falls below its steady-state level, and the government reduces withdrawals to return the fund to its long-run level.

5.1.2 Monetary policy

Figure 4 displays the economy's response to the monetary policy shock. The monetary policy contraction increases the (expected) real interest rate and induces savers to reduce consumption. Consequently, firms reduce price growth and demand less labor, and unions set a lower real wage. Non-savers consume less due to the decline in labor income. The real exchange rate appreciates on impact to satisfy the uncovered interest rate parity condition.

The exchange rate appreciation reduces the value of the fund in domestic currency and thereby the medium-term component of the withdrawal, and hence the monetary policy shock leads to lower government expenditure in the future. Hence, government consumption expenditures fall following the initial increase due to a higher price of non-traded goods. The falling medium-term component of the withdrawal also implies that transfers will be lower and have a negative effect on consumption by non-savers. The short-term component of withdrawals increases to cover the increased budget deficit from lower tax revenues and higher transfers to households.

5.1.3 Government consumption

Figure 5 displays the economy's response to a government consumption shock. The government finances the increase in government consumption with withdrawals from the sovereign wealth fund in the short run.

The government consumption increase is a positive demand impulse to firms in the non-traded sector, which respond by higher price growth and a higher demand for labor. Both effects induce the central bank to raise the nominal interest rate, resulting in a higher real interest rate and an appreciated real exchange rate. Facing higher real interest rates and lower future transfers savers reduce consumption. Consuming less, savers desire to work more which puts downward pressure on the real wage. However, increased labor demand outweighs this effect and lead to a higher real wage. Non-savers increase consumption on impact as labor income increases, before falling below steady state as the employment effect fades and the wealth effect on real wages dominates.

The exchange rate appreciation reduces the value of the fund in domestic currency and thereby the medium-term component of the withdrawal. Hence, the government consumption shock leads to lower future government expenditure through the medium-term component. However, for consumption expenditures the effect is small compared to the initial shock. Furthermore, the effect on real government consumption expenditure is muted by a higher price of non-traded goods. The expansionary effects on output and labor income of the government consumption shock are important drivers of the withdrawal from the sovereign wealth fund. Three effects contribute. First, the level of output increases, increasing tax revenue. Second, labor's share of income increases, thereby increasing the average tax rate in the economy. Third, the employment increase reduces the need for transfers to households. In total these effects result in a high degree of self-financing of the government consumption shock in the short run, and a small response of the short-term component of the withdrawal from the fund. There is a second peak in the short-term component of the withdrawal due to production and labor utilization undershooting during the transition back to steady state. Hence, transfers to households increase.

The present value multiplier of output answers the question: by how much does the present value of output increase over the next k quarters relative to the present value of government consumption over the same period? The present value multiplier is defined as Leeper et al. (2017)

$$PVM(k) = \frac{\mathbb{E}_t \sum_{j=0}^{k} \left(\Pi_{i=0}^{k}\left(1 + r_{t+i}^{c}\right)\right) \hat{y}_{t+j}^{c}}{\mathbb{E}_t \sum_{j=0}^{k} \left(\Pi_{i=0}^{k}\left(1 + r_{t+i}^{c}\right)\right) \hat{g}_{t+j}^{c}}$$

where r_t^c is the consumption real interest rate, $\hat{y}_t^c$ is the deviation of the value of output in consumption units from its steady state value, and $\hat{g}_t^c$ is the corresponding deviation of government consumption expenditure from its steady-state value.[10]

The red line in figure 6 displays the present value multiplier when measuring the value of output and government consumption expenditure in current prices. The impact multiplier is 0.98 in the baseline calibration, which is high for open-economy models. The positive effect on output of higher real government consumption declines at a faster rate than the effect on government consumption expenditure. Hence, the present value multiplier is lower at longer horizons. The present value converges to 0.74 in the long-term.

The unit of measurement of output and government consumption expenditure is rarely discussed in empirical studies of government spending multipliers. Hall (2009) argues for using data in chained prices for both GDP and government consumption, while studies often deflate nominal series with a common price index (Ramey and Zubairy, 2018). Depending on the choice of deflator, the researcher might capture effects coming from relative prices in their estimate of the multiplier. The dashed and dotted, blue, line in figure 6 represents the present value multiplier calculated by holding prices and the interest rate constant, in line with the approach taken by Hall (2009). The government consumption shock increases the relative price of domestically produced goods and thereby increases the relative price of output. Hence, multipliers calculated using data in current prices with a common deflator, runs the risk of exaggerating the multiplier. The discrepancy between the two present value multipliers falls as the horizon increases, and both converge to a value 0.74.

5.2 Transmission of shocks and the size of the sovereign wealth fund

In this section, I analyze the consequences of the sovereign wealth fund's size for the propagation of domestic business cycle shocks. To assess the role of the fund's size in the propagation of shocks, I recalibrate the budget deficit to GDP ratio and the size of the fund relative to GDP to their average values in the 2002 to 2006 period. Henceforth I refer to this calibration as the small-fund steady state, and the previous calibration (based on the 2014 to 2018 period) as the baseline calibration.

How does the size of the sovereign wealth fund affect the propagation of the shocks? First, mechanically, the larger is the fund the more its value moves relative to steady-state GDP in response to a shock. Second, the effect on the budget deficit (i.e. the total withdrawal) depends on the conditional correlation between the exchange rate and the short-term component of the withdrawal caused by the shock. A positive correlation increases the budget deficit and thereby increases government expenditure with a larger fund. Hence, with a larger fund government expenditure increases, relative to the small-fund period, following the shock. Finally, whether a larger fund amplifies or mitigates the propagation of a shock to a variable depends on how the components of government expenditure affects the variable.

Figure 7 shows that following a technology shock, the exchange rate effect dominates the fall in fund value due to lower tax revenue and higher transfers to households. Thus, the fund increases, rather than declines, in value in the latter calibration period. Hence, with a larger fund the medium-term component of the withdrawal, and thereby government expenditures, increase following a technology

[10] Ramey (2019) discusses the use of alternative definitions of the government spending multiplier and concludes that definitions which capture the cumulative effects on output and spending are preferable relative to definitions using period-by-period deviations of output and spending from steady state.

shock. Consequently, transfers to households increase and consumption by non-savers is more procyclical than with a small fund. In contrast, government consumption crowds out household consumption relative to the small-fund steady state and reduces consumption by savers. Thus, the fund's size reduces differences in consumption outcomes, but does not affect aggregate consumption. Furthermore, the real exchange rate depreciates by less to induce households to consume less non-traded goods. Finally, with a larger fund government consumption is positively correlated with output and amplifies movements in output, hours, and real wages. The amplification of hours and real wages also contribute to make consumption by non-savers procyclical.

The mechanical exchange rate effect in response to a monetary policy shock triples as the fund increases in size, as can be seen in figure 8. Consequently, a larger fund increases future reductions in government expenditures. Larger reductions in real government consumption and transfers to households, amplify the propagation of the shock to output, hours, real wages, and consumption by non-savers. The decline in real government consumption and corresponding crowding in of consumption by savers, is not enough to cancel out the exaggerated decline in consumption by non-savers. Hence, household consumption is also more procyclical, and closer to the consumption response by savers. Hence, the difference in consumption outcomes declines relative to the small-fund steady state.

A larger fund has relatively small effects for the propagation of the government consumption shock, as can be seen in figure 9. The larger fund implies that real exchange rate effect forces the deficit and government consumption back to steady state at a quicker rate. This in turn implies less crowding out of savers' consumption and a larger decline (and smaller initial increase) in consumption by non-savers. Thus, a larger fund reduces the difference in consumption outcomes between savers and non-savers following the shock. Overall the size of the fund has small consequences for the output response to the shock.

6 Robustness

In this section, I analyze whether the results regarding the size of the fund are sensitive to model assumptions. The shock size is kept constant across the simulations, and hence the peak impact of output might differ from one. First, I consider a case without nominal and real rigidities. Next, I consider the role of shock persistence.

6.1 The role of nominal rigidities

In these simulation, I set the Calvo-parameters, indexation, and habit persistence parameters to zero. The real exchange rate exhibits larger movements on impact and is less persistent in the friction-free economy. Hence, nominal rigidities reduce the impact of the size of the fund on the medium-term component of the fund withdrawal.

For a technology shock, the absence of rigidities implies that output, consumption, and real wages increase on impact. Furthermore, the decline in hours worked is much smaller (not shown), and the price of non-traded goods declines on impact. Consequently, the short-term component of the withdrawal and the total withdrawal *decline*. The increase in the medium-term component of withdrawals, due to a larger fund, increases real government consumption (the plot shows government consumption expenditure), and therefore also output and employment relative to the small-fund steady-state. Furthermore, the transfers to households increase, and a larger fund increases the volatility of consumption by non-savers. However, consumption by savers is crowded out and a larger fund reduces differences in consumption outcomes following the shock. Overall, consumption is less volatile with a larger fund in the absence of rigidities. While, the qualitative effects remain when there are no rigidities, the relative effect is smaller.

A shock to government consumption reduces output by less in the absence rigidities of due to more crowding out of consumption by savers. Hence, the spending reversal triggered by the medium-term component plays a relatively larger role in output. As movements in consumption are larger, the quantitative role of the size of the fund is relatively smaller in consumption by the two household types. However, a larger fund contributes to more equal consumption outcomes.

6.2 The role of shock persistence

In this section, I consider the effect of increasing the persistence of the technology and government consumption shocks, ρ_Z and $\rho_{z,G}$ respectively, from 0.7 to 0.9. I do not consider the monetary policy shock, as there is endogenous persistence in the policy rule. Increased shock persistence increases the real exchange rate response on impact and its longevity, thus reinforcing the consequences of a larger fund. Consequently the real exchange rate effect plays a larger role in the expenditure components and the budget deficit. The qualitative responses are similar as in the baseline calibration. However, there is more crowding out of consumption by savers which reduces the difference in the maximum impact on consumption between the two steady states.

7 Conclusion

In this paper, I have studied the consequences of a larger sovereign wealth fund for the propagation of business cycle shocks within the context of a dynamic stochastic general equilibrium model for the Norwegian economy. I found that a larger fund amplifies the effect of technology and monetary policy shocks on output, while the effect on output from a government consumption shock is muted (in particular for more persistent shocks). A larger fund reduces the effect of technology and government consumption shocks on aggregate consumption, while increases the effect of a monetary policy shock. A larger fund lead to more equal consumption outcomes following the shocks I consider.

The current paper is an analysis of the positive consequences of a fiscal rule which ties withdrawals to the domestic-currency value of an increasingly large fund, but suggest alternatives for the fiscal authority on how to treat exchange rate effects to smooth variations in output. For example, supply shocks, like the technology shock, cause a positive correlation of output and the real exchange rate on impact. Hence, conditional on observing a simultaneous depreciation (apprecation) of the real exchange rate and positive (negative) output growth, the government could choose to ignore the change in the fund's value when deciding on the level of withdrawals, and thereby reduce the increase (decrease) in output coming from having a larger fund. However, this would come at the cost of increasing the decline in employment. Alternatively, the fiscal authority can adjust the degree of pass-through from the exchange rate to fund withdrawals based on whether the real exchange rate and output are above or below their long-term levels. The advice is simple in theory, however, identifying the long-term level of output and the real exchange rate is a challenging task. Even if there is a reliable method to identify these components in real-time, further analysis is required whether it would be optimal.

The analysis might benefit from several extensions. First, in the analysis, I do not allow for discretion on the part of the fiscal authority. This implies a naive reaction to changes in the fund's value. Such behavior contrasts to the conclusion in NOU 2015:9 (2015), which concludes that flexibility in the implementation of the rule was a key component of its success. Hence, a more complete analysis should assess how discretionary deviations from the rule matters for the propagation of business cycle shocks. Treating withdrawals from the fund as the outcome of a maximization problem might resolve the issue. Temporary exchange rate changes, as in the current analysis, represent temporary income variations and should according the permanent income hypothesis lead to small changes in spending. However, adopting a maximization-perspective would not, necessarily, resolve concerns of how to implement discretion on the part of policy makers. Second, temporary shocks may have permanent effects on the level of sovereign wealth fund. This might be the case for the shocks studied in this paper, but is even more likely for shocks originating in the foreign sector. For example, the fiscal authority might not reduce future withdrawals to counteract large negative returns on the investment portfolio, or in response to lower oil prices. Furthermore, shocks originating in the foreign sector which lead to large changes in the fund value might be correlated, aggravating the decline in the fund value. I leave these concerns for future research.

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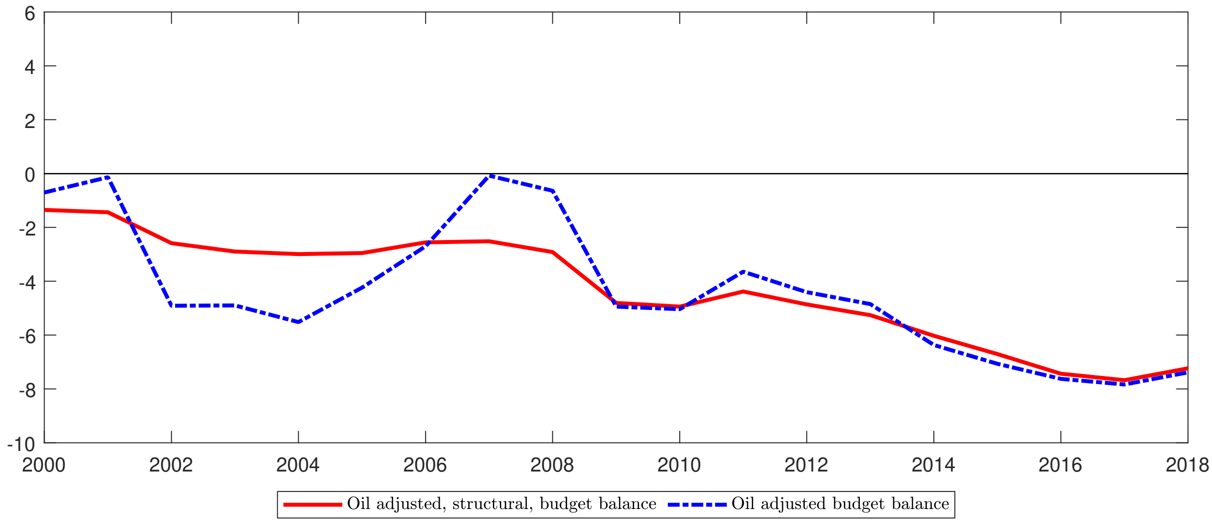
A Data plots

A.1 The budget deficit

Panel A



Panel B

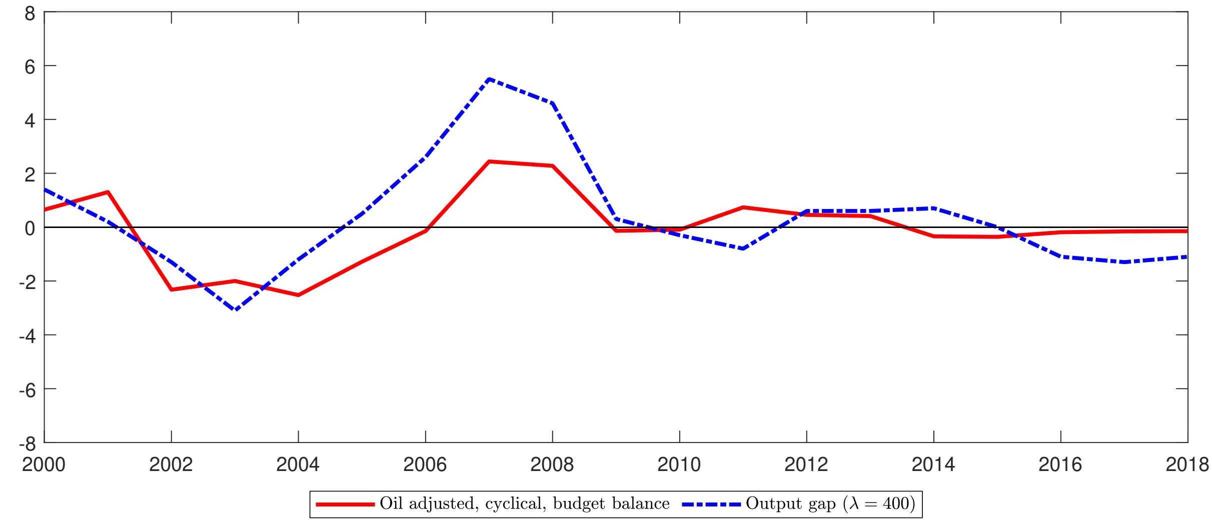


Figure 1: The development of different measures of the budget balance in Norway as a share of trend GDP since 2002. Panel A compares the the structural budget balance with the actual budget balance, both as a share of trend mainland GDP. Panel B plots the cyclical budget balance as a share of GDP, and the output gap. The trend value of mainland GDP is calculated using a two-sided Hodrick-Prescott filter with a smoothing parameter of 400. Source: Meld. St. 1 (2019 -2020) (2019).

A.2 Hours decomposition

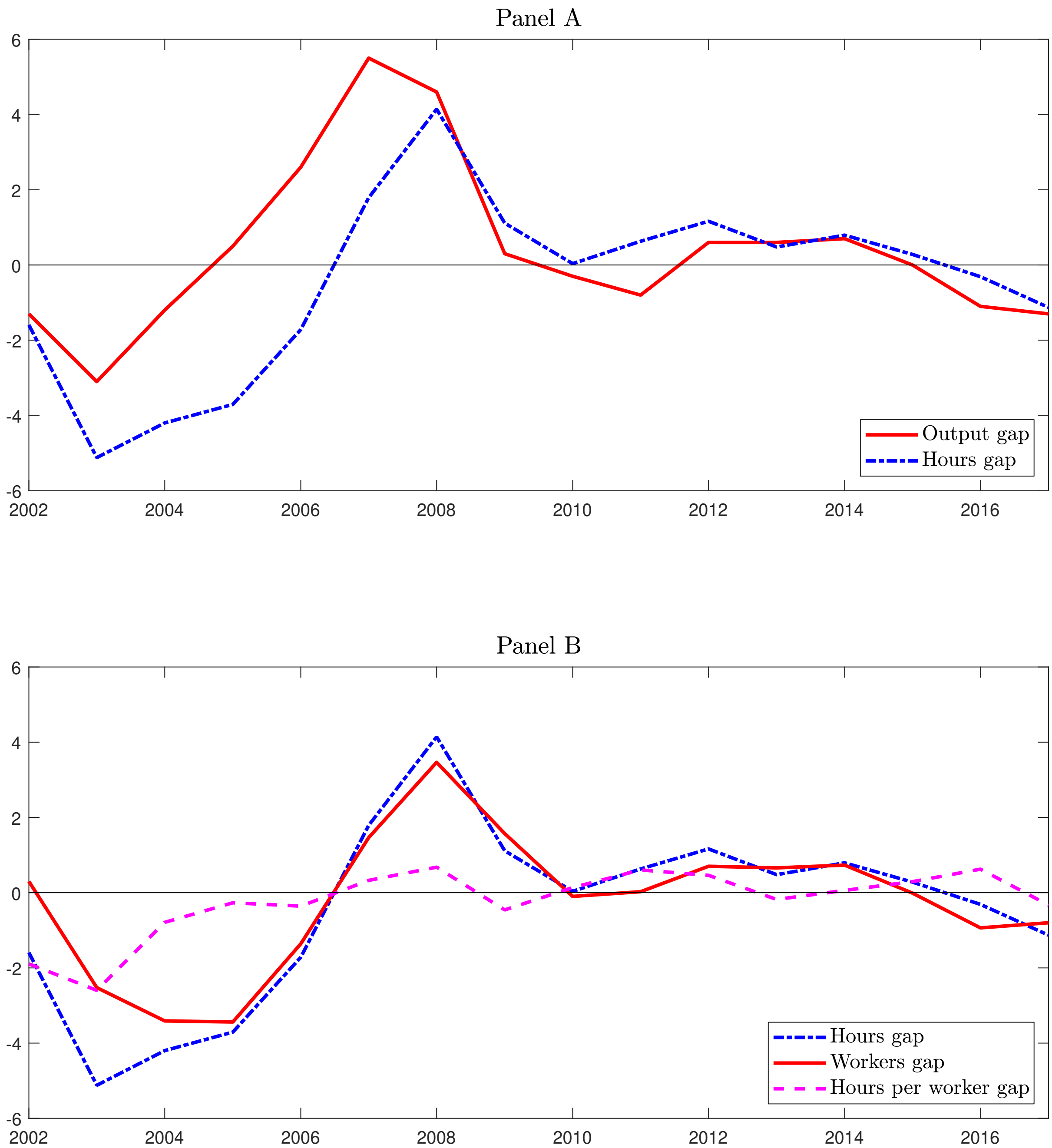


Figure 2: Panel A: the output gap for the mainland economy and the gap in total hours worked by employees in the mainland economy. Panel B: the contributions of hours worked per employee and the number of employees to the gap in total hours worked in the mainland economy. Gaps constructed using the two-sided Hodrick-Prescott filter with smoothing parameter of 400. Sources: Meld. St. 1 (2019 -2020) (2019) and SSB.

B Results

B.1 Impulse responses functions - baseline calibration

Technology shock

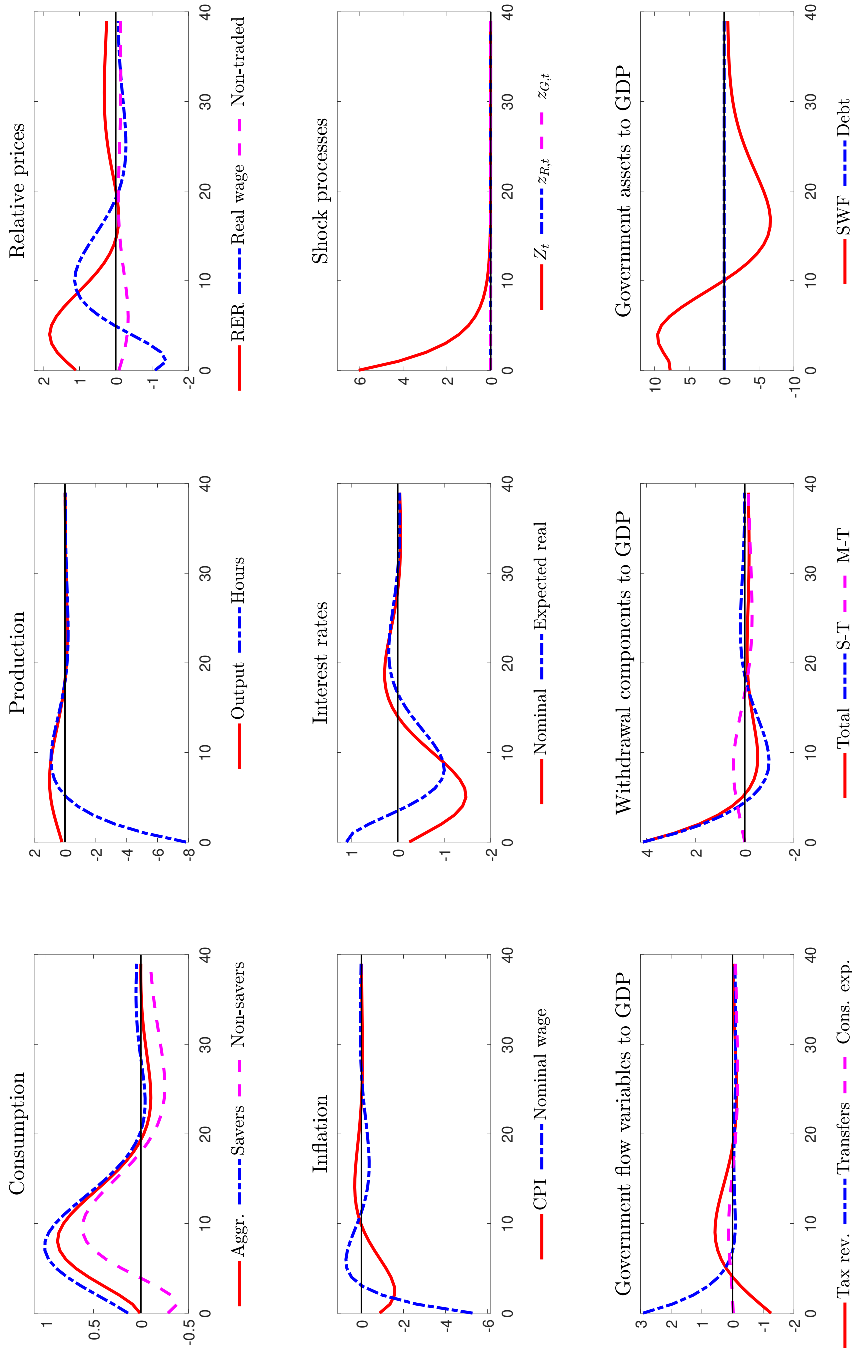


Figure 3: Impulse response functions for a technology shock in both sectors, $u_{Z,t}$, in equation (42). Real variables and relative prices are in percent deviation from steady state, nominal variables and the expected real interest rate are annualized and in percentage point deviations from steady state, fiscal variables are ratios to steady-state quarterly GDP and represented as percentage point deviations from steady state. S-T and M-T refer to the short-term and medium-term component of the withdrawal from the fund respectively.

Monetary policy shock

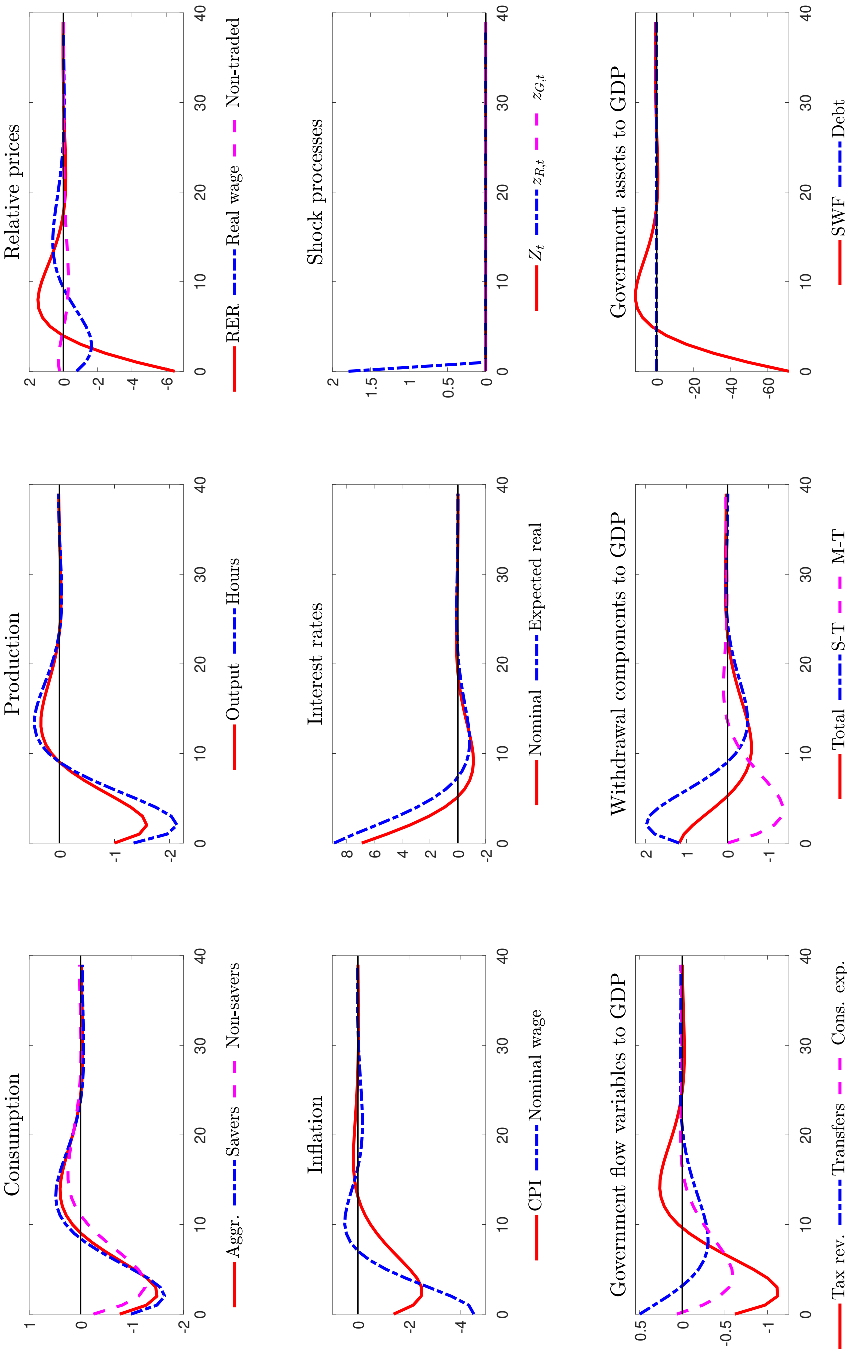


Figure 4: Impulse response functions for a monetary policy shock, $u_{R,t}$, in equation (43). Real variables and relative prices are in percent deviation from steady state, nominal variables and the expected real interest rate are annualized and in percentage point deviations from steady state, fiscal variables are ratios to steady-state quarterly GDP and represented as percentage point deviations from steady state. S-T and M-T refer to the short-term and medium-term component of the withdrawal from the fund respectively.

Government consumption shock

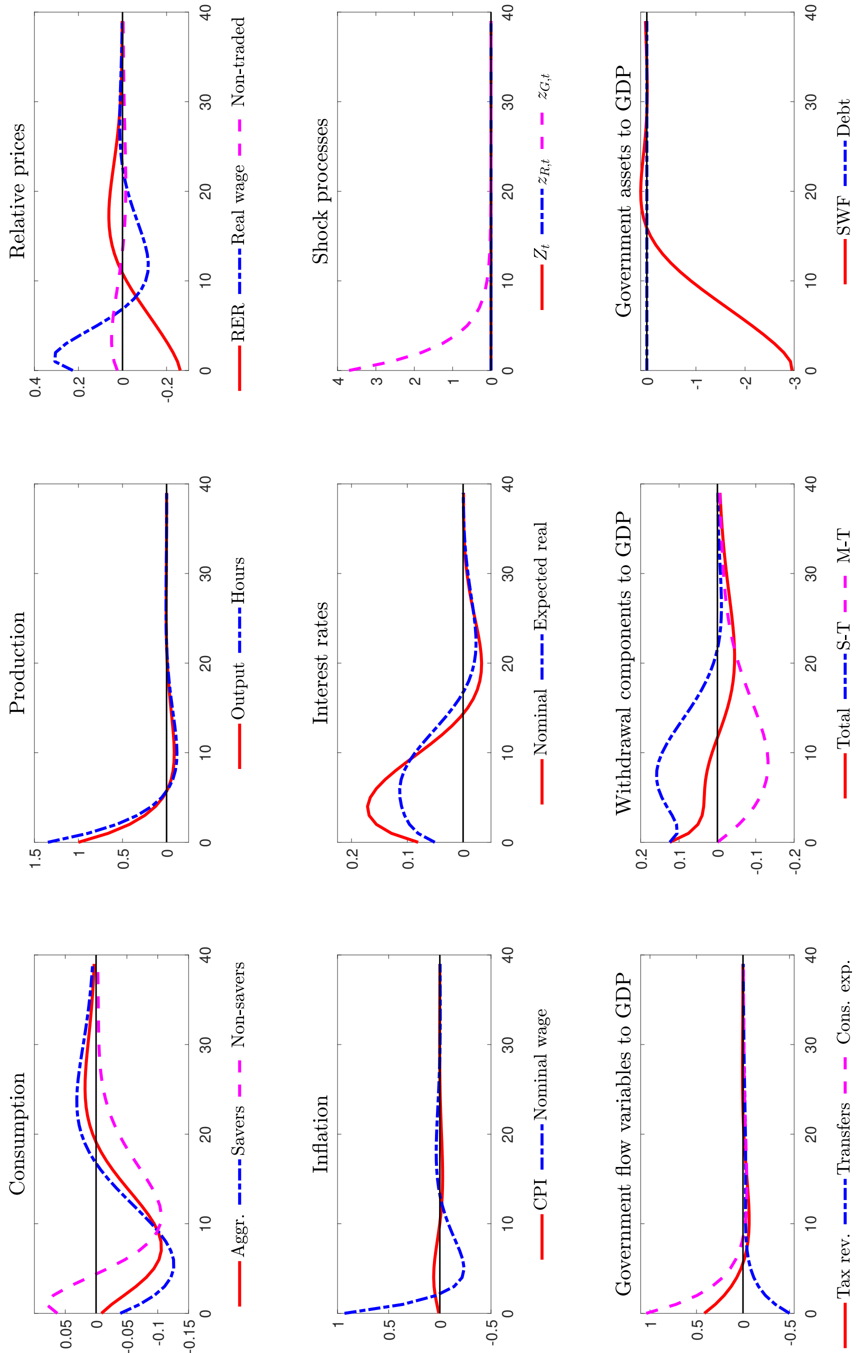


Figure 5: Impulse response functions for a government consumption shock, $u_{g,t}$, in equation (44). Real variables and relative prices are in percent deviation from steady state, nominal variables and the expected real interest rate are annualized and in percentage point deviations from steady state, fiscal variables are ratios to steady-state quarterly GDP and represented as percentage point deviations from steady state. S-T and M-T refer to the short-term and medium-term component of the withdrawal from the fund respectively.

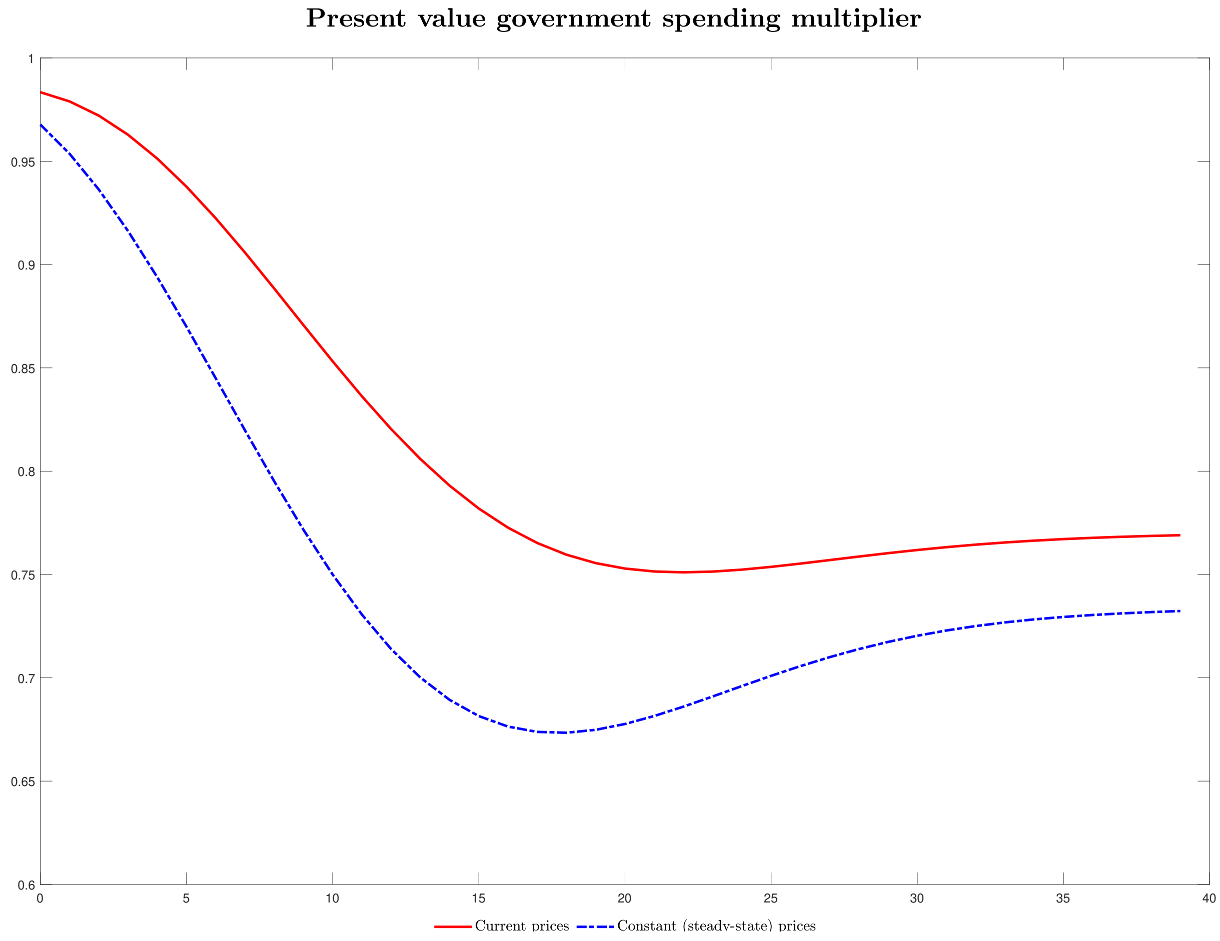


Figure 6: Present value government spending multiplier

B.2 The effect of fund size

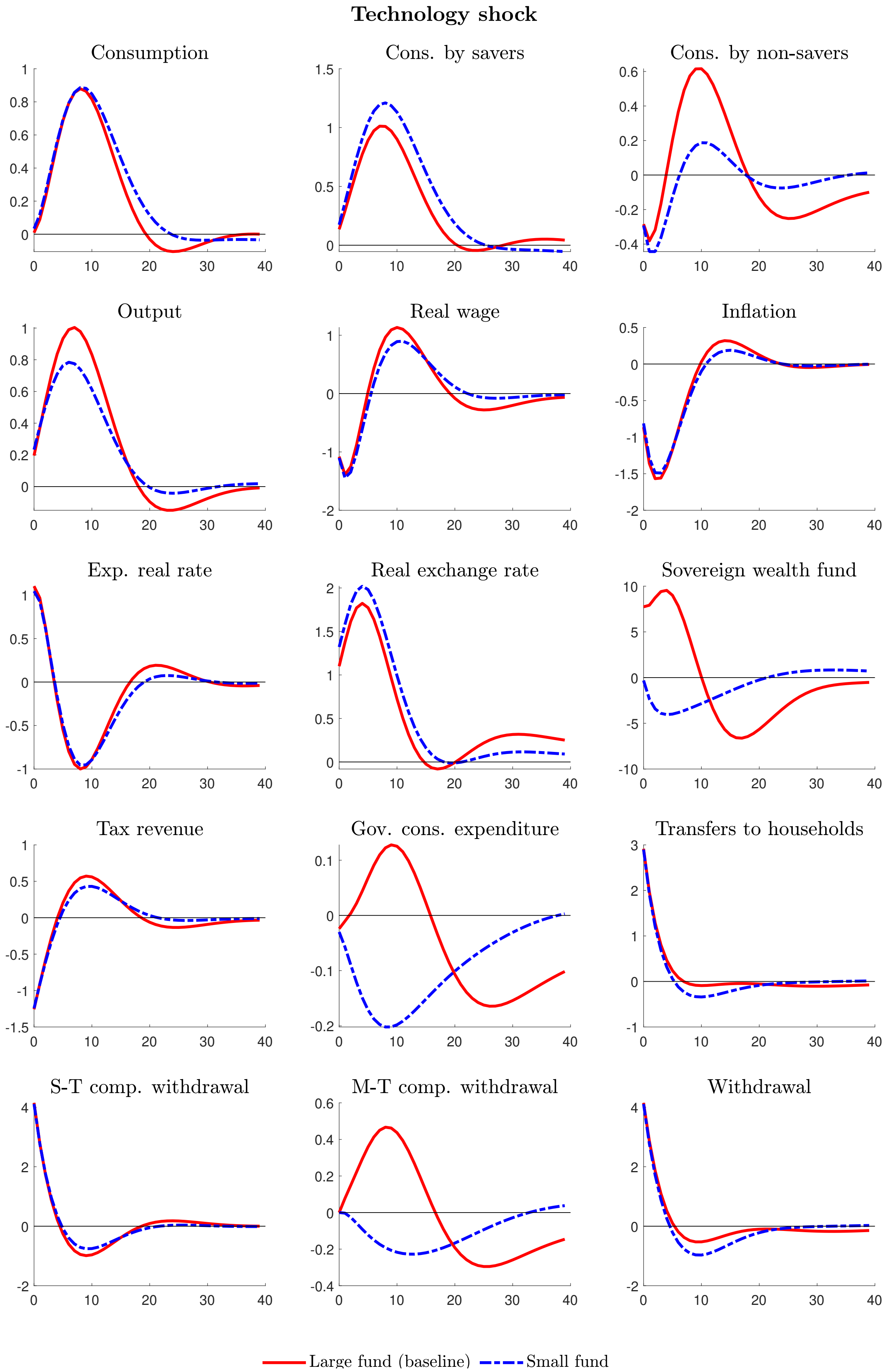


Figure 7: Impulse response functions for a technology shock in both sectors, $u_{Z,t}$, in equation (42). Real variables and relative prices are in percent deviation from steady state, nominal variables and the expected real interest rate are annualized and in percentage point deviations from steady state, fiscal variables are ratios to steady-state quarterly GDP and represented as percentage point deviations from steady state. S-T and M-T comp. withdrawal refer to the short-term and medium-term component of the withdrawal from the fund, respectively.

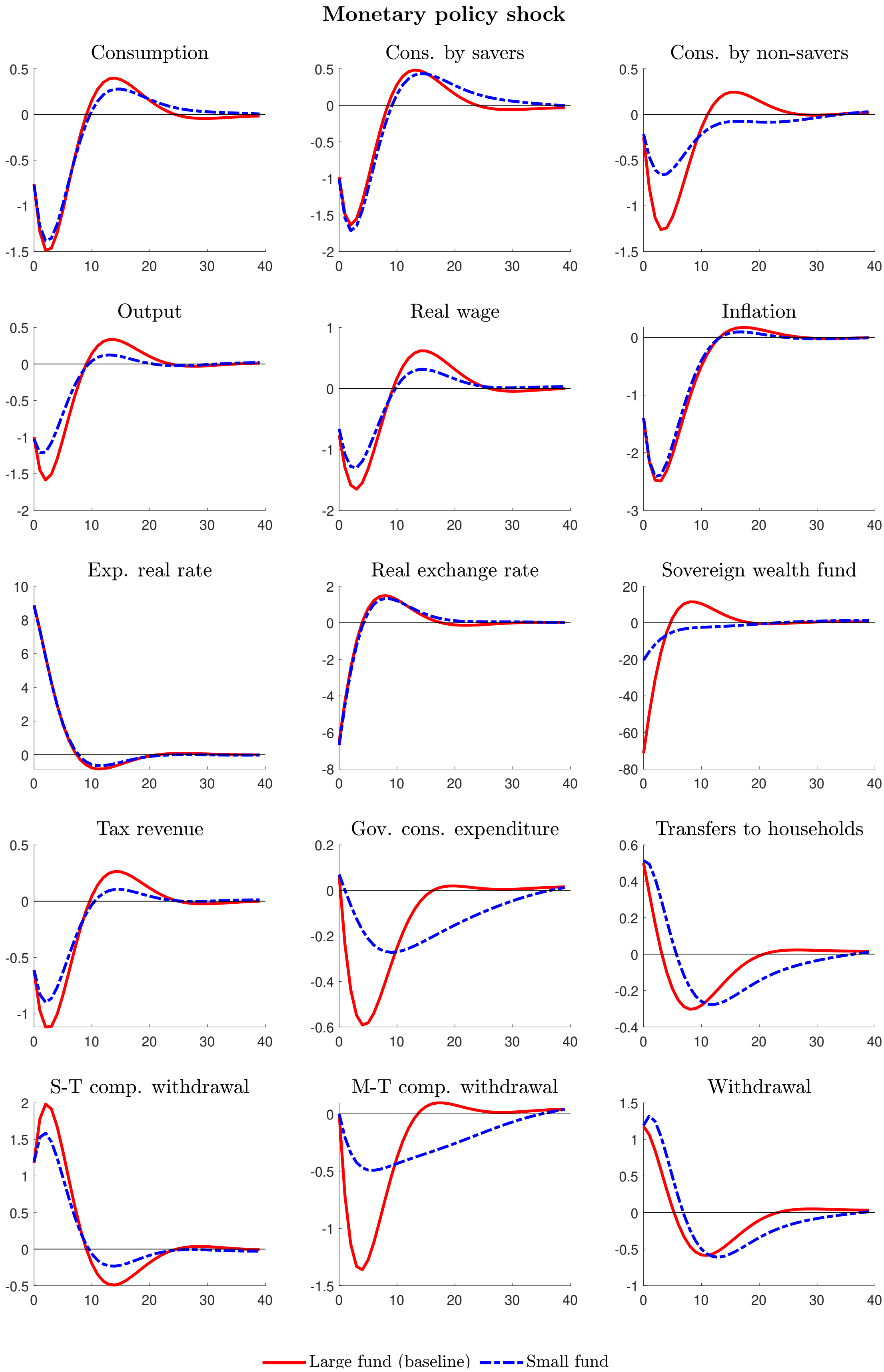


Figure 8: Impulse response functions for a monetary policy shock, $u_{R,t}$, in equation (43). Real variables and relative prices are in percent deviation from steady state, nominal variables and the expected real interest rate are annualized and in percentage point deviations from steady state, fiscal variables are ratios to steady-state quarterly GDP and represented as percentage point deviations from steady state. S-T and M-T comp. withdrawal refer to the short-term and medium-term component of the withdrawal from the fund, respectively.

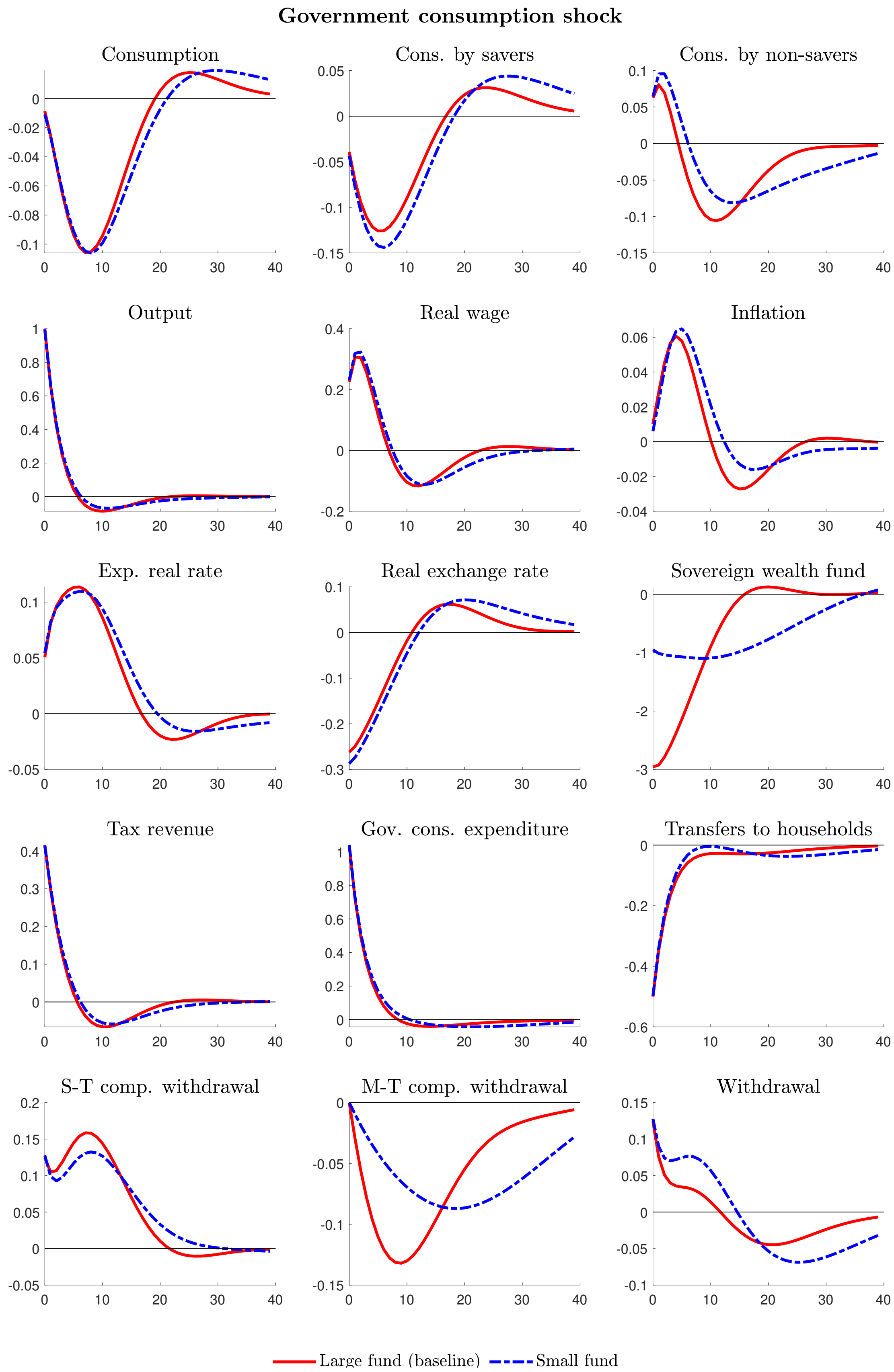


Figure 9: Impulse response functions for a government consumption shock, $u_{g,t}$, in equation (44). Real variables and relative prices are in percent deviation from steady state, nominal variables and the expected real interest rate are annualized and in percentage point deviations from steady state, fiscal variables are ratios to steady-state quarterly GDP and represented as percentage point deviations from steady state. S-T and M-T comp. withdrawal refer to the short-term and medium-term component of the withdrawal from the fund, respectively.

C Robustness

In this section, I recompute the results with respect to the fund size under different assumptions regarding real and nominal rigidities, and the persistence of the shocks.

C.0.1 No rigidities

The following computations assume that there are no real or nominal rigidities. That is $\theta_j = \chi_j = 0, j = N, H, F, W$. Furthermore, $h_c = 0$ and $\rho_R = 0$.

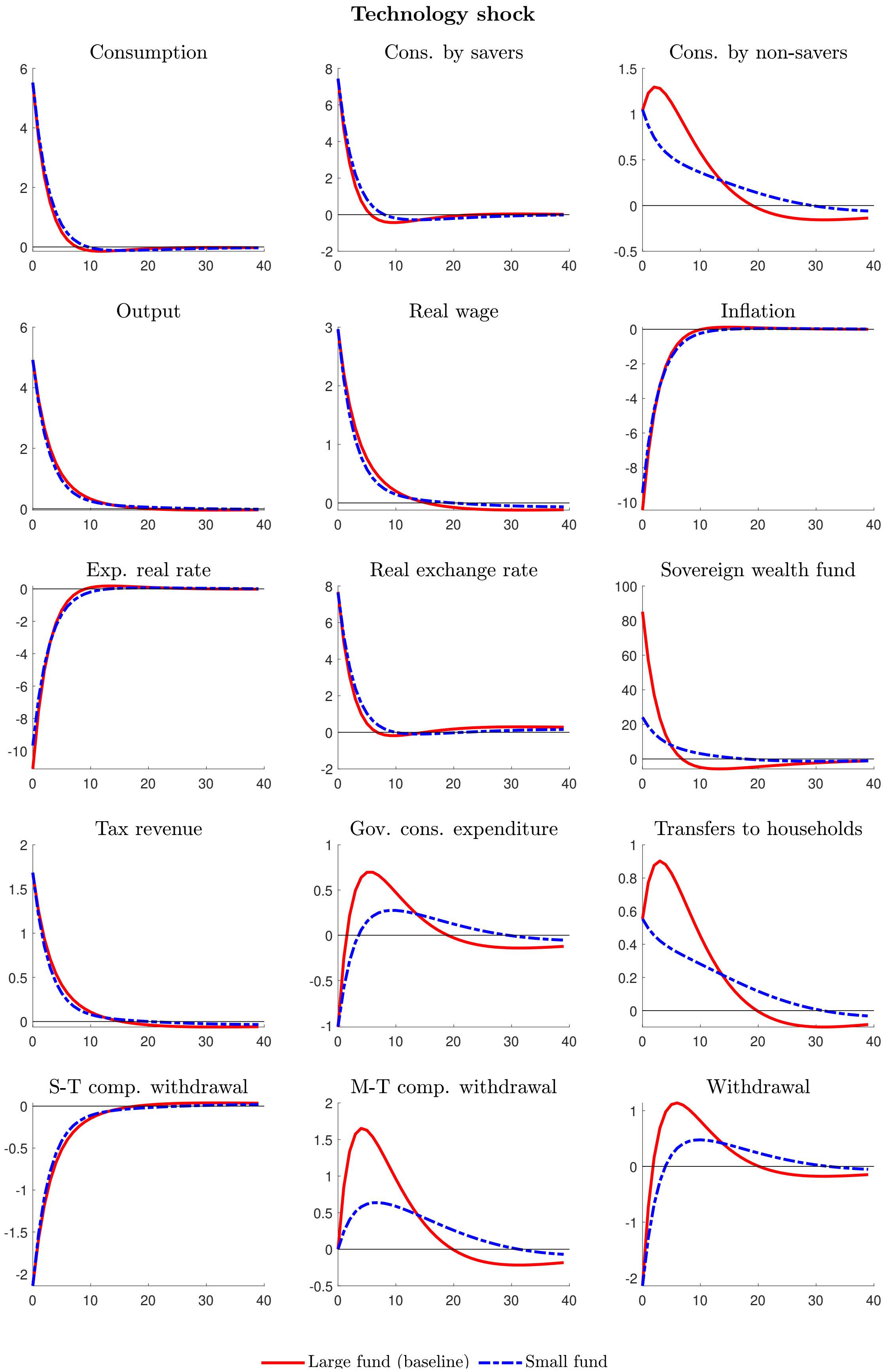


Figure 10: Impulse response functions for a technology shock in both sectors, $u_{Z,t}$, in equation (42). Real variables and relative prices are in percent deviation from steady state, nominal variables and the expected real interest rate are annualized and in percentage point deviations from steady state, fiscal variables are ratios to steady-state quarterly GDP and represented as percentage point deviations from steady state. S-T and M-T comp. withdrawal refer to the short-term and medium-term component of the withdrawal from the fund, respectively.

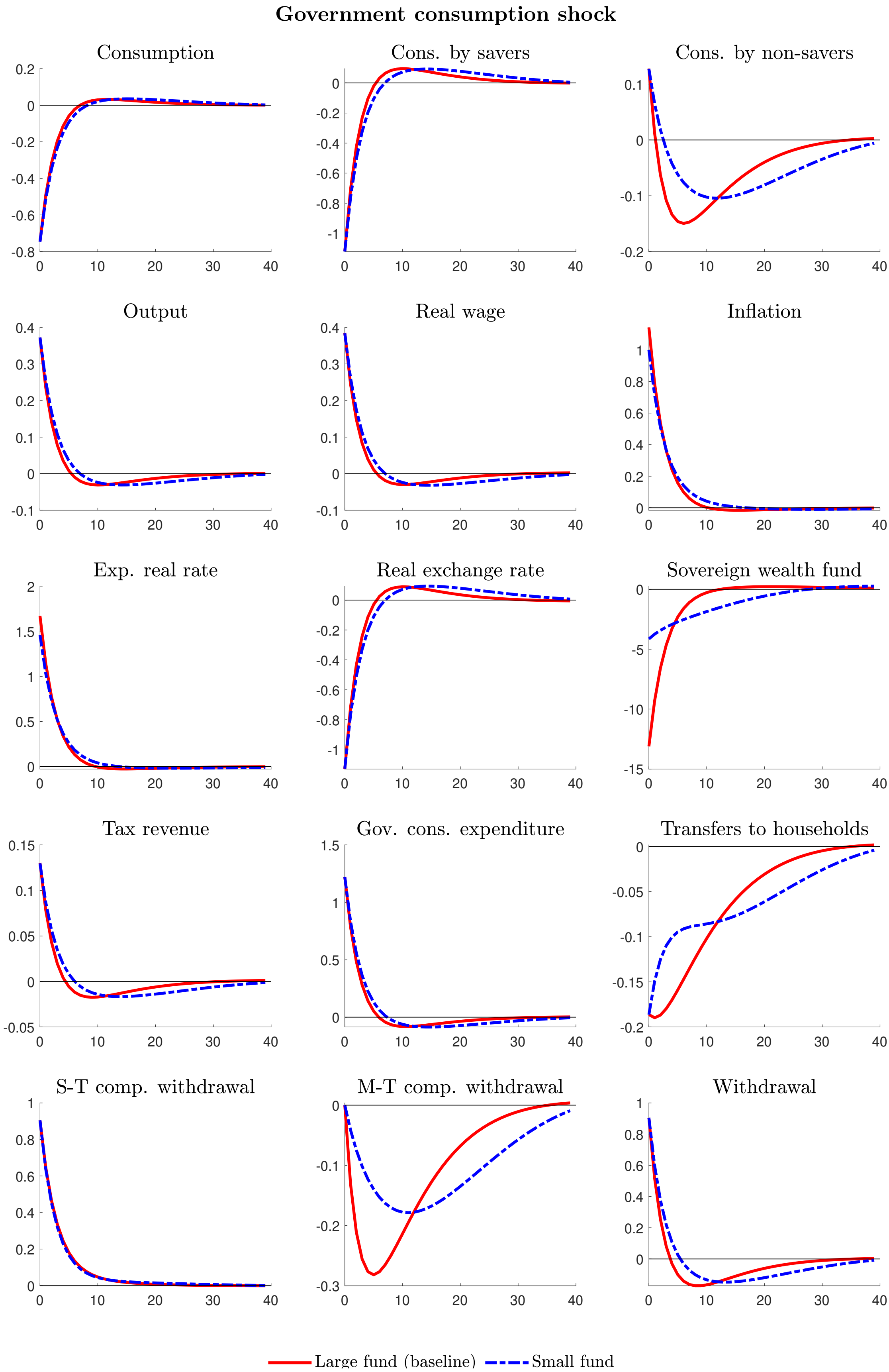


Figure 11: Impulse response functions for a government consumption shock, $u_{g,t}$, in equation (44). Real variables and relative prices are in percent deviation from steady state, nominal variables and the expected real interest rate are annualized and in percentage point deviations from steady state, fiscal variables are ratios to steady-state quarterly GDP and represented as percentage point deviations from steady state. S-T and M-T comp. withdrawal refer to the short-term and medium-term component of the withdrawal from the fund, respectively.

C.0.2 Shock persistence

This section repeats the analysis under the assumption that $\rho_Z = \rho_{z,g} = 0$.

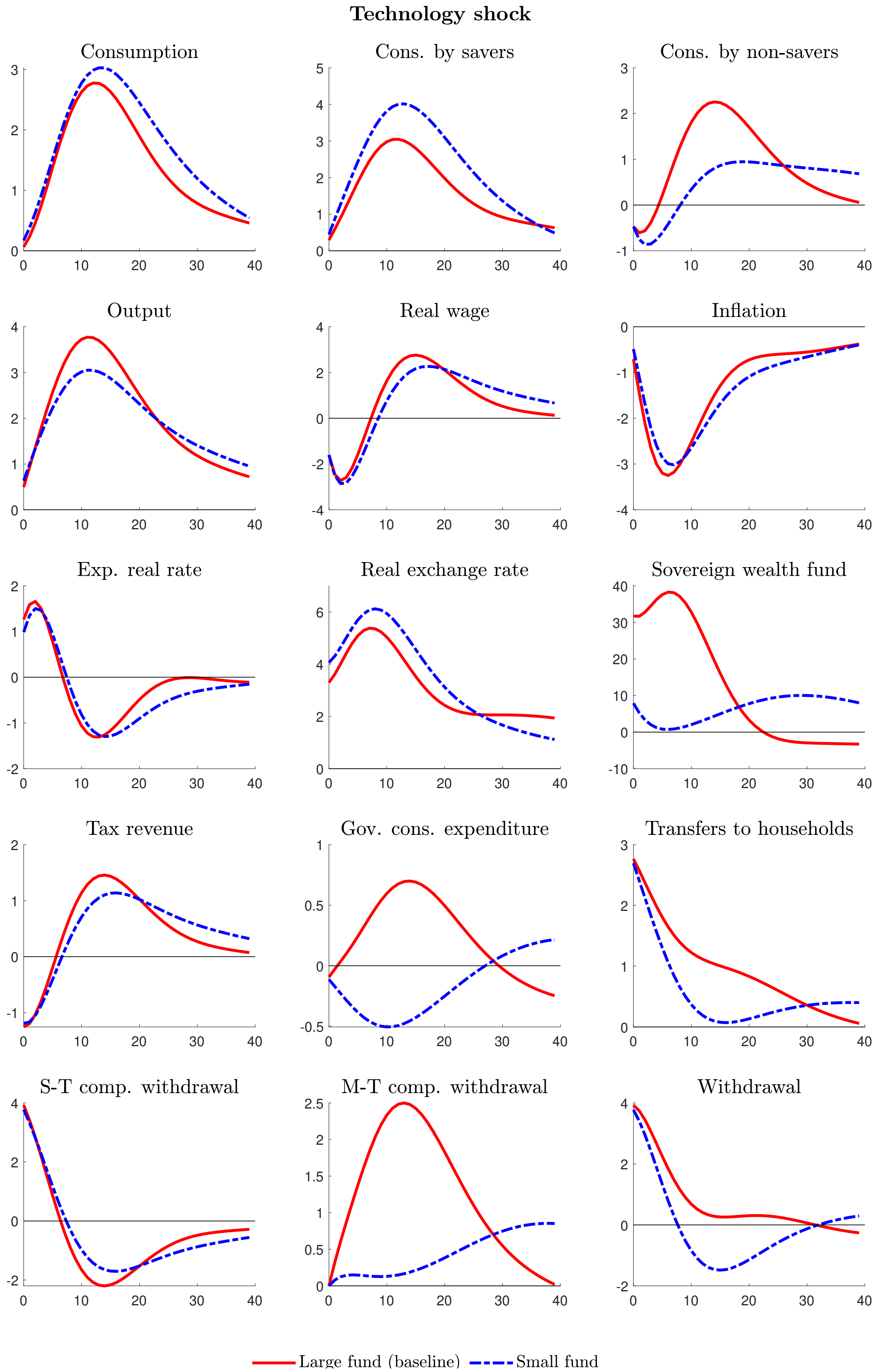


Figure 12: Impulse response functions for a technology shock in both sectors, $u_{Z,t}$, in equation (42). Real variables and relative prices are in percent deviation from steady state, nominal variables and the expected real interest rate are annualized and in percentage point deviations from steady state, fiscal variables are ratios to steady-state quarterly GDP and represented as percentage point deviations from steady state. S-T and M-T comp. withdrawal refer to the short-term and medium-term component of the withdrawal from the fund, respectively.

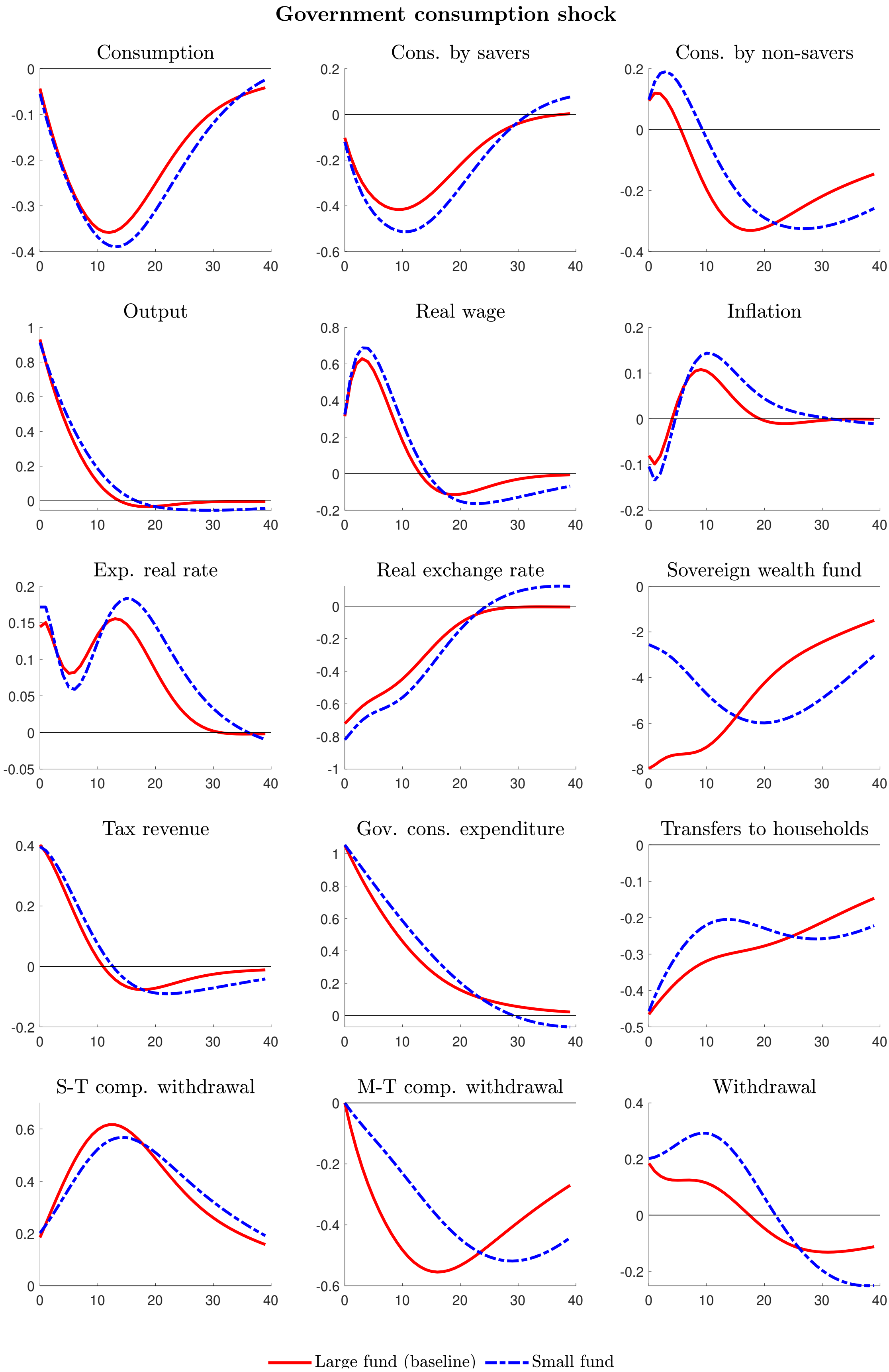


Figure 13: Impulse response functions for a government consumption shock, $u_{g,t}$, in equation (44). Real variables and relative prices are in percent deviation from steady state, nominal variables and the expected real interest rate are annualized and in percentage point deviations from steady state, fiscal variables are ratios to steady-state quarterly GDP and represented as percentage point deviations from steady state. S-T and M-T comp. withdrawal refer to the short-term and medium-term component of the withdrawal from the fund, respectively.

II State-dependent fiscal multipliers in NORA
A DSGE model for fiscal policy analysis in Norway

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State-dependent fiscal multipliers in NORA - A DSGE model for fiscal policy analysis in Norway☆

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ABSTRACT

We develop a novel medium-scale DSGE model, called NORA, for fiscal policy analysis in Norway. NORA contains a sheltered and exposed sector allowing us to model wage bargaining between a labor union and the exposed sector, reflecting Scandinavian wage formation institutions. Wages are subject to a downward nominal wage rigidity (DNWR). Inspired by many countries' fiscal policy responses to the Great Recession and the coronavirus pandemic, we investigate the model's ability to generate state-dependent fiscal multipliers. We find, that both the zero lower bound on nominal interest rates and DNWR individually can account for higher fiscal multipliers during recessions. In joint presence, however, the existence of DNWR reduces the multiplier at the ZLB. Moreover, the DNWR significantly relaxes the paradox of toil at the ZLB. We show that the state-dependency is robust to alternative assumptions about the origin of the recession, the nature of the fiscal stimulus and its financing source.

1. Introduction

The Great Recession and more recently the coronavirus pandemic has prompted many governments around the world to use fiscal policy to provide stimulus and alleviate the effects of economic recession. Underlying such action is the belief that fiscal stimulus is particularly effective and worthwhile in adverse economic conditions. Blanchard (2019), Eichenbaum (2019) as well as Rachel and Summers (2019) have recently argued for a more prominent role of fiscal policy in stabilizing the economy during recessions. While there is ample empirical evidence for state-dependency of fiscal policy,[3] there are relatively few structural models that can shed light on the different transmission channels of fiscal policy both in "normal" times and times of economic hardship. In this paper, we present NORA, a DSGE model developed for analysis of fiscal policy in Norway. The model features a rich description of public spending and taxation and is suited to analyze fiscal policy in a real-

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[3] See, for example, results and literature review in Fazzari et al. (2014) or Ramey and Zubairy (2018).

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istic setting. It has been developed in order to, among other things, investigate fiscal multipliers in Norway under varying economic circumstances. NORA is the outcome of a two-year long modeling project at the Ministry of Finance, and has been developed in collaboration with Statistics Norway and Norges Bank.

In this paper, we analyze the ability of two non-linearities to generate state-dependent fiscal multipliers in our model, namely the zero lower bound (ZLB) on the nominal interest rate and a downward nominal wage rigidity (DNWR).[4] Both frictions are likely to play a role in recessions. Compared to many other developed countries, the financial crises affected the Norwegian economy to a modest extent and the central bank policy rate never reached zero. However, the recent coronavirus outbreak and the related economic turbulences have prompted the Norwegian central bank, similarly to numerous other monetary authorities around the world, to lower its main policy rate and effectively reaching the zero lower bound. There is also clear evidence of downward nominal rigidities of wages in Norway. Holden (2004) shows that institutionalized collective wage setting systems, as present in Norway, imply that workers or unions have a strategic advantage in avoiding cuts to nominal wages. Empirical evidence on downward nominal wage rigidities in Norway have been presented in Holden and Wulfsberg (2008) and more recently by Ku et al. (2020). As we will show in this paper, the presence of ZLB and DNWR can significantly alter the transmission channels of fiscal stimulus during recessions and give rise to state-dependent multipliers.

The contribution of this paper is two-fold. First, we contribute to the literature on medium-scale DSGE models used for fiscal policy analysis by including several novel extensions. The model possesses a high degree of disaggregation on both the spending and the revenue side. In particular, NORA features a realistic distinction between capital income taxation of households and corporate profit taxation. The model also captures the Government Pension Fund Global (GPFG), the Norwegian sovereign wealth fund, used to finance public expenditures. Moreover, NORA contains two domestic intermediate good sectors capturing a sheltered service sector and an exposed manufacturing sector. This allows us to model wage bargaining between a labor union and firms in the exposed sector, reflecting the institutional wage formation system in Norway. As wage formation systems in many countries, particularly the Nordic countries, deviate significantly from the modeling approaches in the current DSGE literature, we provide a novel way to implement this institutional setting.

Second and inspired by the fiscal responses of many governments to recessions, we investigate the state-dependency of the fiscal multipliers. Specifically, we analyze the transmission channels of fiscal stimulus when the economy is in a recession in which the ZLB and DNWR constrain the economy as opposed to in the steady state. Our approach departs from the existing studies in a key aspect: we provide a unified framework in which both the ZLB and DNWR hold. This allows us to study the frictions' relative contribution to the state-dependency of the fiscal multipliers. As we will argue, the presence of both rigidities gives rise to important interaction effects that, to our knowledge, have not received attention yet. Moreover, our relatively rich fiscal sector allows us to study the robustness of state-dependency of the multiplier for a wide array of assumptions about the nature of the fiscal stimulus.

In our analysis we find that both the ZLB as well as the DNWR can individually account for counter-cyclical state-dependency of government spending and tax multipliers. At the ZLB, fiscal stimulus induces inflation through higher aggregate demand, resulting in a falling real interest rate and stimulating investment as well as consumption. Recessions during which the DNWR becomes binding, fiscal expansions do not lead to an increase in nominal wages. Marginal costs of firms and thus inflation increase only modestly. Constant nominal wages then lead to falling real wages, stimulating rather than crowding-out private sector activity. Our central finding, however, relates to a situation in which both rigidities are present in the model. We show, that the DNWR tends to dampen the extent to which fiscal multipliers are higher at the ZLB relative to the steady state. This is because the DNWR limits the increase in inflation, leading to a smaller fall in the real interest rate for a binding ZLB and by extension in smaller fiscal multipliers relative to when the DNWR is not present. The effect is quantitatively important: In a model with only the ZLB present, the multiplier in a recession is three times larger relative to steady state, while in a model with both the ZLB and the DNWR the multiplier only doubles in the same recession. Furthermore, contrary to the literature on the paradox of toil initiated by Eggertsson (2010), we find that supply-side fiscal stimulus through tax cuts is not strongly or not at all pro-cyclical if the DNWR is taken into account. The paradox of toil arises when labor tax cuts lower inflation during a ZLB episode and thus increase the real interest rate. The existence of DNWR, however, dampens the fall in wages and thus prices in such a way, that the paradox is strongly relaxed. We establish these results not only through simulation experiments using the calibrated, full model, but also through a theoretical analysis in a simplified version of the model. We perform several robustness checks with respect to the model's ability to generate state-dependent multipliers and to give rise to interaction effects between the ZLB and DNWR. Exploiting the rich fiscal heterogeneity of the model we show, that the state-dependency of the multiplier is robust to alternative assumptions about the spending component which is increased for stimulus purposes, the time of implementation and financing. Furthermore, we demonstrate, that the state-dependency is stronger in a model calibration reflecting less open economies. This is due to the negative effect on exports from an appreciated real exchange rate following the fiscal spending increase, a channel also present during recessions. Finally, we show that the interaction effects between ZLB and DNWR are independent of the particular Norwegian setting considered in our model but a fundamental feature of New Keynesian DSGE models.

Our model stands in the tradition of medium-scale DSGE models recently developed at policy institutions to assess the impact of a rich set of policy measures fiscal authorities can undertake. For example, such models are used to evaluate the temporary and permanent effects of fiscal spending and tax reforms, as in the extended version of the ECB's New Area-Wide Model (Coenen et al., 2008) and the FiMOD model developed at the Bundesbank (Stähler and Thomas, 2012), or to estimate the contribution of fiscal policy to business cycle fluctuations, as in the GEAR model developed at the Bundesbank (Gadatsch et al., 2016) and the Global Multi-Country Model developed at the European Commission (Albonico et al., 2019). NORA resembles these models in many respects but also differs along several dimensions where traditional models do not fit the Norwegian context. In particular, wage formation in existing models, which is typically built around the framework proposed by Erceg et al. (2000), does not fit the institutional framework in Norway where wage negotiations between a labor union and firms in the exposed sector seek to preserve the competitiveness of the exposed sector and maintain a high level of employment. This wage bargaining process alongside with the distinction between sheltered and exposed sector is explicitly modeled in NORA. Moreover, unlike existing fiscal policy models that assume public spending is financed using a combination of higher taxes and government borrowing, NORA includes a model of the Government Pension Fund Global (GPFG), the Norwegian sovereign wealth fund, which is the main public financing vehicle in Norway. Finally, none of these fiscal policy models provide a convincing modeling approach to the particularities of Norwegian corporate profit and shareholder income taxation.

Our paper is also related to the literature using DSGE models to investigate the state-dependency of fiscal multipliers, see for example Cogan et al. (2010), Christiano et al. (2011), Coenen et al. (2012), Leeper et al. (2017). These papers analyze fiscal multipliers at the zero lower bound (while ignoring downward nominal wage rigidities) and find that fiscal spending is more effective in raising output when the

[4] Specifically, we consider a zero lower bound on nominal wage growth.

nominal interest rate is at the zero lower bound. More recently, Shen and Yang (2018) as well as Dupor et al. (2019) have argued, using a relatively standard NK-DSGE model, that the existence of a DNWR (while not studying a binding ZLB) can also rationalize higher fiscal multipliers during recessions.[5] None of these papers, however, have examined the joint presence of both rigidities.[6] Our main contribution to this literature lies therefore in showing that interaction effects of the ZLB and the DNWR have important implications for the state dependency of spending and tax multipliers.

The remainder of this paper is organized as follows. Section 2 introduces the full model while section 3 illustrates the main state-dependency effect in a simplified version of the model. Section 4 describes the calibration of the model and illustrates its fit with empirical results on the Norwegian economy. Section 5 analyzes the transmission channels of a fiscal spending stimulus from an economy in steady state as well in a recession and determines the fiscal multipliers in both states. We furthermore investigate the role played by the ZLB and DNWR in generating the observed state-dependency and analyze various tax multipliers. In section 6 we perform a number of robustness checks. Section 7 concludes.

2. The model

NORA belongs to the class of small open economy DSGE models and shares many elements with prominent examples such as Justiniano and Preston (2010) or Adolfson et al. (2007). The economy described by this model is assumed to have strong trade and financial linkages with the rest of the world, but is sufficiently small to not affect the world economy itself. Shocks to foreign variables are transmitted to the domestic economy through movements in the real exchange rate, the return on foreign bonds and the demand for exports. Consistent with most analysis of the Norwegian economy NORA focuses on developments in the mainland economy, i.e. excluding the off-shore oil sector. The production and taxation of the off-shore oil sector is not modeled. However, we include interlinkages between the off-shore oil sector and the mainland economy in the form of the oil sector's demand for domestically-produced investment goods.[7]

There are two types of households in the economy. First, an infinitely-lived utility-maximizing (Ricardian) household chooses how much to spend on consumption each period. 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 does not 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 that typically characterizes this class of models, see Galí et al. (2007).

A novel feature in NORA is the way we model wage formation and unemployment. Consistent with the institutional framework for wage bargaining in Norway (the so-called "frontfag" model), we assume that wage negotiations in the exposed sector of the economy sets the norm for wage growth in the rest of the economy. An important purpose of this setup, 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. Specifically, we assume that wages are set by 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. Wage growth is subject to a downward nominal wage rigidity. High unemployment, ceteris paribus, 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 (2005). Labor force participation is modeled in reduced-form, and responds 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 more exposed to competition from abroad, both from imported goods and from their reliance on exports. Firms in both sectors use labor and capital to produce an intermediate good that is bundled with imported goods to make different types of final goods. The firms face a choice between paying out dividends to Ricardian households or investing in fixed capital that is used in production.[8] Investment can either be financed through retained profits (equity) or borrowing from banks (debt).

Firms that produce the intermediate good have pricing power because they produce differentiated goods that are imperfect substitutes. Importers reprocess a homogeneous foreign good into a differentiated imported intermediate good and set a price on it. 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. Domestic intermediate goods firms additionally incur adjustment costs when varying the level of investment.

NORA includes a relatively disaggregated description of government spending and taxation in Norway. In particular, households pay a flat tax on their total (ordinary) income, a shareholder tax on dividends, a surtax on labor income and transfers as well as social security contributions. Firms pay taxes on their profits net of deductions as well as

[5] Other transmission channels for the state-dependency of fiscal multipliers have been proposed. Ghassibe and Zanetti (2019) and Ziegenbein (2019) use a search-matching framework to show that spending multipliers are counter-cyclical while tax multipliers are pro-cyclical. Similarly, Michaillat (2014) demonstrates that the public employment multiplier is counter-cyclical. At the core of these three papers search-matching frictions, either in the labor or goods market, cause fiscal policy to be state-dependent. Another recent approach has been developed by Canzoneri et al. (2016) using counter-cyclical financial frictions to generate state-dependency of fiscal spending.

[6] A partial exception is Burgert et al. (2019) who consider the interaction of a DNWR and the ZLB in a robustness analysis. However, they do not provide a full decomposition of interaction results and consider the special case of an economy within a monetary union.

[7] 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.

[8] DSGE models often 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.

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, subject to a zero lower bound on the nominal interest rate.

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

2.1. Households

Following Mankiw (2000) and Galí et al. (2007), we assume that the economy is populated by a share $(1-\omega)$ of Ricardian households, denoted by superscript R, and a share $\omega \in [0,1)$ of liquidity-constrained households, denoted by superscript L. The Ricardian household chooses current consumption with a view to maximize its lifetime utility, while liquidity-constrained households simply consume all available income net of taxes. 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.[9]

2.1.1. Ricardian household

Expected lifetime utility of the Ricardian household at time 0 is given by

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

where C_t^R captures the consumption level, the parameter h the degree of consumption habits and the parameter σ the inverse of the intertemporal elasticity of substitution.[10] The term Z_t^U is a shock that increases households preference for consumption.[11] In line with the literature on state-dependent multipliers, we will use this shock to drive the economy into a recession by decreasing Z^U for some time and thus inducing a slump in consumption and therefore a recession. 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, OI_t^R, and given by

$$\begin{aligned} OI_t^R = \; & LI_t^R + UB_t(L_t - E_t) + TR_t^R + \frac{P_{t-1}}{P_t} DP_{t-1}^R (R_{t-1} - 1) + \\ & (DIV_t^M + AV_t^M) S_{t-1}^{R,M} + (DIV_t^S + AV_t^S) S_{t-1}^{R,S}. \end{aligned} \tag{2}$$

Labor income is given by $LI_t^R = W_t N_t^P + W_t^G N_t^G$ where W_t is the real wage rate and N_t^P the number of hours worked in the private sector. Given the importance of the public sector as an employer in Norway we follow Stähler and Thomas (2012) and assume that the Ricardian household can be employed also in the public sector, with $W_t^G N_t^G$ denoting the Ricardian household's income from such employment. The government wage is given by W_t^G and hours worked by N_t^G. We assume that government wages are proportional to private wages, i.e. $W_t^G = MARKUP^{GW} W_t$, where $MARKUP^{GW}$ is a fixed parameter. The 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 E_t. The term TR_t^R denotes lump-sum transfers to the Ricardian household.

We define the price level in the economy as P_t, which reflects the nominal price of one consumption good before tax and is equal to the marginal cost of the final consumption good producer, introduced in section 2.5.2. Hence, real variables, if not otherwise stated are to be understood as given in units of the final consumption good. We define pre-tax inflation as $\pi_t^{ATE} = \frac{P_t}{P_{t-1}}$. And after-tax inflation as $\pi_t = \frac{P_t^{Nom,C}}{P_{t-1}^{Nom,C}}$, where $P_t^{Nom,C}$ the nominal price of the consumption good faced by the household, i.e. including tax.[12] Generally, we will express prices throughout the model as prices relative to P_t. For example, the relative price of the consumption good paid by the household is given by $P_t^C = \frac{P_t^{Nom,C}}{P_t}$.

The term $DP_{t-1}^R(R_{t-1} - 1)$ captures net nominal interest income on bank deposits held at the end of the last period, where the first term captures the amount of bank bonds and R_{t-1} the nominal interest rate. We convert this interest income into this period's value by dividing through by the inflation rate. Dividends per share DIV_t^M and DIV_t^S are paid to the household that holds shares in firms in the manufacturing (denoted by superscript M) and services (denoted by superscript S) sectors. The total amount of dividend income is determined by the product of dividends with the corresponding 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 stock) in the manufacturing sector (and equivalently in the service sector) are given by $AV_t^M = \frac{P_t^{Nom,E,M} - P_{t-1}^{Nom,E,M}}{P_t}$, where $P_t^{Nom,E,M}$ denotes the nominal price of a share in the manufacturing sector (price of equity), with $P_t^{E,M}$ being the real price (relative to P_t).

In line with the Norwegian tax code, the tax base for the household ordinary income tax is defined as follows

$$\begin{aligned} TB_t^{OIH,R} = \; & OI_t^R - TD^{OIH} \\ & - RRA_t \left(\frac{P_{t-1}^{Nom,E,M}}{P_t} S_{t-1}^{R,M} + \frac{P_{t-1}^{Nom,E,S}}{P_t} S_{t-1}^{R,S} \right) \alpha_t^{OIH}. \end{aligned} \tag{3}$$

Hence there are two deductions to the ordinary income tax base. The first deduction TD^{OIH} represents an allowance on personal income. It is calibrated to match the empirical 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. This deduction has the effect that the return up to the rate-of-return allowance is exempt from taxation while only the remaining equity premium on stocks is taxed at the household level.[13] The adjustment factor $\alpha_t^{OIH} > 1$ increases the effective tax rate on the equity premium.[14] This detailed modeling of the shareholder allowance

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

[10] We do not include disutility of labor in the utility function as households are not assumed to set wages. Instead our wage formation model is based on Nash bargaining between a labor union and exposed sector firms to be introduced in section 2.3.

[11] All shock processes in NORA are collectively discussed in section A.9.

[12] So called ATE-inflation is a measure of inflation adjusted for tax changes and excluding energy products compiled by Statistics Norway. NORA does not model energy prices separately such that we simple differentiate between inflation after taxes (π_t) and before (π_t^{ATE}).

[13] Absent the rate-of-return allowance the overall 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 a general discussion in Sørensen (2005).

[14] The real-world 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.

allows us to derive more realistic insights on the ordinary income tax multiplier, which we analyze later.

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

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

where τ_t^{OIH} is the household ordinary income tax rate, τ_t^{LS} is a labor surtax on labor income and transfers and τ_t^{SSH} is the rate of social security contributions.[15] The term TD^{LS} captures a deduction to the tax base of the labor surtax and social security contributions and $T_t^{L,R}$ represents lump-sum taxes. For ease of later 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 is then given by

$$DP_t^R + (P_t^{E,M} S_t^{R,M} + P_t^{E,S} S_t^{R,S})(1 + F_t^S)$$
$$= \frac{1}{\pi_t^{ATE}} DP_{t-1}^R + P_{t-1}^{E,M} S_{t-1}^{R,M} + P_{t-1}^{E,S} S_{t-1}^{R,S}$$
$$+OI_t^R - T_t^R - P_t^C C_t^R - P_t^I Inv_t^{H,R} + AVT_t^R$$
$$+\Pi_t^{X,R} + \Pi_t^{C,R} + \Pi_t^{F,R} + \Pi_t^{B,R}. \quad (4)$$

Following the approach in Graeve and Iversen (2017) we introduce financial fees F_t^S charged when trading in firm stocks resulting in a gap between the required return on equity and the required return on bank deposits, which we interpret as an equity premium.[16] The retail price of the consumption good (including taxes and fees) is given by P_t^C and set by the final consumption good sector. Housing investments $Inv_t^{H,R}$ are purchased at price P_t^I and follow a reduced-form process to be introduced in section 2.8. Other income and costs consist of an asset valuation tax refund AVT_t, and lump-sum redistribution of profits from exporting firms ($\Pi_t^{X,R}$), from consumption retailers ($\Pi_t^{C,R}$), from financial intermediaries ($\Pi_t^{F,R}$) as well as from the banking sector ($\Pi_t^{B,R}$).[17]

The Ricardian households maximize the present value of the expected stream of future utility subject to the budget constraint. The maximization problem yields a first-order condition for deposits, which is given by

$$\lambda_t = \beta E_t \left[\frac{\lambda_{t+1}}{\pi_{t+1}^{ATE}} (1 + (R_t - 1)(1 - \tau_{t+1}^{OIH})) \right]. \quad (5)$$

where λ_t is the real shadow value of one unit of savings. For later 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 ***consumption*** is given by

$$\lambda_t = \frac{\exp(Z_t^U)(C_t^R - H_t)^{-\sigma}}{P_t^C (1-h)^{-\sigma}}, \quad (6)$$

where $H_t = hC_{\{t-1\}}^R$ is the habit stock of consumption.

Combining equations (6) and (5) yields the well-known Euler equation.

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

$$P_t^{E,M} = \sum_{j=1}^{\infty} \frac{1}{R_{t+j}^e} DIV_{t+j}^M, \quad (7)$$

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.[18]

2.1.2. Liquidity-constrained households

The liquidity-constrained household, following Galí et al. (2007), consumes all of its disposable income net of taxes. Disposable income consists of income from public and private employment, unemployment benefits and transfers:

$$OI_t^L = W_t N_t^P + W_t^G N_t^G + UB_t(L_t - E_t) + TR_t^L. \quad (8)$$

Note, that the we assume that hours worked as well as the participation and employment rate do not differ across the Ricardian and liquidity-constrained household. Consumption expenditures are then given by

$$P_t^C C_t^L = OI_t^L - (OI_t^L - TD^{OIH})\tau_t^{OIH} - (OI_t^L - TD^{LS})(\tau_t^{LS} + \tau_t^{SSH}). \quad (9)$$

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

2.1.3. Household aggregation

Without loss of generality, we normalize the population size to 1. The parameter $\omega \in [0, 1)$ denotes the share of liquidity-constrained households in the economy. The aggregate consumption and transfers are then given as

$$C_t = \omega C_t^L + (1-\omega) C_t^R,$$
$$TR_t = \omega TR_t^L + (1-\omega) TR_t^R. \quad (10)$$

We implicitly assume that the total amount of hours worked in the private and public sector is proportional to the size of the household.[19] For those variables specific to the Ricardian household we rescale by the share of the Ricardian household in the overall population to arrive at an aggregate measure.

$$X_t = (1-\omega) X_t^R \text{ for}$$
$$X_t \in \{DP_t, T_t^L, S_t^M, S_t^S, Inv_t^H, AVT_t, \Pi_t^X, \Pi_t^C, \Pi_t^F, \Pi_t^B\}.$$

[15] 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 rate paid by all workers in the economy.

[16] 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.

[17] The asset valuation tax refund is a pragmatic solution to the fact that capital gains in NORA are (unlike in the real world) realized every period. Because the firm share price is forward looking it reacts strongly to shocks that hit the economy, implying that capital gains tax revenue can be very volatile. To avoid this we redistribute capital gains tax revenue back to the Ricardian household in a lump-sum fashion in each period. Because the Ricardian household maximizes expected lifetime utility and is assumed to have complete access to financial markets, temporary income movements caused by the asset valuation tax refund will then not affect their decision-making process strongly. Profits from monopolistically-competitive exporting, consumption firms and banks are included to close the model. The financial fees imposed on stock holdings are paid 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. The definitions of the other profit terms will follow in section 2.4 and 2.5.2.

[18] Following Uribe and Schmitt-Grohé (2017) we have, without loss of generality, normalized the number or stocks in the model to 1.

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

2.2. Labor market

Labor supply, employment and unemployment For simplicity we assume that the Ricardian and liquidity-constrained household have the same labor supply L_t, employment rate E_t and unemployment rate U_t. Labor supply, which we interchangeably refer to as labor force participation, follows directly the model of labor supply in Statistics Norway's large-scale macroeconometric model MODAG/KVARTS, see Gjelsvik et al. (2013), which includes reduced-form processes for the participation rate of seven distinct population groups.[20] 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.[21] The latter captures the commonly-observed discouraged worker effect whereby workers who believe that their chances of finding a job are low in a recession (when unemployment is high) leave the labor force rather than incur the monetary and psychological costs of searching for a job, see Dagsvik et al. (2013). The reduced-form processes for participation rates take the form

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

Total labor supply is then given by the sum of group-specific participation rates weighted by the relative size of the population groups

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

where w_j capture the population weights for each subgroup. The variable Z_t^L denotes a shock to the overall labor force participation rate.

With hours worked in the total economy being determined through a microfounded decision problem on the firm side, we resort to a reduced-form model of the employment rate along the lines of Uhlig (2004). For this purpose, we first define the number of hours worked per employee in the economy NE_t 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 then impose that the employment rate is a sluggish process that responds more slowly to economic shocks than hours worked per worker (i.e. the intensive margin of labor supply).[22] 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 sluggishness in the creation of new or destruction of old jobs, and 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). The unemployment rate relates the number of unemployed to the number of people in the labor force: $U_t = \frac{L_t - E_t}{L_t}$. Due to the reduced-form nature of unemployment, our model is silent on whether unemployment is voluntary or involuntary.

[20] 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.

[21] 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.

[22] 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.

2.3. Wage formation

The institutional framework for wage bargaining in Norway is based on the so-called "frontfag" model whereby 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 this institutional setup 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 NOU (2013:13) (Holden III Committee). There is ample empirical evidence documenting the successful implementation of the model. For example, Bjørnstad and Nymoen (1999) show that high wage rarely occur during periods of low profitability in the exposed sector, while periods of high profitability result in higher wage claims. Gjelsvik et al. (2015) find empirical support for the fact that the sheltered sector follows wage settlements in the exposed sector, thereby preventing circumvention of profitability concerns of the exposed sector.[23]

Hoel and Nymoen (1988), Nymoen and Rødseth (2003) and Forslund et al. (2008) have developed partial equilibrium models of the frontfag model in which wages are set through bargaining between workers, that are represented by a union that acts in their interest by aiming for a high level of wages, and exposed-sector firms, that are represented by an employer organization aiming for high profits. The current 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.[24] In contrast to the existing literature, the wage bargaining in NORA occurs in a general equilibrium setting and is subject to wage stickiness as well as downward nominal wage rigidity, which will be crucial for our results in section 5.

We assume that the payoff function of the union is a utility function that increases with worker's pre-tax real wages.[25] The union's reference

[23] The role of the exposed sector in setting the norm for wage growth in small open economies was analyzed 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.

[24] We calibrate the export content of the manufacturing sector reflecting the industries classified as exposed sector in the official wage negotiations.

[25] 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 find little effect of labor taxes on bargained wages.

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. 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. Following the literature, the reference utility of firms is set to zero on the assumption that failure to reach an agreement implies no production and zero profits. Hence, the real wage W_t^{NB} that corresponds to the Nash bargaining solution can be found by maximizing the following Nash product

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

where $V(W)$ captures the payoff function of the union given a real wage W, V_t^0 denotes the union's reference utility, and the payoff function of firms equals profits in the manufacturing sector Π_t^M. The parameter γ governs the relative bargaining power of the parties involved. The payoff function of unions is given by

$$V(W) = c^N + \log(W), \tag{14}$$

where c_N is a constant that ensures a positive value of V at relevant wage levels.[26] The payoff function in equation (14) increases with the wage level $V_w > 0$ while gains at higher level of wages are valued less in utility terms $V_{ww} < 0$. Manufacturing sector profits will be defined in section 2.5.3. The union's reference utility is given by

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

where $\nu_U > 0$ is a parameter that determines the importance of unemployment for the reference utility and hence the negotiated wage. We take the logarithm of unemployment given evidence by Blanchflower and Oswald (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 (corresponding to a vertical shift in the wage curve).

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

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

where τ_t^{SSF} is the social security tax paid by firms and N_t^M is the amount of hours worked in the manufacturing sector. As can be shown (see Appendix A.2), the Nash bargaining wage increases with the value of V_t^0 and hence falls with the level of unemployment. In addition, the Nash bargaining wage increases with higher profitability in the manufacturing sector, caused for example by reduction in the social security tax paid by firms or by increased demand for manufacturing goods. Conversely changes detrimental to the profitability of manufacturing-sector firms will depress the Nash bargaining wage.

The wage bargaining model thus yields a downward-sloping relationship between the real wage and the level of unemployment which corresponds to the aforementioned wage curve. At the same time, the labor demand function in equation (45) establishes a negative relationship between hours worked and the real wage, and thus between employment and the real wage. Following Nymoen and Rødseth (2003) we can assume that unemployment is a decreasing function of employment and draw the wage curve in Fig. 1 as a function of total employment. The intersection of the wage curve and the downward-sloping labor demand curve in equation (45) determines the level of employment.

[26] We have confirmed, that our main results are robust to an alternative functional form set to $V(W) = c^N + \frac{W^{1-\sigma_N}}{1-\sigma_N}$ and values of σ_N chosen to be between 1 and 2. These results are available on request.

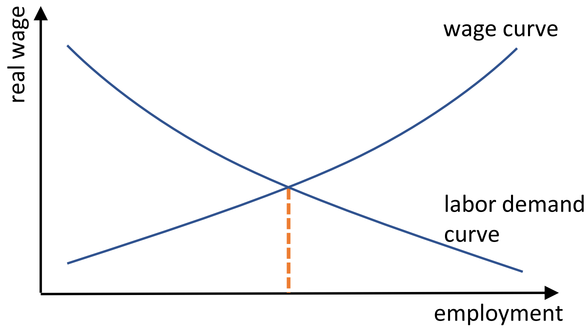


Fig. 1. The wage and labor demand curve.

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

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

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

where W_t^* is the real wage in the economy in period t absent any downward nominal wage rigidity and ρ_W captures the persistence of wages and thus $(1-\rho_W)$ the speed of adjustment of wages towards the Nash bargaining equilibrium.[27] Note, that we implicitly assume that while wages are bargained for the manufacturing sector, the service sector follows the norm set and thus pays the identical wage. This is in line with the frontfag model and empirical evidence documented by Gjelsvik et al. (2015).

We assume, that nominal wages are subject to downward nominal rigidities. Specifically, we impose

$$W_t^{Nom} \geq \gamma^W W_{t-1}^{Nom} \Leftrightarrow W_t \geq W_{t-1} \gamma^W / \pi_t,$$

where W_t^{Nom} and $W_t = \frac{W_t^{Nom}}{P_t}$ capture the nominal and real wage and γ^w the degree of downward nominal wage rigidity. In doing so, we follow the functional form assumed by Schmitt-Grohé and Uribe (2016), who study emerging economies. However, there is ample evidence that DNWR play an important role in developed economies as well. Shen and Yang (2018) document DNWR for the US context, Holden and Wulfsberg (2008) for a range of OECD countries including Norway. More recently, Ku et al. (2020) find strong evidence for DNWR in Norway exploiting quasi-experimental variation in payroll taxes following a EU regulation intervention.

Imposing the DNWR onto the model, we obtain the dynamic wage equation

$$W_t = \max\{W_t^*, \gamma^W W_{t-1} \frac{1}{\pi_t}\}, \tag{17}$$

[27] Wages in this setup react, despite the lack of an explicit forward-looking term in equation (16), to news shocks (i.e. shocks known prior to their realization) as both Ricardian households and firms are forward-looking and take decisions that affect the level of unemployment, prices and profitability in anticipation of future economic developments. Furthermore, assuming that labor union utility is a function of the negotiated nominal wage deflated by the expected future price level only marginally affects 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.

Note, that the DNWR only plays a role in economic circumstances where nominal wage growth is sufficiently small. In section 5 we will create this situation by generating a recession induced by a negative shock to consumption preferences, which lowers aggregate demand, increases unemployment and thus depresses wage growth. Once, equation (17) becomes binding by the lower nominal wage growth limit, fiscal stimulus will not increase nominal wages if the additional aggregate demand impulse is insufficient to lift the economy off the DNWR. Instead, due to stimulus-induced increase in inflation, real wages may fall, which further stimulates the economy. As we will later see, this mechanism can give rise to higher multipliers in recessions.

2.4. 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

$$DP_t + RER_t B_t^F = B_t^M + B_t^S + D_t \tag{18}$$

where B_t^F is the foreign debt of the bank (in units of the foreign final consumption good), RER_t the real exchange rate, $B_t^{\cdot}$ loans to manufacturing/service sector firms and D_t loans to the government. 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

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

subject to the bank's balance sheet constraint. The bank lends at a rate R_t^L to firms and the government. The bank pays an interest rate R_t (set by the monetary authority) on deposits. The last term in the profit equation captures the cost of foreign borrowing where the foreign gross interest rate R_t^{TP} is subject to a debt-elastic risk premium RP_t. The risk premium on foreign borrowing is adapted from Adolfson et al. (2008) and given by

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

where $A_t = \frac{RER_t B_t^F}{Y_{ss}^{CPI}}$ is the domestic-currency value of private sector net foreign liabilities as a ratio to long-run GDP (expressed in consumption units, to be introduced later). In addition, we assume that the risk premium responds indirectly to the oil price through its impact on the value of Norway's offshore sovereign wealth fund, the Government Pension Fund Global (GPFG). The oil price is assumed to affect the value of the GPFG according to the following rule

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

Hence, we capture in a reduced-form fashion that an increase in the oil price would, over time, increase our proxy of the GPFG (OF_t^{RP}) and thus reduce the risk-premium on foreign borrowing by the private sector ($\xi_{OF} > 0$).[28] Z_t^{RP} is a shock to the risk premium.

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

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

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

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

2.5. Firms

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, introduced in section 2.5.3. Monopolistically-competitive importing firms, see section 2.5.4 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, see 2.5.1. Firms in the final consumption and export good sector, however, are assumed to be monopolistically competitive and thus have price-setting power, see section 2.5.2. Exporting firms sell on the world market with a price set in foreign currency, while final consumption good producer sell their goods in the domestic market and choose how quickly to pass through changes in consumption taxes and fees to retail prices.

2.5.1. Final goods sector

The production process of firms in the final goods sector can be separated into two stages as shown in Fig. 2. 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 sector.

Note, in order to measure the multiplier from government purchases, it is important to account for the import leakage of expenditure expansions. If fiscal stimulus, e.g. in the form of tax cuts, leads to higher disposable incomes, then the response of imported consumption is also to be taken into account. Our final good structure, and its calibration to Norwegian Input-Output Tables, is thus essential in allowing us to properly measure fiscal multipliers for a small open economy as Norway.

First stage: composite manufacturing and services sector good For each final good $Z_t \in \{C_t, I_t, X_t, G_t^C\}$, a composite manufacturing

[28] This is similar in spirit to NEMO (Kravik and Mimir, 2019), where the value of the GPFG affects the risk premium directly, and to KVARTS (Boug and Dyvi, 2008), where a higher oil price is assumed to reduce the risk premium. Note, 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 2.6.4 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.

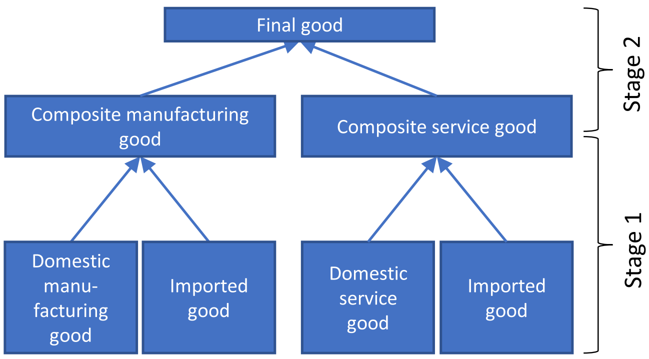


Fig. 2. Final good sector production.

good of volume Z_t^M is produced using domestically-produced manufacturing sector goods of volume $Y_t^{M,Z}$, and imported goods of volume $IM_t^{M,Z}$ using the following production function:

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

where $\alpha_{M,Z}$ is the parameter governing the import/home bias for the composite manufacturing good employed in the production of the final good Z_t^M and $\eta_{M,Z}$ is the elasticity of substitution between the imported and the domestically-produced manufacturing sector good.

The objective of final goods firms in the first stage of production is to minimize the cost of producing the composite good. Let $P_t^M = P_t^{Nom,M}/P_t$ 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. The cost minimization problem yields the following final-good-specific demand functions for domestically-produced manufacturing and imported goods:

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

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

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

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

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

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

The composite service good is produced completely analogously to the composite manufacturing good.

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

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

where α_Z is the final-good-specific composite service good bias parameter and η_Z the elasticity of substitution between the composite manufacturing and service good. The objective of final goods firms in the second stage of production is to minimize the cost of producing a certain level of production Z_t, given the price of the composite manufacturing $P_t^{M,Z}$ and service $P_t^{S,Z}$ good. This yields the following final-goods-specific demand functions

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

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

The relative price of final good Z is then given by

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

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

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

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

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

2.5.2. Final consumption and export good sector

In contrast to the final investment and government consumption good we assume that the second stage of the final good sector for consumption and export 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 good 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, as also found empirically by Benedek et al. (2015) and Voigts (2016). This model feature will lead to a hump-shaped consumption tax (cumulative) multiplier in our results.

The rationale for the export sector's pricing power is unrelated to taxation. Instead it allows local currency price setting, i.e. the setting of prices in the currency of foreign markets to which exporters sell their goods, a practice sometimes called pricing-to-market. This is consistent with the significant amount of evidence of deviations from the law of one price even for traded goods (Betts and Devereux, 2000). As a consequence, crowding-out of fiscal stimulus through appreciation of the exchange rate and depression of exports does not occur immediately but slowly over time.

In the following, we will derive the overall second stage production problem for the export sector, and later state the analogous consumption sector problem. 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

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

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

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

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

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

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

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

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

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

where α_X is the service good bias parameter for exports and η_X is the elasticity of substitution between the composite manufacturing $X_t^M(i)$ and service $X_t^S(i)$ good for the final export good. Exporter i seeks to minimize its costs of producing a certain desired level of production $X_t(i)$, given the price of the composite manufacturing $P_t^{M,X}$ and service $P_t^{S,X}$ good derived earlier. The solution yields the following demand functions for the composite manufacturing and service good by the final good export sector

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

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

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

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

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

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

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

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

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

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.[29]

The solution to the price-setting problem, which involves maximizing the net present value of the expected future value of profits each period in equation (34) subject to the demand function given by equation (29), yields, that all exporting firms set identical prices such that $P_t^X(i) = P_t^X$. Because exporters set identical prices they also have the same output, the same profits, and the same demand for composite manufacturing and service goods, allowing us to drop the i subscript. Export prices in steady state are set at a mark-up over marginal costs:

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

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

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

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

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

2.5.3. Intermediate good manufacturing and services sector

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

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

[29] 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.

[30] 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.

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. Additionally and following Baxter and King (1993) and Sims and Wolff (2018a) we assume that public capital K_t^G can augment productivity of private firms, where κ_M measures the effectiveness of public capital in increasing productivity in the manufacturing sector.[31] The term $Z_t^{Y^M}$ captures the total factor productivity shock.

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

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

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

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

The aggregate price is given by $P_t^M = (\int_0^1 P_t^M(i)^{1-\epsilon_M} di)^{\frac{1}{1-\epsilon_M}}$. 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.

Intermediate sector firms face 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.

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

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

where Inv_t^M denotes investments in the manufacturing sector and δ_{KP} is the capital depreciation rate.[32] Following Gadatsch et al. (2016), firms incur costs to adjusting the level of investment

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

where χ_{Inv} is a parameter determining the magnitude of investment adjustment costs.

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

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

where BN_t^M denotes the real value of new domestic borrowing. We define the debt-to-capital ratio as $b_t^M := \frac{B_t^M}{\lambda_t^{K,M}K_t^M}$ 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 that increases with the amount of borrowing, as captured by the firm's debt-to-capital ratio. In particular, we assume that

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

where ξ_B captures the responsiveness of the risk premium to the debt-to-capital ratio and β^M is a parameter calibrated to ensure that NORA matches the empirical debt-to-capital ratio in Norwegian firms. 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.[33] This risk premium on the borrowing costs of firms creates a credit spread between the interest rate at which banks service deposits ($R_t^L = R_t$) and the effective rate at which firms borrow ($R_t^L RP_t^{B,M}$). The spread is generally counter-cyclical as it will increase in recessions which reduce the shadow price of the capital stock of the firm.

Additionally, firms face costs when adjusting the level of new borrowing, following Alfaro et al. (2018) who argue that it is costly in terms of managerial time to change existing borrowing arrangements. Preserving the symmetry with investment adjustment costs we assume borrowing adjustment costs to be given by

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

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

$$\begin{aligned}\Pi_t^M(i) = \; & P_t^M(i)Y_t^M(i) - (1+\tau_t^{SSF})W_t N_t^M(i) \\ & -(R_{t-1}^L RP_{t-1}^{B,M} - 1)\frac{B_{t-1}^M(i)}{\pi_t^{ATE}} - \\ & -(AC_t^M(i) + AC_t^{Inv,M}(i) + AC_t^{BN,M}(i))\end{aligned} \tag{41}$$

where τ_t^{SSF} is the social security tax (payroll tax) paid by firms.[34] The tax base for the corporate profit tax is then given by

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

Deductable from profits is a depreciation allowance, where the tax depreciation rate is given by δ_τ. 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 either retained in order to finance net investments, used to pay dividends to shareholders, or used to pay profit taxes to the government. Hence, it holds that

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

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

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

[31] In the baseline calibration of the model we assume κ_M to be zero.

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

[33] 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 $R_{t-1}^L(RP_{t-1}^{B,M} - 1)\frac{B_{t-1}^M}{\pi_t^{ATE}} + R_{t-1}^L(RP_{t-1}^{B,S} - 1)\frac{B_{t-1}^S}{\pi_t^{ATE}}$.

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

Firm's stock price As noted in equation (7), which we repeat below for convenience, the firm's stock price is equal to the present discounted value of future dividends

$$P_t^{E,M}(i) = \sum_{j=1}^{\infty} \frac{1}{R^e_{t+j}} DIV^M_{t+j}(i),$$

where the firm's discount factor (from time $t = 1$) is equal to $R^e_{t+j} = \prod_{l=1}^{j} \frac{1-\Delta_{t+l}/\pi^{ATE}_{t+l}\tau^D_{t+l}(1+RRA_{t+l})}{\Delta_{t+l}(1-\tau^D_{t+l})}$. It will prove useful to write the period-to-period discount factor for dividends as

$$DF^{DIV}_{t+j+1} := \frac{R^e_{t+j+1}}{R^e_{t+j}} = \frac{1-\Delta_{t+j+1}/\pi^{ATE}_{t+j+1}\tau^D_{t+j+1}(1+RRA_{t+j+1})}{\Delta_{t+j+1}(1-\tau^D_{t+j+1})}. \tag{44}$$

We can now identify

$$R^K_t := \frac{DF^{DIV}_{t+1} - 1}{1-\tau^{OIF}_{t+1}}$$

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^{DIV}_{t+1} many in period $t+1$ (in real terms) as DF^{DIV}_{t+1} captures their discount factor on dividends. Hence, for firms to rely on equity financing, i.e. a reduction in dividends paid out, the investment, ignoring corporate taxes for now, needs to earn a gross return of DF^{DIV}_{t+1} and hence a net return of $DF^{DIV}_{t+1} - 1$. 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 $(1-\tau^{OIF}_{t+1})$.

Firm's maximization problem Firm i's decision variables are the amount of labor it wants to employ $N^M_t(i)$ given the wage rate in the economy, the amount of investment $Inv^M_t(i)$ it wants to undertake, the amount of new borrowing $BN^M_t(i)$ it needs to carry out that investment, and the price it wants to charge for the good it produces $P^M_t(i)$. The firm chooses the optimal value of these variables in order to maximize its share price, taking into account the physical capital and firm debt constraint as well as the need to satisfy the demand given their price decision. The derivations are provided in the technical appendix.

The first-order condition on labor is given by

$$(1-\tau^{OIF}_t)(1+\tau^{SSF}_t)W_t = (1-\alpha_M)\lambda^{Y,M}_t \frac{Y^M_t(i)+FC^M}{N^M_t}. \tag{45}$$

Hence, firms choose the amount of labor they want to employ in such a way that the after-tax wage equals the marginal product of labor. The first-order condition on investment states, that

$$\begin{aligned} P^I_t = &-(1-\tau^{OIF}_t)\left(\chi_{Inv}\left(\frac{Inv^M_t}{Inv^M_{t-1}}-1\right)Inv^M_t/Inv^M_{t-1} \right.\\ &\left. + \frac{\chi_{Inv}}{2}\left(\frac{Inv^M_t}{Inv^M_{t-1}}-1\right)^2\right)\\ &+ \lambda^{K,M}_t + \frac{(1-\tau^{OIF}_{t+1})}{DF^{DIV}_{t+1}}\chi_{Inv}\left(\frac{Inv^M_{t+1}}{Inv^M_t}-1\right)Inv^M_{t+1}\frac{Inv^M_{t+1}}{(Inv^M_t)^2} \end{aligned} \tag{46}$$

Hence, firms choose the amount of investment in such a way that the marginal value of capital is equal to the price of investment good, consisting of the price of investment and investment adjustment costs. The envelope condition on capital is given by

$$\lambda^{K,M}_t DF^{DIV}_{t+1} = \tau^{OIF}_{t+1}\delta_\tau P^I_{t+1} + \lambda^{K,M}_{t+1}(1-\delta_{KP}) + \lambda^{Y,M}_{t+1}\alpha_M \frac{Y^M_{t+1}+FC^M}{K^M_{t+1}}. \tag{47}$$

The condition captures that the marginal value of capital is a function of its marginal product, the depreciation allowance and the cost of equity-financing. The first-order condition on new borrowing states, that

$$\lambda^{B,M}_t = -1 + (1-\tau^{OIF}_t)DAC^{BN}_t - \frac{1-\tau^{OIF}_{t+1}}{DF^{DIV}_{t+1}}DACBN_{t+1}\frac{BN^M_{t+1}}{BN^M_t}.$$

Hence, each additional unit of new borrowing decreases the value of the firm by one unit, subject to adjustment costs, where $DACBN$ captures the derivative of the adjustment costs on borrowing, analogously defined to DAC in the technical appendix. New borrowing, however, also allows the firm to invest, which has positive effects on the value of the firm. This is captured by the envelope condition on the level of debt B^M_t, which is given by

$$\frac{-\lambda^{B,M}_t DF^{DIV}_{t+1}\pi^{ATE}_{t+1} + \lambda^{B,M}_{t+1}}{(1-\tau^{OIF}_{t+1})} = (R^L_t RP^{B,M}_t(1+\xi_B b^M_t) - 1).$$

The right-hand side of equation captures the marginal cost of borrowing. It depends on the interest rate charged by banks on firm loans R^L_t, the risk premium on firm borrowing $RP^{B,M}_t$, and the marginal increase in the risk premium $\xi_B b^M_t$ caused by an increase in the debt-to-capital ratio, see equation (40). The left-hand side of equation captures the cost of equity financing. In particular the cost of equity declines with the rate-of-return allowance RRA_t, see equation (44). Hence, a higher rate-of-return allowance will reduce the marginal cost of equity financing and shift financing away from debt to equity.[35] The first-order condition on prices implies that all firms set the same price $P^M_t(i) = P^M_t$ which in steady state is given by

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

Hence, the after-tax price of the manufacturing good in steady-state is set as a mark-up over the value of one unit of production.[36] The full dynamic pricing equation is given in the technical appendix.

2.5.4. Imported goods sector

Individual importing firms sell their output $IM_t(i)$ at a relative price $P^{IM}_t(i)$ to perfectly-competitive import retailers who use the bundling function

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

where ϵ^{IM}_t is the elasticity of substitution across imported goods sold by individual importers. Output maximization then implies

$$IM_t(i) = \left(\frac{P^{IM}_t(i)}{P^{IM}_t}\right)^{-\epsilon^{IM}_t} IM_t. \tag{49}$$

where the aggregate price index is $P^{IM}_t = (\int_0^1 P^{IM}_t(i)^{1-\epsilon^{IM}_t} di)^{\frac{1}{1-\epsilon^{IM}_t}}$. Profits by importing firms are given by $\Pi_{F,t}(i) = (P^{IM}_t(i) - RER_t)IM_t(i) - AC^{IM}_t(i)$ where the cost of production equals the real exchange rate RER_t since this is the price at which the importer can purchase one unit of foreign output. Price adjustment costs are analogous to those in the domestic intermediate sectors. The solution to the price-setting problem, which involves maximizing the net present value of profits subject to the demand function is given in the technical appendix. The result implies that all import firms set the same price $P^{IM}_t(i) = P^{IM}_t$, and that in steady state the price is set as a markup over the real exchange rate, i.e. $P^{IM} = RER\frac{\epsilon^{IM}}{\epsilon^{IM}-1}$.

[35] In the appendix section A.6, we show that if the ordinary income tax rate on households τ^{OIH}_t and on firm profits τ^{OIF}_t 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.

[36] In our framework firms operate as stock price maximizer rather than cost minimizer as usually the case in standard DSGE models. This gives rise to a problem whereby the value of one unit of production enters the maximization problem as opposed to the more commonly used measure of marginal costs arising in cost minimization. The two measures are, however, equivalent. As evident from equation (48), the term $\lambda^{Y,M}_t$ can be interpreted as marginal cost in the manufacturing sector such that the after-tax price is set as a mark-up, a function of the elasticity ϵ_M, over marginal cost.

2.6. Monetary and fiscal policy

2.6.1. Central bank

The central bank sets the nominal interest rate according to Norges Banks DSGE model NEMO, see (Kravik and Mimir, 2019), given by the expression

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

where $\widetilde{X}_t \in \{\widetilde{R}_t, \widetilde{\pi}_t^{ATE,Ann}, \widetilde{\pi}_t^{Nom,W}, \widetilde{Y}_t, \widetilde{RER}_t\}$ denotes the (potentially time-varying) "target" value of X_t.[37] The term $\pi_t^{ATE,Ann}$ is annualized quarterly inflation, and $\pi^{Nom,W}$ is nominal wage inflation. The parameters $\rho_R, \psi_\pi, \psi_{\pi,F}, \psi_W, \psi_Y$ and ψ_{RER} capture the weight placed by the central bank on smoothing changes in the interest rate, preventing deviations of annual inflation, current and one quarter ahead, and nominal wage inflation from target as well as keeping output at potential and the real exchange rate at its steady-state value. The term Z_t^R captures a shock to the nominal interest rate.

The rule above governs the interest rate in the absence of the zero lower bound, which we call the shadow interest rate R_t^*. However, we impose, that

$$R_t = \max\{R_t^*, 1\} \tag{50}$$

For most shocks this lower bound of one will not be reached and the interest rate in the economy will simply be given by the shadow interest rate rule above. However, for larger recession, the gross interest rate according to the rule can fall below unity, implying a negative net interest rate, which the ZLB in equation (50) will prevent. In the sense of Leeper (1991), we consider thus an active monetary policy regime in our model as long as the ZLB is not binding. Once the ZLB binds, however, monetary policy becomes temporarily passive.

As will be shown in our results in section 5, a binding ZLB implies less crowding-out of fiscal stimulus since increases in inflation following the boost in aggregate demand will not result in higher real interest rates. This mechanism, alongside the channel operating through the DNWR as discussed in equation (17), is thus important in our model's ability to give rise to the state-dependent nature of fiscal interventions.

2.6.2. Government budget

The government finances its expenditures by levying a range of taxes and through withdrawals from the Government Pension Fund Global (GPFG). Total government revenue is given by the various taxes introduced in the household and firm sector:

$$\begin{aligned} T_t = \; & T_t^L + C_t(\tau_t^C + \tau_t^{CF}) + (W_t N_t^P + W_t^G N_t^G)\tau_t^{SSF} \\ & + \Big(W_t N_t^P + W_t^G N_t^G + UB_t(L_t - E_t) + TR_t + DP_{t-1} \\ & /\pi_t^{ATE}(R_{t-1} - 1) - TD^{OIH}\Big)\tau_t^{OIH} \\ & +(W_t N_t^P + W_t^G N_t^G + UB_t(L_t - E_t) + TR_t - TD^{LS}) \\ & (\tau_t^{LS} + \tau_t^{SSH}) \\ & +(\Pi^{M,TB} + \Pi^{S,TB})\tau_t^{OIF} + \Big(DIV_t + AV_t - RRA_t P_{t-1}^E\Big)\alpha_t^{OIH}\tau_t^{OIH}. \end{aligned} \tag{51}$$

Thus, total tax revenue consists of the lump-sum tax, consumption tax revenue, social security contributions of employers, ordinary income tax on personal income, additional taxes on labor income and transfers, corporate income taxation and dividend as well as capital gain taxation. For the latter, 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 the sum of government purchases, government investment, unemployment benefits, lump-sum transfers and the government wage bill:

$$\begin{aligned} G_t = \; & P_t^{GC} G_t^C + P_t^I G_t^I + UB_t(L_t - E_t) + TR_t + AVT_t \\ & + W_t^G N_t^G (1 + \tau_t^{SSF}). \end{aligned} \tag{52}$$

The government's real value of debt at time t is given by D_t. Recalling that R_{t-1}^L is the nominal gross lending rate, the real value of debt interest payments DI_t is then given by $DI_t = (R_{t-1}^L - 1)/\pi_t^{ATE} D_{t-1}$. Withdrawals from the Government Pension Fund Global (GPFG), that will be discussed in section 2.6.4, are given by OFW_t. In almost all budget years, Norway does not borrow money to finance government expenditures. We therefore enforce a zero total petroleum-adjusted surplus, implying the following government budget:

$$T_t + OFW_t = G_t + DI_t. \tag{53}$$

Hence, we are considering a passive fiscal policy regime in our model (in the sense of Leeper (1991)) as government debt by construction is always held stable. Unless they are "fiscal instruments" used to balance the budget in equation (53), the revenue and current (non-investment) spending components of the government budget are modeled as simple auto-regressive shock processes. Tax rates are assumed to follow the following additive process

$$X_t = X_{ss} + \rho_X(X_{t-1} - X_{ss}) + Z_t^X, \tag{54}$$

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 2.6.3) and non-tax-rate revenue instruments are assumed to follow the following multiplicative process

$$X_t = X_{ss}\left(\frac{X_{t-1}}{X_{ss}}\right)^{\rho_X} \exp(Z_t^X), \tag{55}$$

where $X_t \in \{G_t^C, T_t^L, OFW_t, TR_t^L, TR_t^R, UB_t, N_t^G, \alpha_t^{OIH}\}$. 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. Finally, the RRA_t is set to the level which avoids double taxation of the risk-free return on equity. As shown in the technical appendix this implies that the RRA_t depends on the prevailing interest rate and the household's ordinary income tax rate, i.e. $RRA_t = (R_t - 1)(1 - \tau_t^{OIH})$.

2.6.3. Public investment and capital

We model the public capital stock using a time-to-build specification as in Leeper et al. (2010) and Coenen et al. (2013). In the following, we assume that it takes $N \geq 1$ periods for a given authorized public investment project to become public capital. The accumulation of the public capital stock is then given by

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

[37] In most case this target captures simple the corresponding steady-state value. However, following permanent shocks it is possible that the steady-state interest rate and level of potential output changes. To capture the fact that the central bank would gradually recognize that the economy has moved to a new steady-state and adjust their policy targets, we follow Laxton et al. (2010) and implement a moving average process

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

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

where δ_{KG} is the depreciation rate of public capital and $G^{I,Auth}_{t-N+1}$ is the authorized amount of public investment $N-1$ periods ago. The cost of the authorized public investment project is spread over the time it takes to complete the project. We assume that the spending shares for each period n from authorization to completion of the project are given by ω_n. Hence, ω_n indicates what share of the total authorized investment is constructed in the n-th period since the investment was authorized. Public investment volume each period G^I_t is then given by

$$G^I_t = \sum_{n=0}^{N-1} \omega_n G^{I,Auth}_{t-n}. \tag{56}$$

Equation (56) captures the amount of public investment in period t on all ongoing public investment projects dating back to $N-1$ periods ago. Since public investments have to be fully funded over the implementation period, $\sum_{n=0}^{N-1} \omega_n = 1$ holds. The amount of authorized public investments follows the autoregressive process

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

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

2.6.4. 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.[38] 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:

$$OF_t = (1 + R^{OF})OF_{t-1} - \frac{OFW_t}{RER_{ss}}, \tag{57}$$

where R^{OF} is the constant real rate of return of the fund, RER_{ss} is the steady-state exchange rate, and OFW_t denotes the domestic-currency value of withdrawals from the GPFG. Hence, $\frac{OFW_t}{RER_{ss}}$ captures the value of oil fund withdrawals in foreign currency. During simulations it is possible to use oil fund withdrawals OFW_t as a temporary financing instrument. In order to avoid an imploding (or exploding) value of the fund, however, the take-out rate $TOR_t := \frac{OFW_t}{RER_{ss}\cdot OF_t}$ has to return to the real rate of return of the GPFG in the long run $TOR_{ss} = R^{OF}$. This can be achieved in several ways. For example, a temporary increase in oil fund withdrawals followed by a temporary decrease sufficient to restore the GPFG to its original value would ensure that the take-out rate returns to its sustainable level. Alternatively, a temporary increase in oil fund withdrawals could be followed by a permanently lower level of oil fund withdrawals to take account of the now lower level of sustainable capital income generated by the fund. We resort to this latter alternative in section 6, when checking whether our main state-dependency result is robust to alternative ways of financing the fiscal stimulus.

[38] 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.

2.7. Foreign sector

Following Norges Bank's NEMO, see Kravik and Mimir (2019), we model the foreign sector using an exogenous block that links foreign inflation π^{TP}_t, foreign output by trading Y^{TP}_t and non-trading Y^{NTP}_t partners, the foreign interest rate R^{TP}_t and the oil price P^{Oil}_t. In contrast to NEMO, which includes a microfounded oil production sector, we model also the demand for domestically-produced investment goods from the off-shore oil sector Inv^{Oil}_t in a reduced-form fashion depending on the oil price. We exploit this model of the foreign sector in our result section by testing whether the state-dependency of the fiscal multiplier, which in the literature is usually generated by recessions induced by a consumption preference shock, also holds in global demand recessions.

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

$$Y^{TP}_t = Y^{TP}_{ss}\left(\frac{Y^{TP}_{t-1}}{Y^{TP}_{ss}}\right)^{\rho_{Y^{TP}}}\left(\frac{Y^{F,TP}_t}{Y^{F,TP}_{ss}}\right)^{1-\rho_{Y^{TP}}}\left(\frac{P^{Oil}_t}{P^{Oil}_{ss}}\right)^{-\Psi_{Y^{TP},P^{Oil}}}\left(\frac{Y^{NTP}_t}{Y^{NTP}_{ss}}\right)^{\Psi_{Y^{TP},Y^{NTP}}}\exp(Z^{Y^{TP}}_t),$$

$$Y^{F,TP}_t = Y^{F,TP}_{ss}\left(\frac{Y^{F,TP}_{t+1}}{Y^{F,TP}_{ss}}\right)^{\Psi_{Y^{F,TP},Y^{F,TP}}}\left(\frac{R^{TP}_t}{\pi^{TP}_{t+1}}\Big/\frac{R^{TP}_{ss}}{\pi^{TP}_{ss}}\right)^{-\Psi_{Y^{F,TP},R^{TP}}}.$$

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 the term $Y^{F,TP}_t$, capturing the forward-looking component of output, 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^{NTP}_t, who are assumed to trade with Norway's trading partners but not directly with Norway. The term $Z^{Y^{TP}}_t$ denotes a shock to the output of trading partners. The output of non-trading partners Y^{NTP}_t is given by

$$Y^{NTP}_t = Y^{NTP}_{ss}\left(\frac{Y^{*,NTP}_{t-1}}{Y^{NTP}_{ss}}\right)^{\rho_{Y^{NTP}}}\left(\frac{P^{Oil}_t}{P^{Oil}_{ss}}\right)^{-\Psi_{Y^{NTP},P^{Oil}}}\left(\frac{Y^{TP}_t}{Y^{TP}_{ss}}\right)^{\Psi_{Y^{NTP},Y^{TP}}}\exp(Z^{Y^{NTP}}_t).$$

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), we use the shock $Z^{Y^{NTP}}_t$ to simulate a global demand recession in our analysis of the state-dependency of the multiplier in section 6. Overall global output is then given by a weighted sum of the output of trading partners and non-trading partners:

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

where $\omega_{Y,TP}$ captures the steady-state share of trading partners' output in total global output. Inflation in Norway's trading partners is given by the following system of equations

$$\pi^{TP}_t = \pi^{TP}_{ss}\left(\frac{\pi^{TP}_{t-1}}{\pi^{TP}_{ss}}\right)^{\rho_{\pi^{TP}}}\left(\frac{\pi^{F,TP}_t}{\pi^{F,TP}_{ss}}\right)^{1-\rho_{\pi^{TP}}}\left(\frac{P^{Oil}_t}{P^{Oil}_{ss}}\right)^{\Psi_{\pi^{TP},P^{Oil}}},$$

$$\pi^{F,TP}_t = \pi^{F,TP}_{ss}\left(\frac{\pi^{F,TP}_{t+1}}{\pi^{F,TP}_{ss}}\right)^{\Psi_{\pi^{F,TP},\pi^{F,TP}}}\left(\frac{Y^{TP}_t}{Y^{TP}_{ss}}\right)^{\Psi_{\pi^{F,TP},Y^{TP}}}\exp(Z^{\pi^{TP}}_t).$$

Hence, inflation in foreign trading partners is partly backward looking, captures the positive effect of oil prices on marginal costs and hence on inflation, and incorporates the standard forward-looking Phillips curve dynamics through $\pi^{F,TP}_t$. The shock $Z^{\pi^{TP}}_t$ to the foreign inflation rate can be interpreted as a foreign markup shock. Foreign trading partners' monetary policy is given by a standard Taylor rule where the interest rate responds to the contemporaneous inflation and output

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

The parameters $\psi_{\pi^{TP}}$ and $\psi_{Y^{TP}}$ capture the weights placed by the foreign trading partner central bank on preventing deviations of inflation from target and keeping output at potential, while $\rho_{R^{TP}}$ captures the weight placed on interest rate smoothing. The shock $Z_t^{R^{TP}}$ can be interpreted as a shock to the nominal interest rate in foreign trading partners. The international oil price is forward-looking and responds to movements in global demand

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

where $Z_t^{P^{OIL}}$ can be interpreted as an oil price shock. The equations above are parametrized in the same way as in the estimated version of NEMO. Demand for domestically-produced investment goods by the offshore oil production sector is assumed to depend positively on the oil price and is given by a following reduced-form autoregressive process

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

where $Z_t^{Inv^{OIL}}$ captures a shock to oil sector investment demand. Note, that a shock to non-trading partner output will directly affect the price of oil and thus stimulate oil sector investment demand faced by the mainland economy. The demand for traditional exports from Norway is stimulated indirectly through an increase in output from trading partners.

2.8. Aggregation

To complete the technical description of NORA we define aggregate investment and housing variables as well as define GDP. We also discuss the balance of payments and the aggregate market clearing condition.

Housing We differentiate between housing investment and investment in physical capital in the corporate sector.[39] Housing investment is modeled as a reduced-form process and assumed to evolve in line with long-run changes in GDP, i.e. $Inv_t^H = Inv_{ss}^H \widetilde{Y}_t / Y_{ss}$. The moving-average process for GDP ($\widetilde{Y}_t$, defined in section 2.6.1) ensures housing investment will gradually converge to a new level following permanent changes in GDP. This implies that for any temporary shocks, housing investment will not react at all. Housing capital evolves according to $K_{t+1}^H = (1-\delta_H)K_t^H + Inv_t^H$, where δ_H is the depreciation rate on housing capital. Consumption of housing services, a component of GDP, is defined as $C_t^H = R^H K_t^H$ where R^H is the return on housing capital. We are agnostic about who owns the housing capital and consumes the associated housing services and do therefore not take these into account when we model the household sector.

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

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

[39] 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.

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 $I_t^{ML,P} := Inv_t^M + Inv_t^S$.

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

$$\begin{aligned} Y_t^M &= Y_t^{M,C} + Y_t^{M,I} + Y_t^{M,G^C} + Y_t^{M,X}, \\ Y_t^S &= Y_t^{S,C} + Y_t^{S,I} + Y_t^{S,G^C} + Y_t^{S,X}, \\ IM_t &= IM_t^{M,C} + IM_t^{M,I} + IM_t^{M,G^C} + IM_t^{M,X} + IM_t^{S,C} \\ &\quad + IM_t^{S,I} + IM_t^{S,G^C} + IM_t^{S,X}. \end{aligned} \tag{58}$$

Hence, total output in the manufacturing, service, and import sector consists of the corresponding first-stage inputs into the production of the four final goods. Since, as shown in Fig. 2, 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 consists of a total of eight terms.

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

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

The total value of domestic output (in consumption 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. 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 then be rewritten as

$$P_t^Y Y_t^D = P_t^M Y_t^M + P_t^S Y_t^S + VA_t^X X_t, \tag{59}$$

where $VA_t^X = RER_t P_t^X - MC_t^X$ is the value added per unit in the export sector. Profits in the export sector are then given by $\Pi_t^X = VA_t^X X_t - AC_t^X$.

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

$$Y_t = Y_t^D + R^H K_t^H + \frac{(1+\tau_{ss}^{SSF})W_{ss}^G}{P_{ss}^Y} N_t^G + \frac{P_{ss}^I \delta_{KG}}{P_{ss}^Y} K_t^G + \Delta INV_t. \tag{60}$$

The public wage bill and public capital depreciation are divided by the relative price of domestic output to translate their values, which are given in consumption units, into units of the domestic good. The terms preceding N_t^G and K_t^G in equation (60) are held constant at their steady-state value following the national accounts convention that government employment and capital depreciation are to be valued at base prices. As a consequence, only volume changes (i.e. changes in public employment or the public capital stock) affect the government wage bill and public capital depreciation components in the GDP definition. Inventory changes ΔINV_t are given by an exogenous process.[40]

2.8.1. 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, i.e. $IM_t^{Res} = IM_{ss}^{Res} \frac{IM_t}{IM_{ss}}$, 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, i.e. $NX_t = RER_t P_t^X X_t - P_t^{IM}(IM_t + IM_t^{Res})$, where $RER_t P_t^X$ is the relative domestic-currency price of exports and P_t^{IM} is the relative price of imports. The balance of payments for the economy is then given by

$$NX_t + OFW_t + P_t^I Inv_t^{Oil} = \frac{EX_t P_t^{TP}}{P_t}(-B_t^F) - \frac{EX_t P_{t-1}^{TP}}{P_t}(-B_{t-1}^F) R_{t-1}^{TP} RP_{t-1}(A_{t-1}). \quad (61)$$

The left hand side denotes payments to the domestic economy, consisting of net exports, withdrawals from the GPFG, and the sale of domestically-produced investment goods to the offshore oil sector. The right hand side captures the net change in foreign assets (excluding the GPFG) including interest payments.

Aggregate market clearing We obtain the aggregate market clearing condition by inserting the balance of payments, the government budget constraint in equation (53), the budget constraint for liquidity-constrained households in equation (9), the profit functions of intermediate goods firms in the manufacturing and service sector in (41), and the bank balance sheet in equation (18) into the budget constraint of Ricardian households in equation (4), yielding

$$P_t^Y Y_t^D = C_t + NX_t + P_t^I I_t + P_t^{G^C} G_t^C + AC_t, \quad (62)$$

where AC_t are total adjustment costs in the economy. The equation, thus, shows that total demand in the economy equals total supply as given in equation (59).[41]

3. Theoretical insights into state-dependent multipliers

Before considering quantitative simulations of our full, nonlinear model, we first consider a linear approximation of a simplified version of the full model, enabling us to derive theoretical insights into the role of the ZLB and DNWR in generating state-dependent spending and tax multipliers. Specifically, we consider a closed economy without liquidity-constrained households, banks, and productive capital. There is only one production sector using labor to produce a final good, which is consumed by Ricardians and the government. The production sector sets prices subject to Rotemberg adjustment costs. Wages are set by a union with unemployment in the reference utility. These simplifications isolate the most important transmission channels of fiscal multipliers and are thus instructive in understanding our main results. The details of this model simplification are discussed in Appendix B.

The simplification ultimately yields a generic small-scale New Keynesian (NK) DSGE model, close in spirit to standard handbook approaches such as in Schmidt and Wieland (2013), consisting of a Euler equation, a market clearing condition, a Taylor rule and a NK Phillips curve and a wage-setting equation:

$$\widetilde{C}_t = E_t[\widetilde{C}_{t+1}] - \frac{1}{\sigma}\left(\widetilde{R}_t - E_t[\widetilde{\pi}_{t+1}]\right) - Z_t^U \quad (63)$$

$$\widetilde{Y}_t = \frac{C_{ss}}{Y_{ss}}\widetilde{C}_t + \frac{G_{ss}}{Y_{ss}}\widetilde{G}_t \quad (64)$$

$$\widetilde{R}_t = \psi_\pi \widetilde{\pi}_t + \psi_Y \widetilde{Y}_t \quad (65)$$

$$\widetilde{\pi}_t = \beta E_t[\widetilde{\pi}_{t+1}] + \kappa \widetilde{MC}_t, MC_t = (1+\tau_t^{SSF})W_t \quad (66)$$

$$\widetilde{W}_t = -\kappa_\tau \widetilde{\tau}_t^{SSF} + \kappa_Y \widetilde{Y}_t \quad (67)$$

where $\widetilde{X}_t = (X_t - X_{ss})/X_{ss}$ captures the percentage deviation of variable X relative to its steady state and variable names correspond to those used in the full model.[42] The parameters used in equation (63)–(67) are detailed in the Appendix B and all positive. Hence, the simplified model is characterized by a standard Euler equation in which growth of private consumption (C) increases with the real interest rate and with the consumption preference shock (Z^U). Hence, a negative preference shock will lower the level of private consumption such that its growth to the next period increases. Total production is used for private and public consumption (G). The Taylor rule implies that the interest rate increases with the inflation and output gap, where due to the Taylor principle $\psi_\pi > 1$. Inflation is a function of expected inflation and the marginal cost in production, given by the wage level. Finally, wage bargaining implies that wages increase with employment and thus output (as $Y_t = N_t$), as well as with prices, while falling with the tax rate for social security contributions by firms.[43]

To analyze the state-dependency of the fiscal multiplier and in line with most approaches in the literature, we consider the impact multiplier[44] for a change in government spending G_t, given by

$$M = \frac{\Delta Y}{\Delta G} = \frac{\Delta(G+C)}{\Delta G} = \left(1 + \frac{\Delta C}{\Delta G}\right). \quad (68)$$

Hence, the size of the fiscal multiplier is directly related to the consumption response to the fiscal expansion.

3.1. The role of the ZLB and DNWR

In the following, we consider four scenarios, in which the fiscal expansion can take place: (1) from steady state or (2) during a preference-shock induced recession, in which (2a) only the ZLB is active and becomes binding, (2b) only the DNWR is active becomes binding, (2c) both rigidities are active and become binding. We will show that the differential response of consumption to the government spending increase causes state-dependency of the fiscal multiplier. Specifically, the theoretical analysis will establish, that while each rigidity gives rise to higher fiscal multipliers, the DNWR tends to dampen the state-dependency generating effects of ZLB when interacting.

[40] Steady-state GDP in consumption units Y^{CPI} is then given by the sum of the components of Y expressed in consumption units $Y^{CPI} = P^Y Y$, a measure used in steady-state calibration.

[41] A full derivation of the aggregate market clearing condition can be found in Aursland et al. (2019).

[42] The Euler equation refers to aggregate consumption C rather than C^R as the economy only consists of Ricardians. Government purchases are captured by G, rather than G^C as there are no other spending components.

[43] Note, that the arguments made within this section are also valid in a model where wages are set following household's trade-off between utility from consumption and leisure. In this set-up, following Schmidt and Wieland (2013), wages would follow the equation $\widetilde{W}_t = \eta\widetilde{N} - \sigma\widetilde{C}_t$ where η is the parameter capturing the Frisch elasticity of labor supply. Hence, also in this case, wages tend to increase with the level of employment and thus output in the economy.

[44] In the full model we will additionally consider the cumulative multiplier.

1) Fiscal expansion from steady state:

Given an increase in G_t, output increases (equation (64)) and thus also wages (equation (67)). As a consequence of the NK Phillips curve, inflation picks up, which in turn causes a hike in nominal interest rates (equation (65)). According the Taylor principle, nominal interest rates increase more than inflation, such that the real interest rate $(\widetilde{R}_t - E_t[\widetilde{\pi}_{t+1}])$ rises. Consequently, the Euler equation (equation (63)) predicts a postponement and thus fall in consumption on impact. Given this crowding out of consumption, the multiplier falls below one.[45]

2a) Fiscal expansion during a recession in which only the ZLB exists and binds:

We now consider a sufficiently negative shock E^U, such that R hits the lower limit imposed by the ZLB, i.e. $R = 1$ (as R captures the gross return). The shadow gross nominal interest rate R^*, defined as the interest rate that would hold in the absence of the ZLB, is then below unity. In the log-linearized model, this implies that equation (65) is replaced by $\widetilde{R}_t = \widetilde{R}_{ZLB}$, where $\widetilde{R}_{ZLB}$ corresponds to a gross interest rate of one.

Considering, the same fiscal expansion as before, we still obtain an increase in output, wages and inflation. However, if the government expansion is small enough not to increase R_t^* beyond the limit imposed by the ZLB, the nominal interest rate will not increase and remain at $\widetilde{R}_{ZLB}$. Hence, as inflation increases, while the nominal rate remains unchanged, the real interest rate falls, generating a positive substitution effect on consumption. The government spending multiplier in a recession with a binding ZLB lies thus above the multiplier during steady-state as in the latter case real interest rates increase and a negative substitution effect on consumption materializes.

2b) Fiscal expansion during a recession in which only the DNWR exists and binds:

The existence of the DNWR implies a lower bound on the real wage, as given by (17). The real wage at the DNWR in log-linearized form, is then given by $\widetilde{W}_t = \widetilde{W}_{t-1} - \widetilde{\pi}_t$. Analogously, we now consider a negative consumption preference shock, which is sufficiently strong to induce a negative output gap and consequently a fall in the real wage (through equation (67)), such that the DNWR becomes binding.

When considering the same fiscal expansion as before, we obtain an increase in the output gap. However, the inflation gap is not increased to the same extent as before, as the wage gap does not increase initially. Given this weaker inflation response, the nominal interest rate will respond less than in the scenario when the expansion occurs in steady state, but more, than when the expansion occurs in a recession with a binding ZLB (where it does not respond at all). From this follows, that the multiplier in a recession with a binding DNWR will be larger than the steady-state multiplier but smaller than the multiplier during a ZLB episode.

2c) Fiscal expansion during a recession in which both the ZLB and DNWR bind:

We now consider the same preference shock as before, such that both the ZLB and DNWR become binding. The fiscal expansion increases the output gap, while only weakly affecting inflation due to the initial unresponsiveness of wages at the DNWR. Due to the ZLB, the nominal interest rate does not increase. However, as inflation only weakly picks up, the real interest rate $(\widetilde{R}_t - E_t[\widetilde{\pi}_{t+1}])$ does not fall strongly, contrary to the scenario when the fiscal expansion is implemented in a recession with the DNWR not existing. Consequently, the multiplier in a recession with both rigidities present and active is still larger than the multiplier from steady-state (as the real interest rate does not increase), but it is smaller than the multiplier in the recession with only the ZLB active and binding (as the real interest rate only weakly falls).

In the full model, a number of additional channels will play a role in determining the spending multiplier, but ultimately these follow similar patterns as found in this simplified model. One important deviation from the closed economy character of the simple model will be the consideration of imports and exports in the full model, whose existence tend to lower the size of the fiscal multipliers. This will be discussed in more detail in robustness section 6.

3.2. The paradox of toil

In this section we will demonstrate the existence of the paradox of toil for tax cuts at the ZLB, as established by Eggertsson (2010). However, we also show, that the paradox is relaxed when a given recession not only activates the ZLB but also the DNWR. The theoretical insights on the tax multiplier derived here, will be instrumental in understanding the full model simulation result in 5.5.

As household level tax cuts in our model mostly operate through demand-side effects (through higher disposable incomes), we consider for the sake of analyzing the paradox of toil the social security contributions by firms. Cuts to these can be considered supply-side interventions similar in spirit to the cut in labor taxes studied by Eggertsson (2010).

First, we consider the steady-state transmission of this reform, which implies a drop in marginal costs due to the cut in the payroll tax. This translates into lower inflation. While nominal wages fall (following the general price level), real wages increase due to surplus sharing in Nash bargaining across firms and unions.[46] This prompts monetary policy to cut the nominal interest rate, and due to the Taylor principle, the real interest rate falls. Both the drop in the real interest rate as well as the increase in real wages induce a crowding in of consumption, leading to a positive tax multiplier.

If the same reform is undertaken during a recession in which the ZLB is active and binding, the interest rate cannot fall despite the fall in inflation. As a result, the real interest rate increases and tends to crowd out consumption, decreasing the tax multiplier and possibly even pushing it into negative territory. This is what Eggertsson (2010) coined the paradox of toil: A tax cut at the ZLB decreases output rather than stimulating it.

However, the paradox is considerably relaxed when taking into account that the recession also implies a binding DNWR. In this case the tax cut will not affect nominal wages. Consequently, the drop in marginal costs is not as pronounced and the corresponding drop in inflation milder than in the scenario without the DNWR. This causes a less severe increase in real interest rates and less crowding out of private consumption. As we will see in the numerical simulation of the payroll tax cut, see section 5.5, this relaxation of the paradox of toil is strong enough to reverse the sign of the tax multiplier, such that supply-side tax cuts are expansionary at the ZLB when at the same time the DNWR binds.

4. Calibration

NORA is calibrated to the Norwegian mainland economy and at quarterly frequency. In a first step a subset of the parameters that determine the steady state of NORA are chosen such that the model's deterministic steady state replicates a number of long-run moments in

[45] For the sake of this theoretical analysis we ignore financing effects, that would by themselves reduce consumption, e.g. through a cut in transfers or a rise in taxes. However, these financing effects are present both in steady state as well as in recessions such that they do not affect the degree of state-dependency of the fiscal multiplier. In fact, in the simulation of the full model, see section 6, we will show that state-dependency of the fiscal multiplier is upheld for a number of different financing instruments.

[46] Wage costs fall despite the increase in wages, as the additional surplus of lower payroll taxes is shared in Nash bargaining. Hence, unions benefit from higher wages, while the increase in wages is held low enough to not increase after-payroll-tax wages relative to the pre-reform level.

the data, while the remaining steady-state parameters are set either according to microeconomic evidence or by following the related literature. Second, we chose values for the parameters, which only affect the dynamic behavior of the model, such, that to obtain a good match with impulse responses of Norges Banks estimated DSGE model of the Norwegian economy, called NEMO (Kravik and Mimir, 2019). While the parameters values here describe our baseline calibration, note, that we later perform extensive robustness checks on our results with respect to several important parameter values.

4.1. Steady-state parameters

Table 1 contains the model and long-run empirical values for a number of important moments, indicating also whether the empirical values are used as a target. We solve the steady state analytically conditional on the long-run targets, and the parameters chosen in line with microeconomic evidence and the literature, see Appendix A.10 for the technical details. An overview of the values of the steady-state parameters in NORA are reported in Table 2.

The steady-state gross inflation rate in Norway π_{ss}^{ATE} is set to Norges Banks inflation target of 2% annually as is inflation in Norway's trading partners π_{ss}^{TP} following NEMO (Kravik and Mimir, 2019). Setting the discount factor β to 0.9973 yields a steady-state nominal interest rate of 3.94 percent per annum, equalling NEMOs long-run value. In line with the assumptions in NOU (2016) we assume that the steady-state equity premium is 3 percent per year, necessitating a value for financial fees of $F^S = 0.0074$.

We set the service sector bias of the four final goods (α_Z with $Z \in \{C, I, G^C, X\}$) to match the corresponding sector-contents of the final goods as reflected in Norwegian input-output tables.[47] Analogously, we use input-output tables to determine the import content of the composite manufacturing and service good 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.[48]

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 government investment must equal depreciated public capital in the steady state, we can not match both empirical moments and, thus, we overestimate public capital depreciation as a share of GDP (at the cost of matching inventory changes). The tax depreciation rate is set to $\delta_\tau = 0.033$ corresponding to the average tax depreciation rate in the data, see Appendix E.2 for details. The government wage bill as a share of GDP is calibrated to its empirical counterpart by setting the wage mark-up $MARKUP^{GW}$ to 1.41. The size of Norway's trading partners Y_{ss}^{TP} is set to be consistent with the calibrated export-to-GDP ratio. To match the empirical private sector capital to output ratio, we set α_S and α_M to 0.32, imposing identical capital intensities in the two domestic sectors. We set the deprecation rate of private capital δ_{KP} to 0.0217 (approximately 9.0 percent per annum) to match the private investment to capital ratio. Analogously, we set the depreciation rate for housing $\delta_H = 0.0121$ (approximately 4.9 percent per annum) using the housing investment to capital ratio. The return on housing is set to $R^H = 0.0169$ in order to match the housing consumption to GDP ratio.

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 effective tax rates in NORA, see more details in Appendix E. We set the tax deduction parameters according to the values in Table 2 such that the tax base to GDP ratio is in line with the data. In order to replicate the size of the labor income share in domestic production, we set fixed costs in the manufacturing (FC^M) and service sector (FC^S). Despite not being able to calibrate the amount of oil fund withdrawals OFW directly as it is used as a residual to ensure the balance of payments, the fit with the empirical value is very good. Lump-sum taxes, which do not have any empirical counterpart, are used as a residual in the government budget and therefore not calibrated.

We normalize (without loss of generality) hours worked per worker per period NE to one in steady state. This has the convenient consequence that total hours worked N equals the employment rate E in steady-state and can be interpreted as such. The private (N^P) and public (N^G) sector employment to population ratios are set to their empirical counterparts. Steady-state participation rates for the seven subpopulations are taken from KVARTS 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 the fixed costs in the manufacturing and service sector to the appropriate values, see Appendix A.10 for details. The constant in the union utility function c_N is set to 103.3 to ensure that the wage setting equation holds in steady state.

The remaining steady-state parameters are set according to microeconomic evidence and the related literature. 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 literature. Furthermore, we set the share of liquidity-constrained households ω to 0.3, which is within the range of estimates found by Campbell and Mankiw (1991), as well as in line with estimates of the share of liquidity-constrained households within medium-scale DSGE models in Cogan et al. (2010) and Coenen et al. (2012).

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 multisectoral SNOW model (Rosnes et al., 2019). The corresponding elasticity for the foreign economy η_{TP} is set at 1.5, in line with the most of the literature including Konjunkturinstitutet's SELMA model (Konjunkturinstitutet, 2019) and the estimated RAMSES model at the Swedish Riksbank (Adolfson et al., 2013). The elasticity of substitution across sectors η_Z is set close to 1 for each of the four final goods $Z \in \{C, I, X, G^C\}$. This is in line with the value used by Bergholt et al. (2019) for Norway. The elasticity of substitution between differentiated intermediate home goods can be related to the degree of competition in the domestic economy given that $\epsilon/(\epsilon - 1)$ can be interpreted as a price markup. In line with NEMO we set the elasticity of substitution to 6 for domestically-produced manufacturing (ϵ_M) and service sector (ϵ_S) goods, imported goods (ϵ_t^{IM}), and exported goods (ϵ_t^X), which implies a markup of 20 percent. Following Voigts (2016) we set the elasticity of substitution across final consumption good firms to $\epsilon_C = 30$.

The parameters governing the wage bargaining problem are chosen as follows. We follow Gertler and Trigari (2009) and set the bargaining parameter γ to 0.5. We chose the weight of unemployment in the reference utility v_U to be 0.8. This value is calibrated to match the peak response of 0.3–0.4 pp fall in unemployment in response to a 1% permanent increase in public spending as estimated in Holden and Sparrman (2018).

The steady-state value of the scale-up factor on dividend taxation, α_{ss}^{OIH} is set to 1.44, in accordance with the statuary scale-up factor from the Norwegian tax code. The fixed rate of return of the oil fund is set to the steady-state risk-less return on foreign bonds R_{ss}^{TP}. The tax deduc-

[47] These data are based on a version of the input-output tables that correspond to the aggregation level in NORA.

[48] As noted in section 2.8.1 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.

Table 1
Steady-state calibration.

Description	Model	Data	Target
Monetary variables (annualized rate)			
Inflation rate Norway	1.02	1.02	Yes
Nominal interest rate Norway	1.039	1.039	Yes
Inflation rate trad. part.	1.02	1.02	Yes
Nominal interest rate trad. part.	1.039	1.039	Yes
GDP components (ratio to mainland GDP)			
Consumption	0.431	0.431	Yes
Housing consumption	0.086	0.086	Yes
Government purchases of goods and services	0.067	0.067	Yes
Government wage bill	0.169	0.169	Yes
Public capital depreciation	0.056	0.038	No
Government investment	0.056	0.056	Yes
Housing investment	0.062	0.062	Yes
Private investment	0.090	0.090	Yes
Oil sector investment	0.073	0.073	Yes
Total imports	0.348	0.348	Yes
Imports by importing firms	0.315	0.315	Yes
Residual imports	0.033		No
Exports	0.224	0.224	Yes
Changes in inventory	0.001	0.052	No
Stocks (ratio to mainland yearly GDP)			
Private capital stock	1.036	1.036	Yes
Housing capital stock	1.266	1.266	Yes
Public capital stock	0.694	0.694	Yes
Net foreign debt	0.504	0.504	Yes
Government Debt	0.397	0.397	Yes
Government budget (ratio to mainland GDP unless otherwise indicated)			
Unemployment benefits	0.006	0.006	Yes
Transfers	0.192	0.192	Yes
Transfers to liquidity-constrained household	0.101		No
Transfers to Ricardian household	0.091		No
Oil fund withdrawals	0.060	0.058	No
Lump-sum taxation	0.054		No
Labor surtax tax base	0.654	0.654	Yes
Ordinary income (household) tax base	0.518	0.518	Yes
Social security rate (firms) tax base	0.413	0.479	No
Corporate profit tax base	0.124	0.124	Yes
Consumption value-added tax rate	0.191	0.191	Yes
Consumption volume fees tax rate	0.063	0.063	Yes
Ordinary income tax rate	0.205	0.205	Yes
Labor surtax rate	0.028	0.028	Yes
Social security rate (households)	0.077	0.077	Yes
Social security rate (firms)	0.150	0.150	Yes
Corporate profit tax rate	0.242	0.242	Yes
Labor market (ratio to population unless otherwise indicated)			
Total employment rate	0.682	0.682	Yes
Public sector employment rate	0.191	0.191	Yes
Private sector employment rate	0.490	0.490	Yes
Unemployment rate (percent of labor force)	0.044	0.044	Yes
Labor force participation rate	0.713	0.713	Yes
Labor income share	0.471	0.471	Yes

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

tion parameters $TD^{OIH}, TD^{OIF,M}, TD^{OIF,S}, TD^{LS}$ are chosen, such that the steady-state size of the corresponding tax bases (as % of GDP) match their empirical counterparts.

4.2. Dynamic parameters

The dynamic parameters, of which an overview is provided in Table 3, are chosen either in line with corresponding parameter values in Norges Banks estimated DSGE model NEMO or, where this is not possible due to differences in the models, to achieve model behavior in line with NEMO or other empirical evidence.[49] Table 4 provides a quantitative comparison with relevant studies.

We begin with the labor market. We chose ρ_E to obtain a sluggishness of unemployment to a permanent government spending shock in line with Holden and Sparrman (2018). The parameter governing the

[49] Details on the methodology of matching NEMO's impulse responses can be found in an earlier technical documentation of NORA (Aursland et al., 2019).

Table 2
Steady-state parameters.

Parameter	Description	Value
Σ	Intertemporal elasticity of substitution	1.01
$\eta_{M,C}$, $\eta_{S,C}$	Elasticity of substitution across imports and domestic goods for consumption	0.5
$\eta_{M,I}$, $\eta_{S,I}$	Elasticity of substitution across imports and domestic goods for investment	0.5
$\eta_{M,GC}$, $\eta_{S,GC}$	Elasticity of substitution across imports and domestic goods for government purchases	0.5
η_X^M, $\eta_{S,X}$	Elasticity of substitution across imports and domestic goods for exports	0.5
η_C	Elasticity of substitution across sectors for consumption	1.01
η_I	Elasticity of substitution across sectors for investment	1.01
η_{GC}	Elasticity of substitution across sectors for government purchases	1.01
η_X	Elasticity of substitution across sectors for exports	1.01
η_{TP}	Foreign elasticity of substitution across imports and domestic goods	1.5
ϵ_M	Elasticity of substitution across differentiated intermediate manufacturing sector goods	6
ϵ_S	Elasticity of substitution across differentiated intermediate service sector goods	6
ϵ^{IM}	Elasticity of substitution across differentiated imported goods	6
ϵ^X	Elasticity of substitution across differentiated export goods	6
ϵ_C	Elasticity of substitution across differentiated consumption goods	21
Ω	Share of liquidity-constrained households	0.3
B	Discount factor	0.9973
δ_{KP}	Private capital depreciation (quarterly)	0.0217
δ_{KG}	Public capital depreciation (quarterly)	0.0201
δ_H	Housing capital depreciation (quarterly)	0.0121
δ_τ	Tax depreciation rate (quarterly)	0.0330
$\alpha_{M,C}$, $\alpha_{S,C}$	Import content of composite consumption good	0.54, 0.25
$\alpha_{M,I}$, $\alpha_{S,I}$	Import content of composite investment good	0.68, 0.28
$\alpha_{M,GC}$, $\alpha_{S,GC}$	Import content of composite government purchases good	0.87, 0.15
$\alpha_{M,X}$, $\alpha_{S,X}$	Import content of composite export good	0.33, 0.20
α_C	Service sector bias of final consumption good	0.65
α_I	Service sector bias of final investment good	0.84
α_{GC}	Service sector bias of final government purchases good	0.83
α_X	Service sector bias of final export good	0.55
α_M, α_S	Capital elasticity in production function	0.32
F^S	Financial fees on stocks (quarterly)	0.0074
c_N	Constant in union's utility function	103.3
R^H	Return on housing capital (quarterly)	0.0169
Γ	Bargaining power parameter	0.5
ν_U	Weight of unemployment in reference utility	0.8

rate of adjustment of wages ρ_W is set to 0.95 generating similar degrees of wage stickiness as in NEMO. The elasticity of the risk premium to net foreign assets (ξ_{NFA}) is set to 0.001 close to the value in NEMO. Finally, we determine the role of oil price movements on the risk premium via the introduced wealth fund proxy ($\rho_{OF,RP}$) to be 0.81 and the elasticity of the risk premium to changes in the wealth fund (ξ_{OF}) to be 0.017. These parameters give us movements in the risk premium for comparable shocks in line with NEMO. The parameter governing the risk premium for firm borrowing (ξ_B) is set to 0.025 in line with Bernanke et al. (1998) and Christensen and Dib (2008). In line with the NEMO estimate, we impose a high degree of consumption habits.

Adjustment cost parameters for investments as well as in the domestic, import and export sectors are chosen to obtain equally sluggish responses as in NEMO. The adjustment cost parameter in the final good consumption sector, $\chi_C = 21$, is calibrated to match the results from Benedek et al. (2015), who measure the total pass-through of a standard VAT reform, announced 1 year ahead. The parameter determining the degree of backward indexation of prices (ω_{Ind}) is set 0.63 to achieve best fit with NEMO.

The parameters of the monetary policy rule are directly taken from NEMO. In the presence of permanent shocks, see section 2.6.1, there is a role for the parameters governing the speed at which monetary policy moves to new targets for output and nominal interest rate. We set both $\rho_{\widetilde{Y}}$ and ρ^R to 10, implying a rather slow transition to new targets. This way we ensure that the movements in the targets only play a role in the long-run. The persistence parameters for the shock process are also directly taken from NEMO. All parameters governing the foreign sector are directly taken from NEMO due to identical functional forms, with the exception of the last two parameters. Here we converge from the structure in NEMO but find parameter values that yield similar responses of oil investments for a number of shocks. We set the elasticity of the demand for investment goods by the oil production sector with respect to the oil price ($\psi_{InvOil,POil}$) to 0.092 and the persistence parameter of oil sector investments (ρ_{InvOil}) to be 0.7428.

Finally, NORA contains a number of autoregressive parameters ρ_X that capture the persistence of the tax rates (equation (54)) and various spending components (equation (55)). These are generally set to zero, if not otherwise stated in the simulation section.

4.3. Model validation

In this section we compare the dynamic properties of the model with evidence from established and estimated models of the Norwegian economy as well as empirical results on Norway. We use Statistic's Norway large-scale macroeconometric model KVARTS as well as the empirical work by Holden and Sparrman (2018) to validate our response to an increase in government consumption. We also use Norway's central bank estimated DSGE model NEMO and the structural VAR study by Bjørnland and Halvorsen (2014) to compare our results for selected non-fiscal shocks.[50] As evident from Table 4, our results are well in line with these studies.

5. The state-dependency of the fiscal multiplier

In this section we investigate the degree of state-dependency of fiscal multipliers. To do so we first discuss the transmission channels of an increase in public purchases of goods and services from the steady state. Second, we investigate the effect of the same fiscal intervention

[50] We provide additional comparisons to NEMO in our technical documentation in Aursland et al. (2019).

Table 3
Overview on dynamic parameters.

Parameter	Description	Value
Labor market		
ρ_E	Persistence in employment	0.72
ρ_W	Persistence in wages	0.95
Risk premia		
ξ_{NFA}	Risk premium parameter for net foreign assets	0.001
ξ_{OF}	Risk premium parameter for sovereign wealth fund proxy	0.017
$\rho_{OF,RP}$	Persistence in wealth fund proxy	0.81
ξ_B	Risk premium parameter on firm borrowing	0.025
Habits		
H	Habit persistence in consumption utility	0.95
Adjustment costs		
χ_M	Adjustment cost parameter for manufacturing sector	1000
χ_S	Adjustment cost parameter for service sector	1000
χ_{IM}	Adjustment cost parameter for imports	1000
χ_X	Adjustment cost parameter for exports	864.7
χ_C	Adjustment cost parameter for consumption goods	21
ω_{Ind}	Degree of indexation in price adjustments	0.62
χ_{Inv}	Adjustment cost parameter for investments	13.0
χ_{BN}	Adjustment cost parameter for new debt	0.025
Monetary policy		
ρ_R	Persistence in interest rate	0.67
ψ_π	Interest rate response to annual inflation	0
$\psi_{\pi,F}$	Interest rate response to one-quarter-ahead annual inflation	0.29
ψ_W	Interest rate response to nominal wage inflation	0.87
ψ_Y	Interest rate response to output	0.24
ψ_{RER}	Interest rate response to real exchange rate	0.02
ρ_X	Persistence in target	10
Shock processes		
θ_U	Persistence in consumption preference shock	0.7248
θ_{YNTP}	Persistence in global demand shock	0
Foreign sector		
$\omega_{Y,TP}$	Weight of trading partner output in global output	0.1
ρ_{YTP}	Persistence in trading partners' output	0.615
ρ_{YNTP}	Persistence in non-trading partners' output	0.926
$\rho_{\pi TP}$	Persistence in foreign inflation	0.886
ρ_{RTP}	Persistence in foreign interest rate	0.841
$\psi_{YF,TP,YF,TP}$	Persistence in forward-looking foreign output	1
$\psi_{YF,TP,RTP}$	Effect of real interest rate on foreign IS curve	0.757
$\psi_{YTP,pOil}$	Effect of oil price on trading partners output	0.0048
$\psi_{YNTP,pOil}$	Effect of oil price on non-trading partners output	0.0012
$\psi_{YTP,YNTP}$	Effect of non-trading partner on trading partner output	1.0994
$\psi_{YNTP,YTP}$	Effect of trading partner on non-trading partner output	0.0114
$\psi_{\pi F,TP,\pi F,TP}$	Effect of inflation in foreign forward-looking Philips curve	0.1497
$\psi_{\pi F,TP,YTP}$	Effect of output in foreign forward-looking Philips curve	0.0462
$\psi_{\pi TP,pOil}$	Effect of oil price on foreign price level	0.0006
$\psi_{\pi TP}$	Responsiveness to inflation in foreign Taylor rule	1.4606
ψ_{YTP}	Responsiveness to output in foreign Taylor rule	0.04
ψ_{pOil}	Persistence in oil price	0.2026
$\psi_{Poil,YGlob}$	Effect of global output on oil price	4.0027
$\psi_{InvOil,POil}$	Effect of oil price on oil sector investment	0.0929
ρ_{InvOil}	Persistence in oil sector investment	0.7428

during an economic recession caused by a negative consumption preference shock, which is strong enough such that both the ZLB and the DNWR become binding. Third, we compare the fiscal multiplier for the intervention undertaken from the steady-state economy and the economy in a recession. Fourth, we investigate the relative contribution of the ZLB and DNWR in generating the observed state-dependency of the fiscal multiplier. Fifth, we consider an economic stimulus policy in the form of tax cuts rather than spending increases and determine the magnitude of state-dependency of various tax multipliers. In doing so we shed new light on the paradox of toil.

To allow for the nonlinear effects from the imposed rigidities, we follow Michaillat (2014) and solve the model under perfect foresight. The nonlinear solution method takes into account the lower limit on nominal wage growth as well as the zero lower bound on the nominal interest rate and allows all agents to internalize these constraints.

5.1. Increase in government purchases from steady state

We begin by analyzing the effect of an increase in public purchases of goods and services (G^C), which is the government expenditure component that is most often considered in the literature. To gain a better understanding of our main results, we therefore first analyze the transmission channels of an increase in government spending from steady state. Fig. 3 illustrates the impulse responses of the main economic variables to an increase in public purchases. The shock is chosen such that the increase in spending occurs gradually and peaks at 1% of GDP after

Table 4
Comparison of dynamic responses in NORA and other models.

Government consumption shock Financed	Variable	Study	Horizon 1Y	2Y	3Y
75% debt, 25% labor tax	Unemployment rate	NORA	−0.4	−0.2	−0.1
75% debt, 25% tax	Unemployment rate	Holden and Sparrman (2018)	−0.3	−0.4	−0.4
75% debt, 25% labor tax	Impact multiplier	NORA	0.85		
75% debt, 25% tax	Impact multiplier	Holden and Sparrman (2018)	0.8		
100% labor tax	Unemployment rate	NORA	−0.3	−0.15	−0.1
100% labor tax	Unemployment rate	KVARTS	−0.25	−0.15	−0.1
100% labor tax	Impact multiplier	NORA	0.6		
100% labor tax	Impact multiplier	KVARTS	0.6		

Monetary policy shock Variable	Study	Horizon Impact	4Q	8Q	12Q
Nominal interest rate					
	NORA	1	1.1	0.3	0.0
	NEMO	1	1.1	0.3	−0.4
	Bjørnland and Halvorsen (2014)	[0.4, 1.4]	[0.5, 1.8]	[−0.5, 1.3]	[−1.5, 0.5]
Output					
	NORA	−0.1	−0.3	−0.3	−0.2
	NEMO 2019	−0.1	−0.4	−0.3	−0.2
	Bjørnland and Halvorsen (2014)	0	[−1.4, −0.6]	[−1.8, −0.8]	[−1.8, 0.2]
Inflation					
	NORA	−0.1	−0.2	−0.2	−0.1
	NEMO	−0.1	−0.2	−0.3	−0.2
	Bjørnland and Halvorsen (2014)	0	[−0.1, 0.5]	[−0.8, 0.1]	[−0.6, 0.1]
Real exchange rate					
	NORA	−2.0	−1.0	−0.1	0.1
	NEMO	−2.0	−1.0	−0.1	0.1
	Bjørnland and Halvorsen (2014)	[−5.2, −0.6]	[−5, −0.6]	[−2.5, 0.2]	[−2.0, 1.0]

Exchange rate shock				
Nominal interest rate				
NORA	0.03	0.07	0.05	0.02
NEMO	0.03	0.07	0.05	0.03
Bjørnland and Halvorsen (2014)	[0.10, 0.30]	[0.00, 0.35]	[−0.10, 0.40]	[−0.10, 0.47]
Output				
NORA	0.0	0.0	0.0	0.0
NEMO	0.0	0.0	0.0	0.0
Bjørnland and Halvorsen (2014)	[0, 0]	[−0.2, 0.1]	[−0.2, 0.2]	[−0.2, 0.2]
Inflation				
NORA	0.0	0.02	0.03	0.01
NEMO	0.0	0.03	0.01	0.01
Bjørnland and Halvorsen (2014)	[0, 0]	[−0.08, 0.10]	[−0.04, 0.11]	[−0.05, 0.10]
Real exchange rate				
NORA	1.0	0.3	0.1	0.0
NEMO	1.0	0.3	0.1	0.0
Bjørnland and Halvorsen (2014)	[0.4, 1.2]	[0.1, 1.0]	[−0.6, 0.4]	[−0.7, 0.3]

Note: In Holden and Sparrman (2018) the spending expansion is to three-quarters debt-financed, the remaining share by taxes. In the KVARTS simulation available to us, the spending increase is fully financed by labor taxes. We individually replicate both scenarios in NORA.

five quarters.[51] This reflects that the implementation of discretionary fiscal spending is likely to take time in an event of a recession. Our results are, however, robust to other assumptions about the shock process as we show in section 6.1. The expansion in purchases is financed by a cut in transfers to Ricardians (equivalent to lump-sum taxation) such that the government runs a balanced budget. Hence, in the sense of Leeper (1991), we consider an active monetary policy (as monetary policy responds to inflation and output)/passive fiscal policy regime (as the government runs a balanced budget) in our benchmark analysis.

The increase in government purchases raises demand on domestic firms, who expand production, leading to an increase in GDP. The increase in the real interest rate (to be discussed below) and the cut in transfers to Ricardian households induce a modest reduction in aggregate consumption, which is highly persistent due to consump-

[51] Specifically, we impose an exogenous shock to government purchases from period one to period 5 with the corresponding auto-correlation parameter set to 0.8 such that the level of purchases slowly reverts to its long-run value.

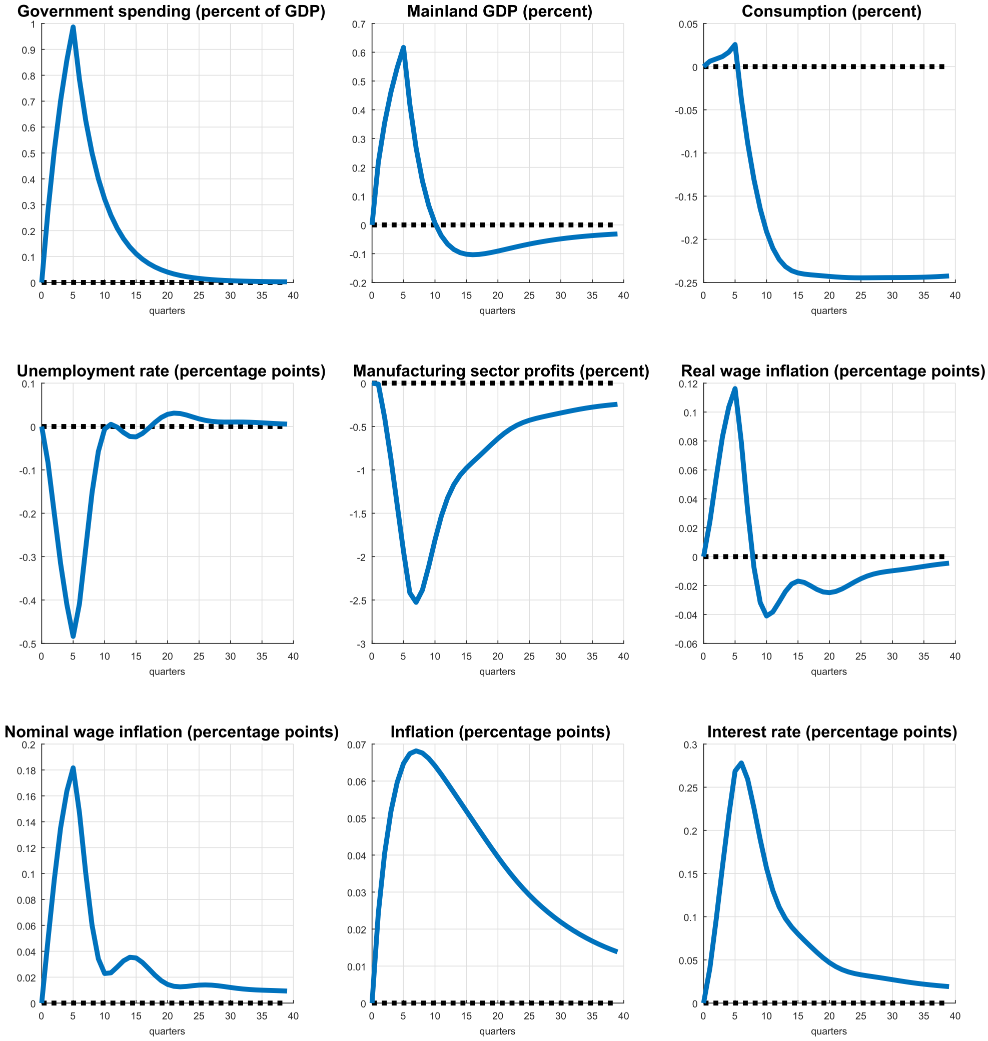


Fig. 3. Fiscal policy shock from steady state.

tion habits.[52] The initial increase in consumption is due to liquidity-constrained households, who face no cut in transfers and experience higher disposable income. The latter increases for two reasons: First, the increase in production of domestic firms is only possible as firms increase hours worked, which leads to an increase in employment. Second, due to the fall in unemployment and the associated increase in the reference utility of unions, real wages increase. The fall in manufacturing sector profits, which follows from a rising real interest rate (and thus higher financing costs) and appreciated real exchange rate (with an absence of a large increase in manufacturing sector demand due to the high service sector bias of public purchases), would by itself tend to lower the bargained wage. However, this effect is, at least in the short-run, outweighed by the fall in unemployment.[53]

The increase in aggregate demand induces firms to increase prices and inflation increases. In response, the central bank increases the nominal interest rate (also in response to higher wage growth), such that the real interest rate rises. Given an increase in real wages and inflation, nominal wage inflation increases above its steady-state level.

The increase in mainland GDP is quantitatively smaller than the increase in government spending. There are two reasons for that. First, government purchases of goods and services have a significant import share (approx. 27% in steady state), such that only the remaining domestic share increases aggregate demand in Norway. Second, crowding out of domestic production occurs through an increase in marginal cost.

[52] Despite this persistence, all variables, including consumption, will ultimately return to their initial steady state as the government spending shock is of temporary nature.

[53] However, note that the fall in manufacturing sector profits is more persistent than the fall in unemployment. This is because unemployment returns to its initial level at approximately the same speed as output, due to the close link of production volume and employment. The more persistent effect of higher interest rates, however, tends to depress manufacturing sector profits for a longer time. As a consequence, in the medium-run, real wages fall to help the manufacturing sector regain its initial level of profitability quicker, which is a key goal in the Norwegian wage formation system.

5.2. Increase in government purchases in a recession

The previous section has already alluded to the channels through which fiscal policy can be affected by the state of the economy. If the nominal interest rate and wage growth do not respond to the fiscal stimulus, the crowding out channels are muted. For this reason, we consider a consumption preference shock, which is strong enough to drive the economy into a recession, and make both the zero lower bound on the nominal interest rate and the downward nominal wage rigidity temporarily binding. In particular, we consider a negative shock to consumption utility (Z^U) in period one to three.[54] Note, that in a robustness exercise in section 6.2, we show that our main results are largely robust to alternative assumptions about the nature of the shock causing the recession. Given the unresponsiveness of monetary policy due to the binding ZLB, the economy is now in a passive monetary policy/passive fiscal policy regime. This is the case for all experiments in which the ZLB becomes binding.[55]

The consumption preference shock is illustrated by the blue, solid line in Fig. 4. We observe that the lower utility derived from consumption induces Ricardian households to reduce consumption expenditures leading to a sizeable drop in mainland GDP. The decline in production results in a fall in labor demand and consequently a large increase in the unemployment rate. Despite the increase in manufacturing sector profits (which is a consequence of the low manufacturing input in consumption and an increase in exports due to a depreciated real exchange rate) the induced fall in the union's reference utility is strong enough to drive real wages down. In fact, the downward pressure on wages is sufficient to reduce nominal wage inflation down to its lower bound.[56] In other words, the economy would exhibit a negative nominal wage growth rate in the absence of DNWR. The existence of DNWR, however, implies that gross nominal wage growth exactly equals $\gamma^w = 1$.[57]

The drop in aggregate demand induces firms to cut prices, leading to a large fall in inflation and consequently a cut in the nominal interest rate.[58] The latter is strong enough to be constrained by the ZLB. This becomes clearer when studying the equation governing the shadow interest rate R_t^* given in section 2.6.1, i.e. the interest rate that would be obtained in the economy in the absence of a ZLB. The fall in price and wage inflation and output caused by the recession implies that the shadow interest rate falls strongly. However, once the shadow (gross) interest rate falls below one, the ZLB (see equation (50)) imposes that the actual policy rate deviates from the shadow interest rate.

In a further simulation illustrated by the red, dashed line in Fig. 4 we now impose the same government purchase shock as in section 5.1 onto the economy that is hit with the preference shock discussed above. The increase in purchases is discretionary and the future path of fiscal spending and financing is known to the agents in the economy at the time of implementation of the program in quarter one (see a related robustness check in section 6.1). Since the increase in government spending acts on an economy whose GDP has been reduced, government spending as percent of GDP now exceeds 1%, despite the identical shock size as in the previous section. The qualitative effects of the increase in purchases on output and employment as well as unemployment remain unaltered across the steady-state and recession scenario. However, the crowding-out channels described in section 5.1 are dampened for two reasons.

First, the shadow interest rate has been pushed below the ZLB following the preference shock. While the fiscal stimulus increases the shadow interest rate just as described in the previous section, this increase will be inconsequential for the economy as long as it does not lead to a shadow interest rate higher than the ZLB. As evident from the lower-right plot in Fig. 4, this is exactly what happens. The net interest rate in the fiscal intervention scenario does not exceed the value of zero during the recession.[59] Hence, the nominal interest rate is not higher relative to the scenario when no fiscal stimulus is provided. In fact, the real interest rate is now lower as inflation lies above the level of the scenario in which the fiscal intervention is not present. As a consequence, the increase in aggregate demand is crowded out to a lesser extent.

Second and very similarly, once wage growth is at the lower bound implied by the DNWR, nominal wages do not increase relative to the baseline. It is again useful, to consider the analogous concept of the shadow nominal wage growth, i.e. the wage growth that would be obtained in the absence of DNWR. The recession pushes the shadow (gross) nominal wage growth below one, such that the tendency of fiscal policy to induce higher wages is dampened as far the increase in shadow nominal wage growth still lies below the limit imposed by the DNWR. Again, this is the case in our experiment, as can be seen from the lower-left plot in 4. With a binding lower bound on gross nominal wage inflation, higher inflation induced by fiscal policy tends to lower the real wage. As a consequence, there is less crowding out of employment and output.

Overall these mechanisms dampen the crowding-out channels, and we expect fiscal policy will have larger effects on output in recessions where the DNWR or ZLB binds. In the next section we seek to quantify the degree of this state-dependency.

5.3. The fiscal multiplier in different states

We are interested in the full dynamic effects associated with the fiscal policy shifts and thus we resort to the use of present-value multipliers. This definition of the multiplier captures the present value of additional output generated by the policy intervention at different time horizons. Specifically, we define the present value multiplier *PVM* as in Leeper et al. (2017) by

$$PVM(k) = \frac{\sum_{j=0}^{k} (\prod_{i=0}^{j} (r_{t+i})^{-1}) \Delta Y_{t+j}}{\sum_{j=0}^{k} (\prod_{i=0}^{j} (r_{t+i})^{-1}) \Delta G_{t+j}}$$

Here ΔY captures the difference between output in the scenario where the fiscal intervention is implemented and output in the otherwise identical scenario where the fiscal intervention is not active.[60] The term ΔG captures the difference in the government spending component that is shocked.[61] Note, that at $k = 0$ the present-value multiplier captures

[54] The recession-causing shock is chosen such that the ZLB and DNWR are binding for two to three years. We achieve this by shocking the consumption utility weight Z^U, such that it falls to approx. 15% of its steady-state value up to period three and gradually reverts back to the steady-state value over the long-run.

[55] Note, that once the negative preference shock abates and the ZLB does not bind anymore, we again return to the benchmark regime of active monetary policy/passive fiscal policy. The model, thus, features only one equilibrium.

[56] Nominal wage inflation in steady-state equals 0.5 percentage points per quarter (equaling 2% annually).

[57] Note, that we perform a robustness check with respect to γ^w in Appendix C and show that also lower values of γ^w uphold our main result.

[58] The steady-state nominal net interest rate (quarterly) equals 0.97% (equalling approx. 4% annually), such that a drop by 0.97 pp implies a zero net nominal interest rate.

[59] Note, that the government spending intervention also has the effect of a slight postponement of the point in time when the ZLB becomes binding. This is due to the fact that our simulation design reflects a situation in which fiscal policy is acting quickly enough to slow down the transition to the ZLB and DNWR. In section 6 we show that the result does not change if the policy intervention comes as a surprise during the trough of the recession.

[60] Hence, for the purpose of calculating the fiscal multiplier during a recession, ΔY captures the difference in output between a simulation in which both the recession (preference) shock as well as the fiscal policy intervention are active and a simulation in which only the recession shock is present.

[61] The multiplier for taxes, which we will consider in section 5.5, is analogously defined (whereby ΔG is replaced by the absolute value of the difference in tax revenue ΔT for the tax revenue component that is shocked).

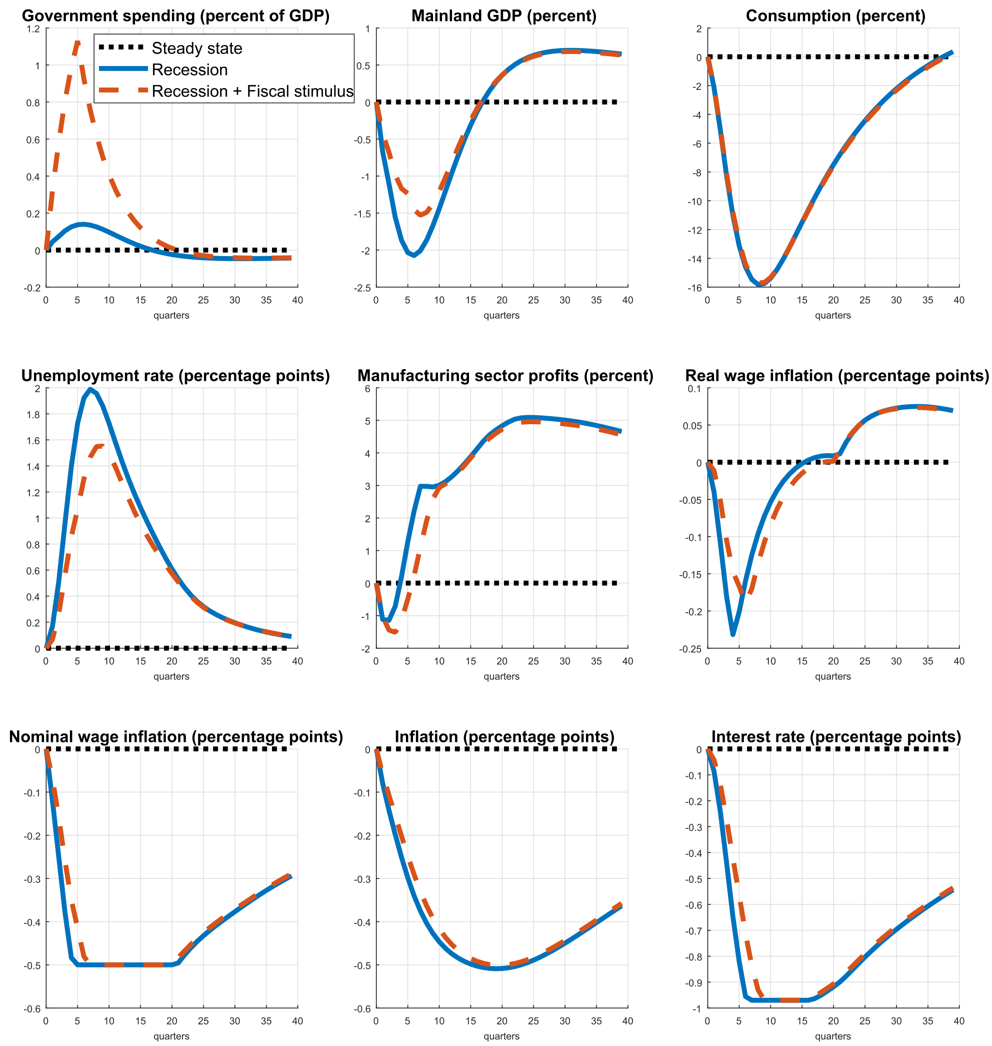


Fig. 4. Fiscal policy shock in a recession.

exactly the impact-multiplier, while at any value $k > 0$ the $PVM(k)$ captures the cumulative effect on output relative to the cumulative expenses of the fiscal intervention.

Fig. 5 reveals a large difference in the fiscal multiplier when the ZLB and DNWR bind. We observe, for example, that the present value multiplier after 10 quarters for government purchases from steady-state is 0.55 while the same intervention during the recession has a multiplier of 0.78 and is thus considerably more effective in boosting output. In the long-run, the difference in present value multipliers becomes even stronger. While crowding out is almost complete after 60 quarters in the steady-state intervention, the recession intervention is crowded out at a much slower pace and we obtain a present value multiplier of 0.65 after 60 quarters.

The impact multiplier, however, is not strongly state-dependent. This reflects that consumption habits slow down the response of consumption to increases in the interest rate. We show in Appendix C, that a lower value of consumption habits yields a much smaller impact multiplier for the steady-state intervention, while the stimulus during recession is not greatly affected by this parameter change. Hence, large differences in impact multipliers arise only in the absence of frictions such as consumption habits.[62] Moreover, in section 6, we test the robustness

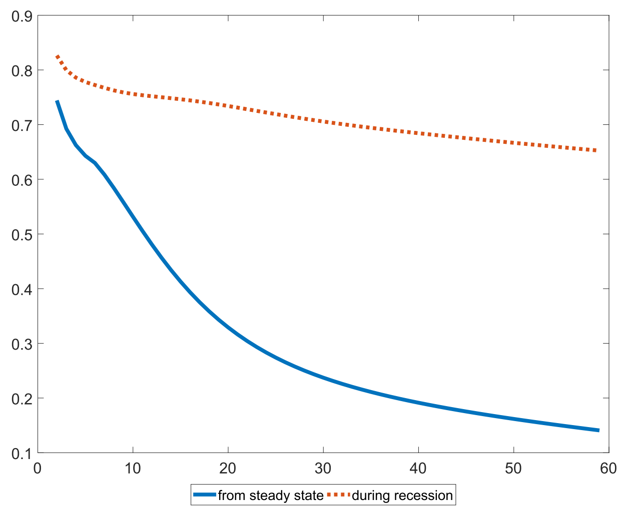


Fig. 5. Present-value fiscal multiplier for government purchases.

of the model's ability to generate state-dependent multipliers for different assumptions about the openness of the economy considered, as well as about the nature of the recession and spending stimulus. The state-dependency of the fiscal multiplier is generally upheld in a wide range of circumstances.

[62] In Appendix C we perform several other robustness checks with respect to important parameters in the model and show, that our main result holds for many different parameterizations of the model.

5.4. The role of the zero lower bound and downward nominal wage rigidity

As we have seen in the previous sections, the dampening of crowding out channels are due to the muted response of both the nominal interest rate as well as nominal wage growth to the government spending shock. In this section we perform three counter-factual exercises in which we seek to quantify the relative importance of the two rigidities. First, we perform a comparison of fiscal multipliers in recession vs. steady-state in a model where both the ZLB and DNWR are switched off, i.e. nominal interest rates can fall below zero and gross nominal wage growth below $\gamma^W = 1$. As evident from Fig. 6b, the state-dependency of the fiscal multiplier is nearly non-existent. Hence, it is only due to the inclusion of strong non-linearities arising from the ZLB and DNWR that the model is able to generate economically significant state-dependency of the government spending multiplier. Other nominal and real rigidities on wages, investments and consumption are not sufficient.[63]

We now resort to a comparison of fiscal multipliers when only one of the two rigidities is active as illustrated in the plots of Fig. 6. Our model suggests that the fiscal multiplier is considerably higher in a recession when only the ZLB is imposed while nominal wages are allowed to fall unrestrictedly. The reason for this is two-fold. First, without a lower bound on nominal wage growth the fall in nominal (and real) wages is larger for a given size of the recession shock. This larger fall in wages leads to a larger reduction in marginal costs and a corresponding larger fall in inflation. Both effects push the shadow interest rate lower than in the case of an active DNWR. As a consequence, a larger part of the fiscal stimulus occurs while at the ZLB and there is less crowding out. Second, and as reflected in a section on theoretical insights in 3.1, the absence of the DNWR leads to an increase in wages following the fiscal expansion, which increases inflation above the level of the recession. As the ZLB implies an unresponsive nominal interest rate, real interest rates fall in response to fiscal spending, which stimulate consumption and investment. However, with a DNWR only the shadow wage increases while real wages do not adjust, such that inflation and the real interest rate fall by less compared to the scenario when the DNWR is not present. Hence, we obtain a smaller fiscal multiplier when both rigidities interact.[64]

Hence, the presence of a DNWR dampens the consequences of the ZLB on the economy for a given size of the recession. This is, however, not to say, that the DNWR by itself does not generate state-dependent effects of fiscal policy. As evident from 6d and in line with our theoretical results from section 3.1 the presence of the lower bound on nominal wage growth is sufficient to obtain higher multipliers during the recession. This is because the absence of an increase in nominal wage growth following the fiscal stimulus, combined with the increase in inflation caused by higher aggregate demand leads to a fall in real wages. This in turn limits the increase in marginal costs and thus inflation and requires a smaller increase in the interest rate as compared to the steady-state fiscal stimulus scenario. Hence, both the lower real wage level (through higher employment) as well as the lower real interest rate enhance the expansionary effects of a spending increase relative to the steady-state intervention.

Overall the results from this section are in line with Sims and Wolff (2018a) who find no state-dependency of the multiplier for public purchases in a DSGE model without strong non-linearities. We also reproduce the result from the large literature reviewed in the introduction of higher fiscal multipliers at the ZLB, and the insights from Shen and Yang (2018) by showing that the existence of DNWR generates state-dependency of the spending multiplier. However, as evident from comparing Fig. 6a and c, we additionally find that the co-existence of both nominal rigidities do not reinforce each other. Instead, for a given recession scenario, the existence of the DNWR (i) leads to the ZLB being a constraint to the economy to a lesser extent and for a shorter period of time and (ii) prevents an increase in nominal wage inflation and the following increase in inflation, and corresponding fall in real interest rates. Both effects work to diminish the fiscal multiplier during the recession. This effect is quantitatively important. Considering the cumulative multiplier after five years (20 quarters), the multiplier is about three times as large in a recession relative to steady state when only the ZLB is present and binding. When both rigidities are present and binding, the five year multiplier is only twice the size in the recession.

5.5. State-dependency of tax multipliers: revisiting the paradox of toil

NORA features a range of tax rates levied on households or firms, allowing us to compare various tax multipliers in Fig. 7 to the purchase multiplier from our baseline comparison in Fig. 5. In this section we consider a permanent tax cut by 1 percentage point in the respective tax rate, as opposed to temporary spending increases.[65] The tax cuts are, as in the case of the spending stimulus, financed by a cut in transfers to Ricardians. Moreover, when calculating the tax multiplier we divide by the absolute value of the tax cut, such that we obtain positive tax multipliers for expansionary tax cuts.

Consider first Fig. 7a–c. A cut in taxes applied to households via the labor surtax, the consumption tax or the ordinary income tax increases the purchasing power of households and increase their consumption level (particularly driven by liquidity-constrained agents as they increase consumption one to one with the amount of reduced taxes). The multipliers are generally smaller than for spending-side policy interventions. We observe some degree of state-dependency of the tax multiplier, which is a consequence of how the increase in aggregate consumption affects the economy from steady state and during the recession: While the aggregate demand increase is crowded out through hikes in the interest rate and wages from steady state, these responses are muted in recessions as in the case of the fiscal spending increase. The hump-shaped response of the consumption tax multiplier arises from the smooth after-tax pricing of the consumption good sector. The state-dependency of the ordinary income tax rate (applied to income from savings and shareholder income) is more pronounced. This is as the tax cut not only stimulates consumption but also investment expenditures in the medium- to long-run, further boosting aggregate demand.

These results are similar to those by Coenen et al. (2012). In their review of several medium-scale fiscal policy models, they find that labor and consumption tax cuts generally exhibit small multipliers and a weak degree of state-dependency. In line with Coenen et al. (2012) we find no pro-cyclicality of the labor tax multiplier, which is in contrast to the paradox of toil found by Eggertsson (2010). This is largely due to the existence of liquidity-constraint agents in our model and in the models analyzed in Coenen et al. (2012), where demand-side impact of tax cuts play an important role, a channel only weakly represented in the

[63] Looking more closely at the state-dependency of the fiscal multiplier when neither ZLB nor DNWR is binding, we find a weakly pro-cyclical impact multiplier for government purchases, which is in line with Sims and Wolff (2018a). However, this small degree of state-dependency is an order of magnitude smaller than the (counter-cyclical) state-dependency of the multiplier found when comparing states with binding and non-binding ZLB and DNWR.

[64] In Appendix D we perform a number of robustness checks, focusing on identifying the importance of the Nordic elements in our model in generating this result. As already argued in 3.1, the tendency for the DNWR to reduce the fiscal multiplier at the ZLB is present in any generic NK DSGE model and should thus not depend on these Nordic elements. Our robustness analysis confirms this as the main results are upheld for alternative assumptions about the openness of the economy, the bargaining power of unions and the use of oil fund resources.

[65] This is as tax cuts in Norway are more likely to occur as part of permanent tax reforms rather than a temporary business cycle stimulus instrument.

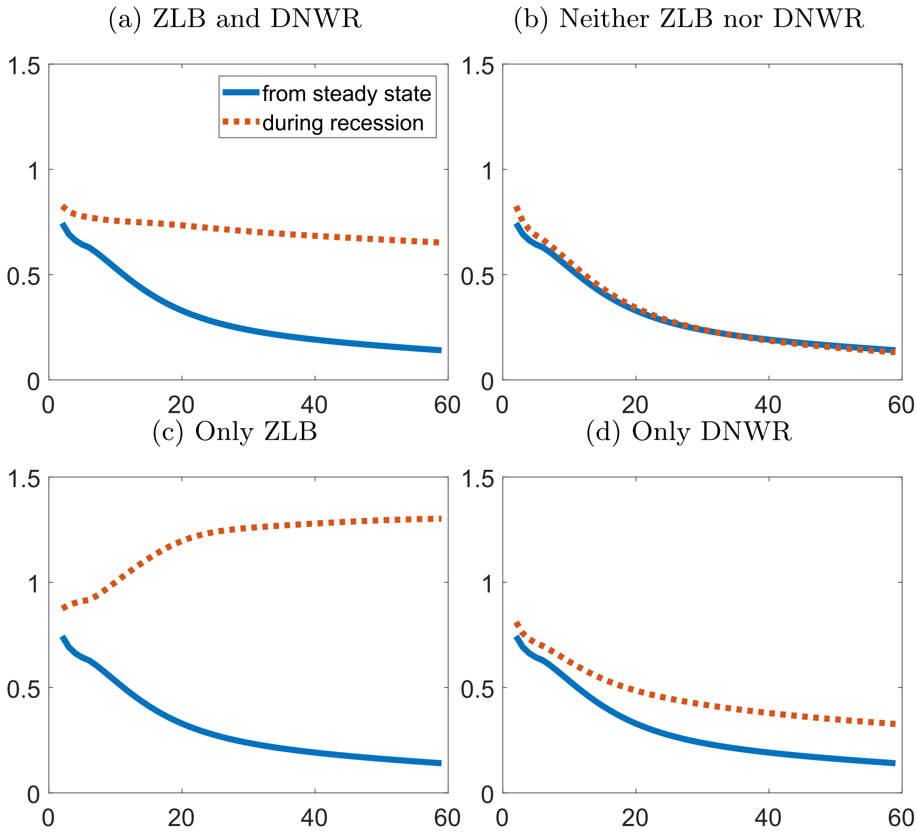


Fig. 6. Present-value fiscal multiplier for government purchases: Role of rigidities.

representative agent framework of Eggertsson (2011).[66]

There are two more reasons for why we observe no paradox of toil for the labor tax cut in NORA. First, contrary to Eggertsson (2010) a cut in the taxation of labor does not induce a shift in the labor supply and a strong fall in wages. As argued in the model description of our wage bargaining setup, unions in Norway internalize a cut in taxation as a cut to public welfare and will for this reason not be willing to accept lower pre-tax wages in response to it. Wages still fall moderately as a response to higher participation (induced by lower taxation of labor income) and consequently higher unemployment. However, these effects are quantitatively smaller and dominated by the positive effect on consumption through an increase in disposable income of liquidity-constrained households, described in the beginning of this section.

The second reason we do not observe a paradox of toil is the presence of a downward nominal wage rigidity in NORA, as already discussed in theoretical section 3.2. To understand this consider a cut in the social security contributions of firms (i.e. a cut in the payroll tax) as illustrated in Fig. 7d. The tax cut implemented from steady state increases the profitability of the exposed sector as wage costs fall. Production increases as more workers are hired, while prices fall due to lower marginal cost. This drop in inflation is such that nominal wage growth drops below its steady-state value. Nevertheless, the real wage increases as the decline in inflation dominates the lower nominal wage growth rate. The central bank cuts the nominal interest rate in response to lower inflation. This and the real wage increase generate the demand needed to satisfy higher production. Hence, this cut can be considered a supply-side intervention by the government similar in spirit to the cut in labor taxes studied by Eggertsson (2010).

When the same tax cut is implemented during a recession in which the ZLB binds, the cut in wage costs faced by firms cannot develop the same effect as the interest rate is constrained and cannot fall further. Instead, the real interest rate increases as inflation falls while the nominal interest rate remains unchanged. In Eggertsson (2010) this leads to a strong negative effect on output induced by the tax cut. In fact, we can replicate this negative effect on output if we remove the DNWR from NORA as shown in Fig. 8. However, in our full model with the DNWR in place and binding, the paradox is considerably relaxed. Now, prices fall to a lesser extent as nominal wages are constrained downwards. As a consequence, the real interest rate increases less as compared to when the DNWR is not present and the negative effect on output is reduced. In fact, the recession multiplier for the payroll tax cut multiplier in our full model is positive at most time horizons as firms increase employment.

The analysis thus points to three ways through which the paradox of toil might be resolved. First, in line with Coenen et al. (2012), the presence of liquidity-constrained agents gives rise to strong demand-side effects of tax-cuts which are particularly effective when the ZLB or DNWR are binding. Second, in economies where there are institutions limiting the effect of taxation on supply-side factors (as through the union's concern for the public welfare associated with tax revenue in Norway) the expansionary effects of taxes are upheld and may even be larger in times of a recession than in steady state. Third, when nominal wage growth is constrained downwards the fall in prices induced by the tax cut and thus the increase in the real interest rate is dampened, and

[66] Sims and Wolff (2018b) find pro-cyclical tax multipliers both in a model with liquidity-constrained households (but with responsive monetary policy) as well as when monetary policy is accommodative (but with no liquidity-constrained households). They report no results, however, for the situation reflected in our model and Coenen et al. (2012), when monetary policy is constrained and at the same time the economy is partly populated by liquidity-constrained agents. Only the combination of both assumptions gives rise to counter-cyclical tax multipliers: When liquidity-constrained agents are present, labor tax cuts will stimulate consumption. When interest rates are unresponsive in recessions, this demand-side stimulus of the tax cut will be crowded out less. Hence, consumption is stimulated more by the tax cut in recessions as compared to the steady state.

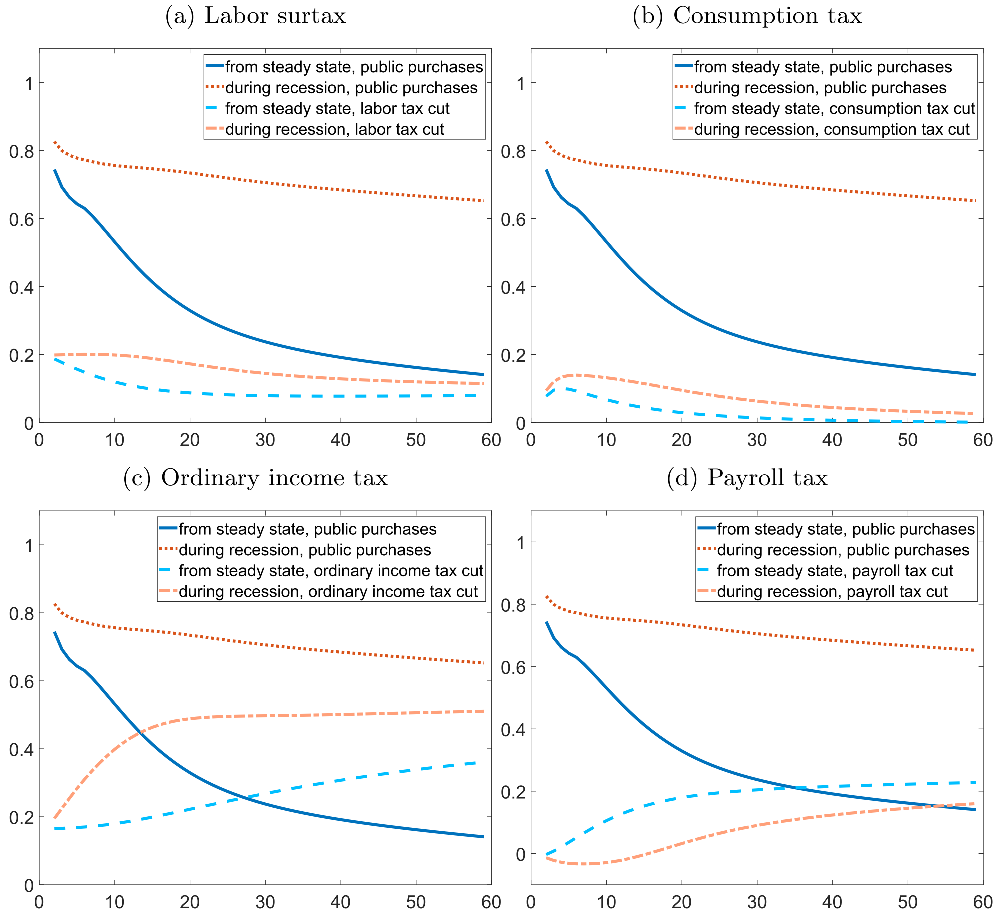


Fig. 7. Present-value tax multiplier.

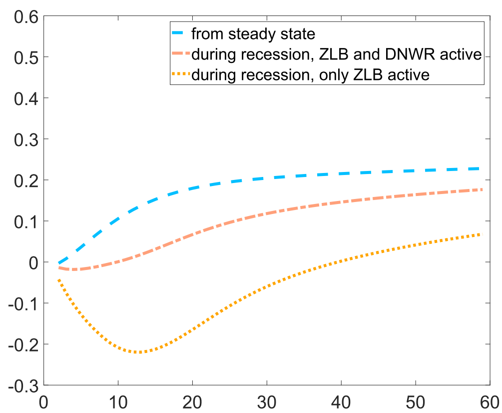


Fig. 8. Present-value tax multiplier for the payroll tax.

the paradox of toil thus considerably relaxed.

6. Robustness

In this section, we perform several robustness checks with respect to the model's ability to generate state-dependent multipliers. These checks can be divided into five groups: We analyze how the degree of state-dependency of the multiplier is affected by (i) different assumptions about the size, duration and anticipation of the purchase stimulus, (ii) different assumptions about the origin and size of the recession and (iii) the state-dependency of the public employment and transfer multiplier. Furthermore, we check (iv) the role of the fiscal instrument used to finance the fiscal expansion as well as for (v) model calibrations reflecting a less open economy.

6.1. The role of the size, duration and timing of public purchases

In Fig. 9 we study the state-dependency of the multiplier under different assumptions about the timing and anticipation of the public purchase increase, its size as well as duration.

Fig. 9a studies a situation in which the purchase expansion does not occur while the recession is evolving as in the baseline scenario but instead begins during the peak of the recession, i.e. in quarter 8. Moreover, the fiscal expansion is unanticipated during quarters 1 to 7. The fiscal expansion at the peak of the recession is equally effective during the first 10 quarters as compared to when the fiscal expansion is initiated at the beginning of the recession. However, as the recession disappears around 10 quarters after its peak, the effectiveness of fiscal policy is strongly reduced as the economy leaves the ZLB and DNWR. Hence, if the fiscal expansion occurs later, a smaller share of the stimulus occurs at a time when it has the highest effect. This has important implications for fiscal policy. While it does not seem to matter greatly, whether the fiscal intervention is anticipated or comes as a surprise, the timing of the fiscal intervention is decisive. If it comes too late, when the economy is already recovering and not constrained by the ZLB or DNWR, the stimulus will be less effective.

Fig. 9b illustrates, that the larger the spending increase (we simulate a small increase half the size of the baseline purchase increase, and a large increase double the size) the smaller will be the fiscal multiplier during a recession. The reason for this phenomenon is that a large increase in purchases will put more upward pressure on wages and the interest rate and consequently the recession the purchase increase oper-

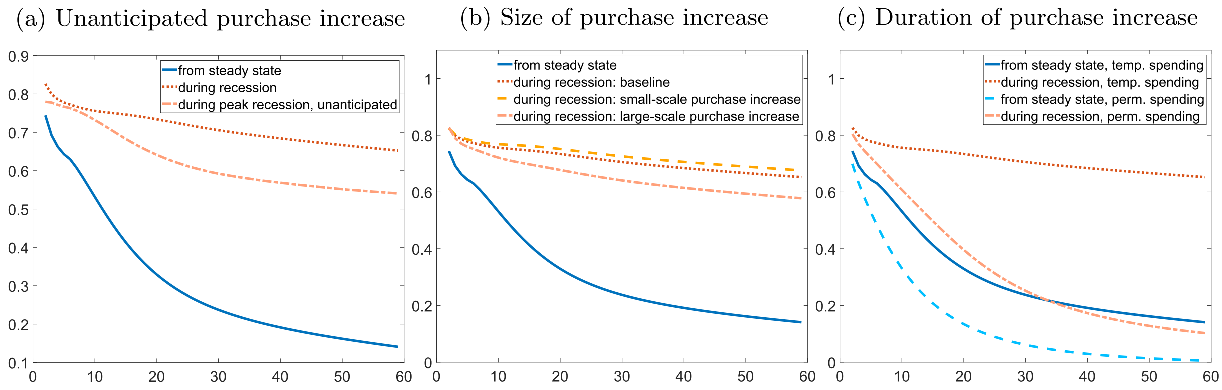


Fig. 9. Present-value fiscal multiplier for government purchases: Alternative assumptions about the size, duration and timing of public purchases.

ates within will be less constrained. A less constrained environment will lead to relatively stronger crowding-out effects.

Fig. 9c illustrates that the duration of the spending increase affects the multiplier considerably. When considering a permanent rather than a temporary expansion (as in the baseline) of public purchases, the multiplier is crowded out much quicker. The reason lies in a negative consumption response of Ricardians who internalize a much larger present discounted value of loss in transfers and hence wealth. This reduction in consumption occurs irrespective of the state such that the relative difference between multipliers from steady state and during a recession is less pronounced compared to a temporary increase in public purchases.

6.2. The role of the nature of the recession

In this section we test the robustness of our main result with respect to two characteristics of the recession considered: its origin and size. The literature on state-dependent multiplier generally uses discounting shocks to drive the economy into a recession (equivalent to our consumption preference shock). An important driver of the business cycle in small open economies is fluctuations in global economics activity and particularly their effects on export good demand from abroad. Hence, in Fig. 10a we test the state-dependency of the fiscal multiplier when the recession is caused by a shock to global output. In particular, we impose a negative shock to non-trading partner output (Z^{NTP}). The shock size is chosen such that the ZLB and DNWR are binding for approximately the same number of quarters as in the preference-induced recession. We observe that the degree to which the multiplier is state-dependent is not severely affected by the origin of the recession.

As shown earlier, the state-dependent nature of the fiscal multiplier arises only in a quantitatively significant way if at least one of the rigidities becomes binding during the recession. A complementary way to illustrate this is to vary the size of the recession. We study in Fig. 10b two additional preference-induced recession scenarios, where the underlying shock to the consumption preference weight is 50% lower or higher than in the baseline scenario. The small-scale recession, which is chosen weak enough to not drive the economy into the ZLB nor into the DNWR, does not give rise to a significantly higher fiscal multiplier relative to the steady-state experiment. On the other hand, the large-scale recession increases the effect of the purchase expansion relative to the baseline recession.

6.3. State-dependency of the multiplier of other public spending components

In Fig. 11 we investigate the state-dependency of the fiscal multiplier of two alternative spending instruments, public employment and directed transfers towards the liquidity-constraint household. In each case, we consider an increase in government spending equal in size and duration to our baseline scenario capturing an increase in public purchases.

We observe that the employment multiplier is somewhat larger than the public purchases multiplier. This is because public employment by construction has full home bias as only domestic workers are hired. During a recession the stimulus provided by public employment is crowded out to a higher extent than for the purchase program during the recession. This is due to the fact that employment increases are mainly crowded out through the wage channel (as unemployment falls and the union's bargaining position strengthens), such that the binding ZLB matters less. Hence, the state-dependency of the employment multiplier is somewhat smaller, but nevertheless still clearly observable.

The multiplier associated with directed transfers to hand-to-mouth spenders is relatively small. This, however, simply reflects the fact that about 40% of the transfers is immediately taxed as personal income and return to the government. The state-dependency of the multiplier, however, is strong as higher consumption expenditures by liquidity-constrained households during a recession, contrary to the steady state, do not increase wage demands or boost interest rates.

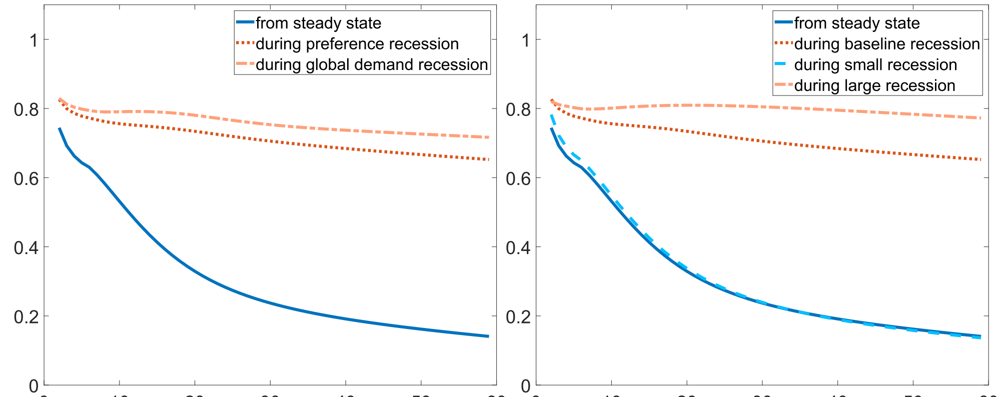
6.4. The role of the financing instrument

In our baseline result we have assumed that the fiscal expansion is financed by a reduction in transfers to Ricardians. While this is a fairly standard assumption in the literature, policy makers are particularly interested in the implications of using more realistic financing instruments. In this section we explore the state-dependency of the fiscal multiplier when a distortionary labor tax or withdrawals from the oil fund are used.[67]

Fig. 12a illustrates the multipliers in the two states considered when the spending increase is financed by transfers (our considered benchmark) and when it is financed by oil fund withdrawals.[68] We observe that the multiplier in either state is largely unaffected by the change in financing instrument. When instead labor taxes are used to balance the budget during the fiscal spending expansion a different pattern arises, see Fig. 12b. The multiplier, both at impact as well as at later points, is considerably lower relative to when transfers are used. This is due to the distortionary effects of labor taxes that not only depress the available income of consumers (directly affecting consumption of liquidity-constrained households) but also induce people to leave the labor force.

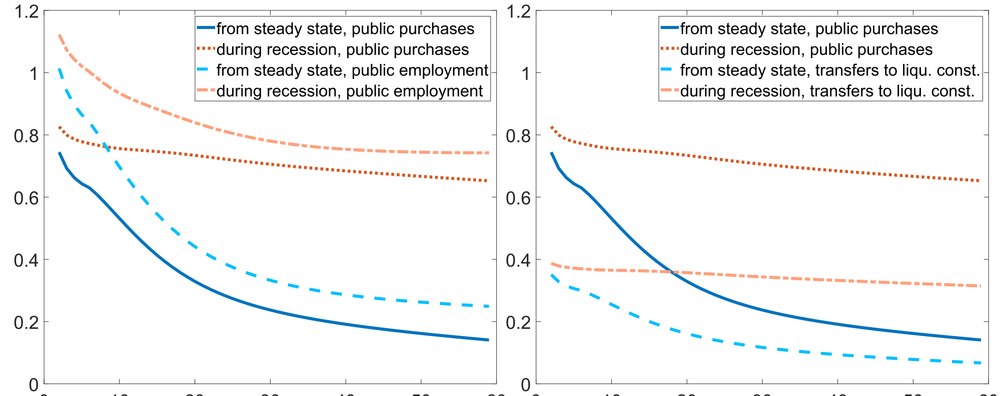
[67] Note, that conceptually withdrawals from the oil fund are very similar to the use of government debt as an increase in the take-out rate today will require a fall at a later point to ensure sustainability of the fund. This fall needs then to be compensated by higher taxes (or less spending). In that sense the fund simply represents a positive, rather than negative, net financial position of the public sector.

[68] Note, that oil fund withdrawals are used only during the first 20 quarters of the simulation to balance the budget, while labor surtaxes are used afterwards.



(a) Origin of recession (b) Size of recession

Fig. 10. Present-value fiscal multiplier for government purchases: Alternative assumptions about the nature of the recession.



(a) Public employment (b) Transfers to liquidity-constrained agents

Fig. 11. Present-value fiscal multiplier for other public spending components.

However, the multiplier is affected in both states in approximately the same way such that again the state-dependency of the public purchase multiplier is upheld. Hence we conclude that the type of financing instrument does not have an important impact on the state-dependency of the fiscal multiplier.

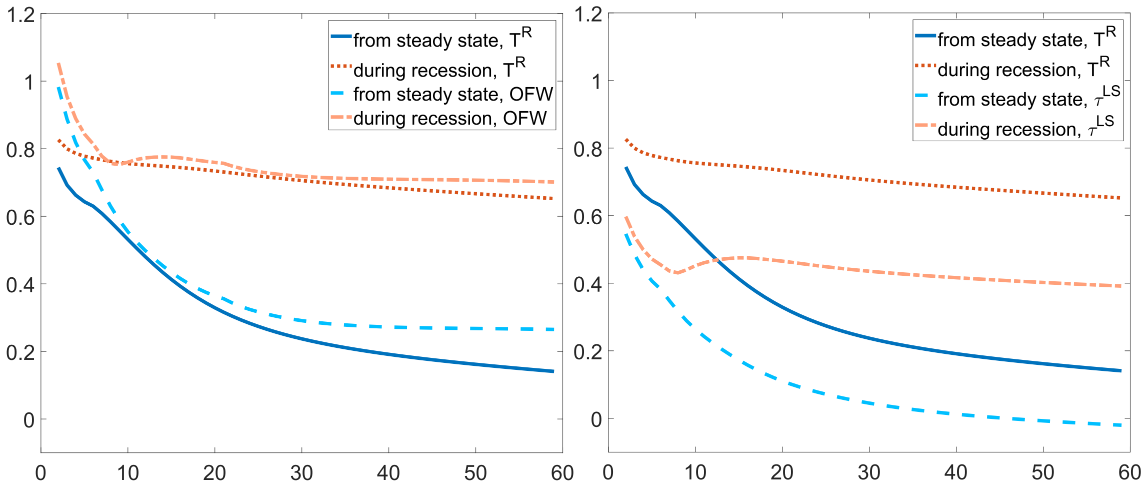
6.5. State-dependency in less open economies

The state-dependency of the fiscal multiplier has in most cases been analyzed within the context of closed economy models. A notable exception is Coenen et al. (2012) who show that the state-dependency falls with the economy's export-to-GDP ratio. In subsequent analysis, we are able to reproduce this result and additionally show, that the state-dependency also falls with lower foreign borrowing costs as well as with the import-content of government purchases.

In Fig. 13 we first depart from our baseline calibration by following Coenen et al. (2012) and scale down the import and export share of our model economy. More specifically, we consider the fiscal multiplier when imports and exports make up only 10% of their benchmark GDP share. In steady-state the multiplier is somewhat larger, reflecting that the home bias of government purchases has increased. However, the multiplier during the recession is considerably larger. This reflects, that crowding out in the new economy mainly occurs through domestic channels rather than a depression of international competitiveness. However, domestic crowding out channels are severely muted during a recession due to the ZLB and DNWR. Consequently, the state-dependency of the purchase multiplier is very large.

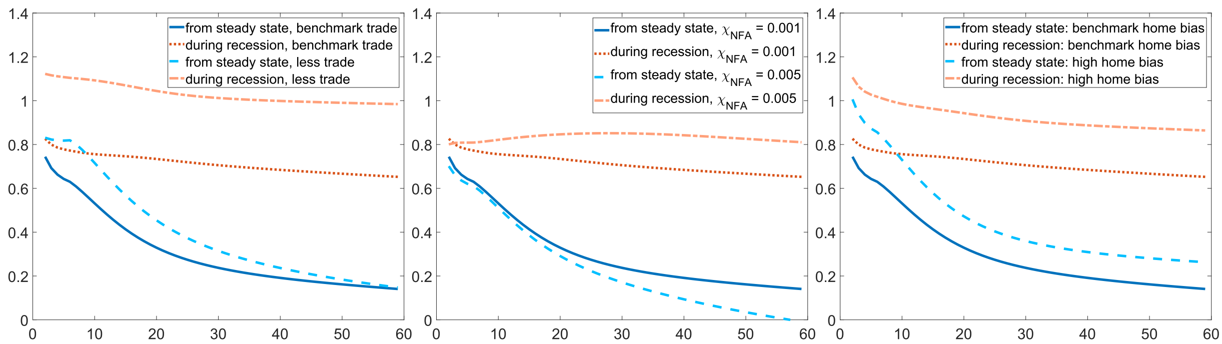
In small open economies the world interest rate plays an important role. In fact, a no-arbitrage condition imposes that real returns abroad have to equal real returns domestically with the risk premium on foreign borrowing being the only intermediating factor. The risk premium parameter on foreign borrowing, χ_{NFA}, governs, how sensitive the domestic interest rate is to changes in the net foreign asset position of the domestic economy. Hence, a higher value of that parameter implies that financing abroad is more costly, such that the economy relies to a higher degree on domestic capital markets. We test the fiscal multiplier in a setting where capital markets are relatively more closed in Fig. 13b. For the fiscal intervention from steady state, we now obtain a lower multiplier. This follows from the fact, that the fall in saving induced by the fiscal expansion is partly compensated by borrowing abroad, which now is more costly. As a consequence interest rates are higher leading to stronger crowding out. When purchases are increased during a recession, the interest rate is bound by the ZLB. Instead, more closed capital markets ensure that more of the purchase increase acts domestically rather than leaking abroad. As a consequence, the state-dependency increases considerably with a 0.8 point difference across steady state and the recession.

A final way to emulate the conditions of a more closed economy is to depart from our baseline calibration for the home bias of government purchases, which is based on an input-output analysis of the Norwegian national accounts, yielding, that approximately a quarter of government purchases are imported. In contrast, we now assume in Fig. 13c, that the import content is 10% of the level in the baseline calibration. Not surprisingly, the multiplier both from steady state as



(a) Transfers vs. oil fund withdrawals (OFW) (b) Transfers vs. labor taxes (τ^{LS})

Fig. 12. Present-value fiscal multiplier for government purchases: Comparing financing instruments.



(a) Trade with foreign sector (b) Risk premium sensitivity (c) Home bias of purchases

Fig. 13. Present-value fiscal multiplier for government purchases: Alternative assumptions about openness of the economy.

well as during a recession is higher since a larger part of the spending impulse actually ends up affecting the domestic economy and boosting output. The state-dependency also increases slightly: While the cumulative multiplier after 60 quarters is higher by about 0.5 in the benchmark calibration, the model with a higher home bias yields a difference of 0.6.

7. Conclusion

In this paper we have presented a medium-scale DSGE model for fiscal policy analysis in Norway, called NORA. The model contains several novel extensions. NORA contains two domestic sectors proxying a sheltered service sector and an exposed manufacturing sector, allowing us to include a realistic model of wage setting as the outcome of Nash bargaining between firms in the exposed sector of the economy and a labor union. NORA features a rich government sector including the most important sources of government revenue and public expenditures in Norway. Specifically, we model a sovereign wealth fund and distinguish between household-level capital income tax and corporate profit taxes. NORA thus allows for the analysis of the transmission channels of a wide array of fiscal policy instruments in a realistic model economy. We believe that the novel extensions contained in this model of the Norwegian economy can be of interest for the development of models for many other countries, particularly for open economies where the distinction of exposed and sheltered sectors is equally important, for countries with a sovereign wealth fund and economies characterized by institutionalized collective wage setting systems.

Inspired by fiscal responses of many governments to recessions and the call for a more active role of fiscal policy in stabilizing economies during recessions expressed by Blanchard (2019), Eichenbaum (2019) as well as Rachel and Summers (2019), we investigate the state-dependency of fiscal multipliers. Specifically, we focus on the different transmission channels of fiscal stimulus when the economy is in steady state as opposed to a recession in which the zero lower bound and downward nominal wage rigidity constrain the economy. We find that both the ZLB and the DNWR can individually generate state-dependency of the multipliers of various fiscal instruments. However, in combination, the presence of DNWR limits the increase in inflation and leads to a smaller fall of the real interest rate. Consequently, the fiscal multiplier during a given recession will be lower when both rigidities are present as opposed to when only the ZLB is binding. We also find, that the existence of the DNWR will dampen deflationary effects from supply-side fiscal stimulus of labor taxation and thus relaxes the paradox of toil significantly. Our results, thus, point to important interaction effects of the ZLB and DNWR during recessions, which have not received attention yet in the literature on state-dependent fiscal multipliers. We perform a number of robustness checks, showing that less open economies tend to have larger degrees of state-dependency and the degree of state-dependency is largely robust to alternative assumptions about the nature of the recession, the size and timing of the stimulus as well as the way of financing it.

Finally, while not explicitly designed to study the coronavirus outbreak, our model can nevertheless provide a starting point for the analysis of fiscal policy measures undertaken to combat the adverse economic effects caused by the pandemic. This is because our two main assumptions about recessions have already or are likely to materialize in the next months. Many central banks around the world have lowered their nominal interest rates considerably, including Norway, which recently (May 2020) set their key policy rate to 0%. Moreover, given the extensive quarantine measures undertaken and the related disruptions to economic activity, large increases in unemployment have occurred, which likely will lead to nominal wage growth falling to low levels. Given the recent developments, we believe that our framework can be adopted to study the effectiveness of fiscal policy measures that we may want to implement after the immediate pandemic crisis is dealt with.

Declaration of competing interest

None.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.euromechsol.2020.104074.

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III Unemployment shocks, cyclical prices and shopping behavior

Unemployment shocks, cyclical prices and shopping behavior

Thor Andreas Aursland, Frode Steen and Simen A. Ulsaker

Abstract

We use rich data from Norway's biggest grocery chain to show how households and grocery stores react to changing economic conditions. We exploit the regional nature of a recession following the drop in the oil price in 2014 and find that when the local unemployment rate increases, households shift toward cheaper stores, and toward bulk and private label products. Households also buy more on sale and the average store level prices decreases. We then derive a novel decomposition of the changes in the prices households pay for products a in large number of product categories. The decomposition allows us to measure the relative importance of the different sources of price cyclicality. We find that a significant part of the cyclicality is explained by grocery stores responding to economic downturns by lowering their prices. Still, changes in household behavior are the main driver of price cyclicality, primarily through increased willingness to take advantage of sales.

1 Introduction

Do households and stores change their behavior over the business cycle? If so, which aspects of shopping behavior and store strategy change, and how large are the effects on average prices and total expenditure? Adverse economic conditions may affect shopping behavior and store strategy along several dimensions. First, individuals who become unemployed have more time available. Second, unemployment is associated with a fall in life-time earnings. These two effects tend to reduce the opportunity cost of time, and thus reduce search costs and thereby increase search effort and result in lower transaction prices. In addition, declines in life-time earnings may result in wealth effects on the composition of the consumption bundle, leading to substitution toward lower priced goods within a given product category. Furthermore, stores may respond to changes in the households' wealth and opportunity cost of time by adjusting their strategies with respect to pricing, campaigns and product assortment.

In this paper, we use two rich data sets from a large Norwegian grocery chain to provide new evidence on how shopping behavior, store choices, and household-level average prices vary over the business cycle. The first data set contains complete transaction histories for a large sample of households, while the second contains complete price-quantity data at the store level for a large set of product categories. Our empirical strategy exploits how the collapse of the oil price in the middle of the 2010s led to a severe worsening of the economic conditions and increasing unemployment rates in certain regions of Norway, while leaving other regions more or less unaffected.

Grocery expenditures are a potential source of cost savings for households when economic conditions deteriorate. Most households allocate a substantial part of their budget to groceries, and, in the short term, it is easier to save on groceries than on other substantial budget posts. According to Statistics Norway's consumer expenditure survey of 2012, expenditures on food and nonalcoholic beverages made up 11.8 percent of the total consumption expenditure, with alcohol and tobacco contributing a further 2.7 percent [Statistics Norway, 2013]. If we count that consumption on housing and transportation as fixed, food and nonalcoholic expenditures alone make up close to 25 percent of the variable consumption. With groceries being the dominant category in the households' variable consumption budget, major changes in income are very likely to affect this consumption category.

We find that households indeed adjust their shopping behavior in response to changes in the local economic conditions. In line with Griffith et al. [2009] and Nevo and Wong [2019], we provide strong evidence for reallocation of household expenditures toward generic brands, bulk items, items on sale, and low-price retailers when the local unemployment rate increases. Having established this evidence, we calculate average (per-unit) household-level prices in a large set of product categories, and find that the average price a household pays in a given category is responsive to business cycle fluctuations. Exploiting changes in prices and in the household's volume shares (at the product–store level), we derive a new decomposition that separates the change in the average price into a set of distinct factors: one component capturing changes in the prices charged by the store (holding the choices of the household unchanged), two components capturing changes in the store and product shares (holding prices charged by the store unchanged), and three components related to the customer's shopping intensity. Our decomposition is new to the literature on price cycles and shopping behavior. We find that while a part of the cyclicality is explained by grocery stores adjusting their prices, changes in household behavior are the main driver of price cyclicality. What we find particularly intriguing with this approach is that it allows us to incorporate the various aspects of household and store responses in the same framework, and to estimate the relative contribution of each component to the aggregate change in the category price.

Our evidence of significant shopping behavior responses to changes in economic conditions have consequences for a wide range of topics. For example, take the measurement of consumption inequality, which often relies on consumption expenditures. Aguiar and Hurst [2007] find that prices paid correlate with household characteristics. Hence, relying on expenditures alone is likely to give an imperfect picture of consumption inequality. Similarly, our results show that the price paid for the same product by a household varies with the business cycle. Thus, taking into account the cyclicality of transaction prices is important when studying consumption inequality (as in e.g., Coibion et al. [2012] and Bayer et al. [2020]).

The Boskin report [Boskin et al., 1996] highlighted four sources of bias in the household price index: i) product substitution, ii) store substitution, iii) quality change, and iv) new products. The current study sheds light on the two first sources. Specifically, we find that both product and store substitution are sensitive to business cycle fluctuations, and that in our data, store substitution is more important than product substitution.

In many theories of monetary nonneutrality and policy, and business cycles, the real interest rate is key in the transmission of shocks. Our results indicate that there may not be *one* inflation rate across households (as documented for the United States by Kaplan and Schulhofer-Wohl [2017]), and therefore the real interest rate will likely vary across households. Thus, our results should be of interest to policy makers. For instance, Kaplan and Menzio [2015] develop a model where shopping behavior plays a crucial role in generating self-fulfilling employment fluctuations. Hence, shopping behavior might not only affect the economy's response to shocks, but also the source of fluctuations itself.

The cyclical behavior of the markup over marginal cost is another key aspect of the transmission of shocks [Nekarda and Ramey, 2013]. While we do not study the markup directly, the cyclical behavior of households is an important co-determinant of the cyclicality of the markup. Finally, price dispersion, and heterogeneity in households' response margins may have implications for important political economy questions on adjustment of public benefits when measuring inequality and comparing real purchasing power [Griffith et al., 2009].

Main findings Overall, we find strong evidence of cyclicality in shopping behavior and store prices.

We estimate a number of household-level fixed effects regressions where we estimate the effect of the unemployment rate in the local market on different aspects of a household's shopping behavior. First, we find that the households substitute toward lower priced stores when local unemployment increases. Second, we consider the shares of total expenditure involving private label products, products bought in bulk, and products bought on sale. We find that all of these shares increase when there is an economic downturn, and that the effects are economically significant. For example, we estimate that a five percentage point increase in the local unemployment rate leads to an increase in the sales share of over two percentage points, which corresponds to over 40 percent of the average sales rate. Not only households but also stores may change their behavior in response to changes in local economic conditions, for example by reducing prices or running more campaigns to counter reductions in household demand. In addition to the household-level regressions, we run two store-level fixed effects regressions where we establish that the average price levels of the stores follow a cyclical pattern.

Both household and store responses to business cycle variations will have an impact on the average (per-unit) price a household pays for products in a given product category. Indeed, we find that household-level average prices for given categories is reduced substantially by an increase in the local unemployment rate. We then decompose the cyclicality of the category prices. An advantage of such a decomposition is that it allows us to estimate the effects stemming from changes both in store and household behavior in a unified model using large and detailed household-level data. This not only allows for high statistical precision but also makes it possible to quantify the relative contribution of the different channels through which the business cycle affects average prices. When decomposing the changes in the category prices, we find that over ten percent of the cyclicality of average prices can be explained by changes in the store prices alone (holding the households' choices fixed). However, most of the variation is due to factors that can be affected by the households. Of these, the component with the greatest contribution (accounting for over 50 percent of the total effect) is the households' propensity to take advantage of temporary price reductions. We also find that households allocate more of their expenditure in low-cost stores, contributing about ten percent of the total effect.

Related literature Our paper is related to a number of articles studying shopping behavior. Aguiar and Hurst [2007] study transaction prices over the life-cycle and find that households with higher incomes and those who spend more time shopping pay lower prices than other types of households. Similarly, Griffith et al. [2009] find that British households realize significant savings from buying in bulk and on sale, and by product and store substitution. Griffith et al. [2015] document how these effects were also present during the great recession in the UK: households decreased the average price paid per calorie by substituting towards generic brands and increasing shopping effort, among several adjustment margins. Studying shopping behavior in the US during the great recession, Nevo and Wong [2019] find that households systematically increased the use of coupons, purchases of generics, and the average size of units purchased when the local unemployment rate increased. Coibion et al. [2015] find that individual households allocated expenditure toward lower-price retailers when the local unemployment rate increased. Argente and Lee [2014] document large differences across income groups in how they adjusted consumption and shopping behavior during the great recession. While low income households already purchased the low price option within a product category, higher income households substituted towards lower priced options.

Missing data on actual consumption, economists are left to use consumption expenditure when imputing individual consumption. As expenditures reflect both price and quantity, interpreting declines in consumption expenditure as declines in consumption will exaggerate the actual decline in consumption if – as our findings suggest – individuals who enter unemployment realize significant price savings. Related to our paper is Campos and Reggio [2019], who find that roughly one sixth of the decline in consumption expenditure when entering unemployment is explained by a drop in transaction prices. Furthermore, this effect might vary across the income distribution.

Nekarda and Ramey [2013] argue that the common assumption of a countercyclical markup in New Keynesian models is based on inconclusive evidence. The authors review the literature, and revisit the methods that have tended to result in countercyclical markups. They conclude that using new data and methods, the evidence points toward procyclical or acyclical markups. Anderson et al. [2018] use scanner data from the retail sector, and find that product prices and replacement costs are acyclical in the United States and Canada. Additionally, for Canada, the authors find no discernible effect on these variables in response to oil price shocks across regions. While our results do not speak to the cyclicality of the markup for each product, they suggest that the average prices charged by stores is countercyclical and that the average household's purchasing prices contribute to a procyclical markup.

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The rest of the paper is organized as follows. In the next section, we present our empirical strategy, before we describe our data in Section 3. Section 4 presents reduced form evidence on business cycle changes and household behavior. Section 5 shows how we decompose a change in a household's average category price using product–store volume shares and prices. Section 6 presents the empirical results using our decomposition. Section 7 concludes.

2 Empirical strategy: The oil shock and the Norwegian economy

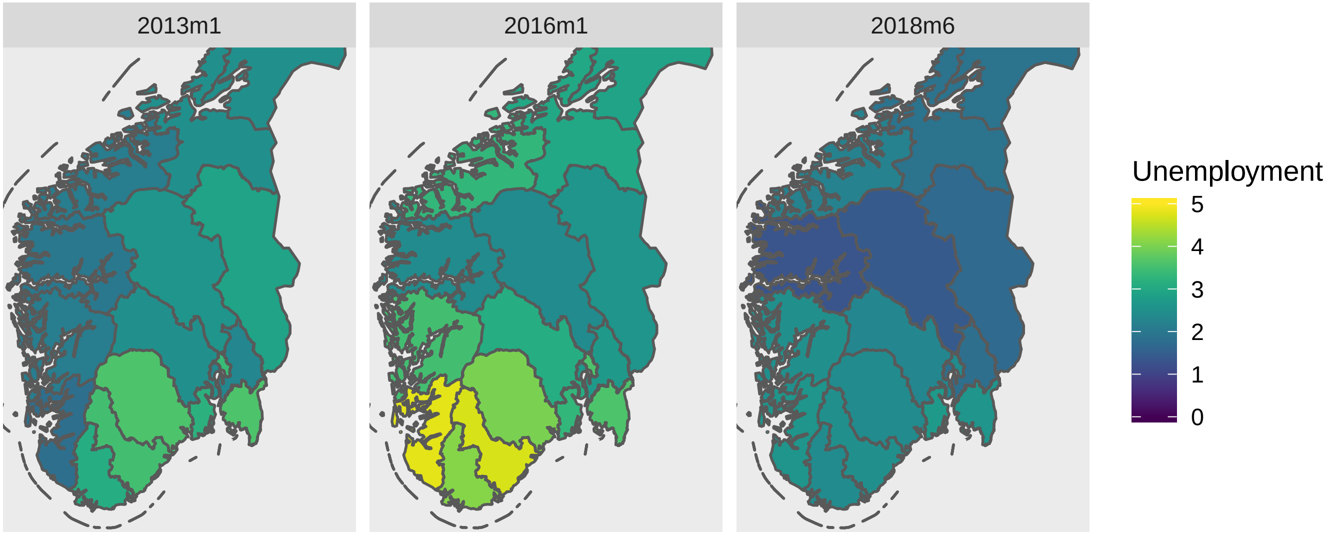
Our empirical strategy is to exploit how the collapse of the oil price in the middle of the 2010s led to a severe worsening of economic conditions and higher unemployment in certain regions of Norway, while leaving other regions largely unaffected. Using data on local unemployment rates together with data on households' transaction histories and store-level prices, we investigate how business cycle variation in prices can be explained by changes in household and store behavior. Specifically, we rely on fixed effects (and first differencing) to eliminate unobservable time-invariant effects (at e.g., the household and store levels). The geographical heterogeneity in the effect of the oil price shock allows us to efficiently control for country wide shocks using time fixed effects.

The petroleum industry is essential for the Norwegian economy, contributing 20 percent of GDP and 49 percent of exports in 2013 [Statistics Norway, 2020a,b]. In 2013, the petroleum industry directly or indirectly employed 8.7 percent of the Norwegian labor force [Hungnes et al., 2016]. However, the industry is largely concentrated along the southwestern coast, where it accounts for substantially larger shares of the economy. In Rogaland county, for example, the petroleum industry directly employs between 15 and 20 percent of the workforce in several municipalities [Ekeland, 2015, 2017].

In January 2013, the Europe Brent spot price was 112 USD per barrel. From the end of 2014 and through 2015, the price dropped dramatically, reaching a 12-year low of 30 USD by January 2016. The price then slowly increased, reaching 74 USD by June 2018 [U.S. Energy Information Administration, 2020]. Figure 1 plots county-level unemployment rate for the counties in South Norway, illustrating the regional nature of the effects of the oil price shock.[1] The highly oil-dependent coastal regions in the South and West experienced significant increases in the unemployment rate from January 2013 to January 2016. At the same time, other counties were unaffected by the shock–some even experienced a reduction in their unemployment rate in the same period. The county most severely hit by the oil price shock was Rogaland. In January 2013, Rogaland's unemployment rate of 1.8 percent was the lowest in the country. By January 2016, the unemployment rate had increased to 4.8 percent, which was the highest in the country. In June 2018, the unemployment had

[1]South Norway covers all but the three most northern counties. See also Table 9 in Appendix D.

Figure 1: County-level unemployment



Notes: The unemployment rate is the share of the workforce that, 1) is actively seeking a job, 2) has been without any work for the last two weeks, and, 3) has registered as unemployed at the Norwegian Labour and Welfare Administration. Data source: Norwegian Labour and Welfare Administration [2018]. See Appendix D for the underlying data.

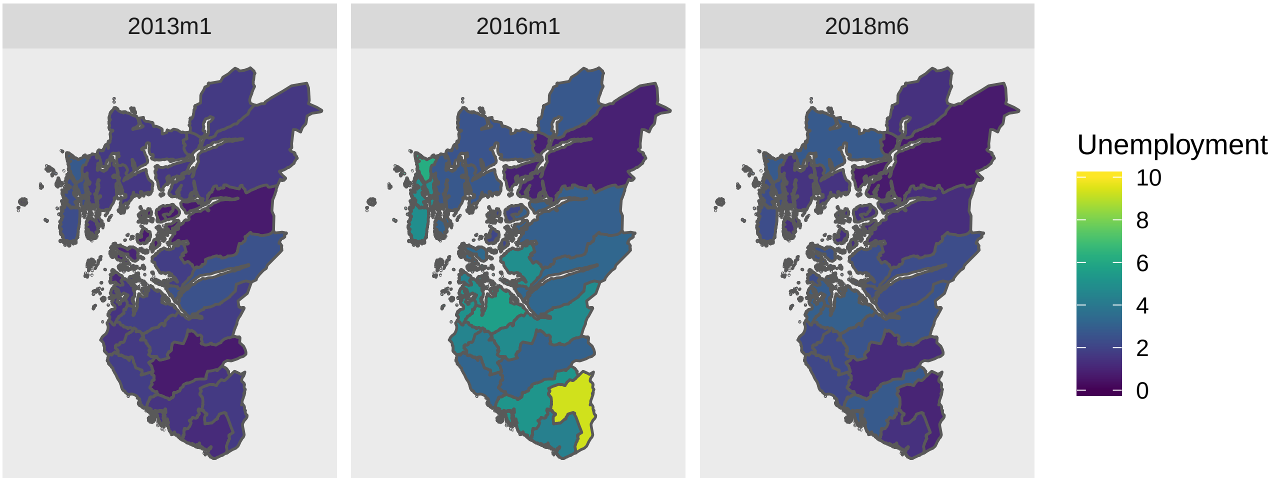
fallen to 2.6 percent. As illustrated in Figure 2, the recession was even more pronounced in some of the municipalities in Rogaland.[2] In the municipality of Sandnes, for example, the unemployment rate rose from 1.9 percent in January 2016 to 5.6 percent in January 2016, before falling back to 2.8 percent by June 2018.[3]

The oil-dependent regions also experienced weak developments in gross product, wage costs, and median income. Figure 3 shows the accumulated percentage increase in these quantities from 2013 to 2016. Rogaland stands out by performing worst by all three measures. In this county, the growth rate in median income was only 1.6 percent, compared with the unweighted average across all counties of 7.3 percent. Similarly, gross product grew only by 2.2 percent, compared with the average of 13.6 percent. Finally, wage costs grew by only 5.3 percent in Rogaland over the period, again significantly below the national average of 10.6

[2]See also Table 10 in Appendix D.

[3]The municipality with the most extreme difference between January 2013 and January 2016 is Lund, where the unemployment rate increased from 1.7 percent to 9.3 percent. However, this increase was not driven primarily by the oil price shock but by a flood in late 2015 that led to the temporary closure of a local factory.

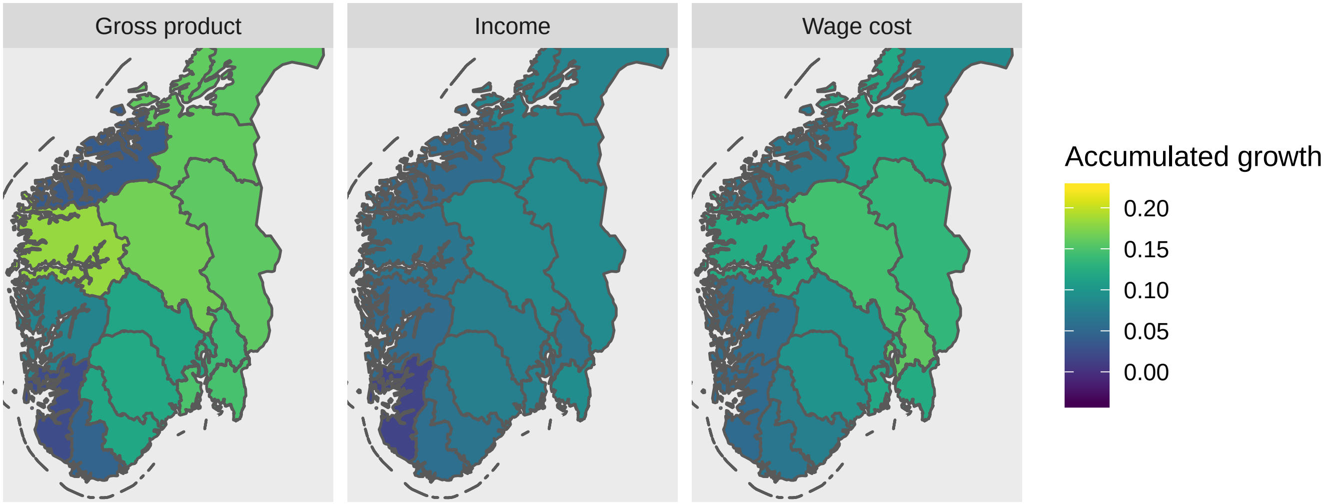
Figure 2: Municipality-level unemployment in Rogaland county



Notes: The unemployment rate is the share of the workforce that, 1) is actively seeking a job, 2) has been without work for the last two weeks, and, 3) has registered as unemployed at the Norwegian Labour and Welfare Administration. Data source: Norwegian Labour and Welfare Administration [2018]. See Appendix D for the underlying data.

percent.

Figure 3: Additional business cycle measures



Notes: The figures shows the accumulated growth rates between 2013 and 2016. Gross product is measured in current prices. Income is the median total income at the household-level. Wage cost is measured in current prices. Data sources: Statistics Norway [2019a,b]. See Appendix D for the underlying data.

3 Data

Our main source of data is a large umbrella chain with several grocery chain concepts. The umbrella chain is present in all counties of Norway and has 13 chain concepts covering all market segments. We have two main data sets. The first contains complete transaction histories from January 2013 to June 2018 for a random sample of households that were members of the umbrella chain's frequent buyer program. Our sample covers roughly five percent of the households in the program.[4] For each transaction, we have information about the name of the product, the store at which it was bought, the price, a sales campaign indicator, and the product category (as defined by the umbrella chain). The second data set contains weekly sales expenditure and quantities at the product level from all the grocery stores in the umbrella chain. These weekly figures are based on transactions from all customers, not only the sample present in our transaction-level data set.

The main purpose of the paper is to investigate how households and stores respond to

[4]In 2018, more than two million Norwegians (out of a population of 5.3 million) were members of the program.

changing economic conditions, and how this translates into the average prices households pay for products in given categories, such as minced meat or soda. We are restricting attention to categories where we can calculate comparable unit prices across products.[5] This means that we do not include categories such as newspapers and ready-to-eat meals, where there is no straightforward and comparable measure of unit. We want to be able to compare prices for exactly the same products across stores and time periods. Therefore, we do not include fresh fruit and vegetables, because the quality of these products may vary between stores and time periods. See Appendix C for a list of the included categories and their expenditure shares. Transactions from all other categories are dropped from all the following analyses and descriptive statistics. In the transaction-level data set, the included categories account for about 32 percent of the total expenditure.

Table 1 reports some descriptive statistics on the households and stores in the data set. From the table, we see that there are 100,261 distinct households in the data set and 2339 distinct stores.

Let us first consider the monthly expenditures at the household-level. Here, we first calculate the average monthly expenditure for each household, before we calculate the average, median and standard deviation for this variable *across* households. When calculating the within household averages, we only use months where a given household had positive expenditure.[6] The average value (across households) of the average (within household) monthly expenditure is about 734 NOK, which corresponded to about 132 USD at the start of our sample period.[7] This monthly expenditure is well below what we would expect the average household to spend on groceries during a month. Note however that this expenditure only covers the categories we consider in the subsequent analysis. As mentioned above, these categories cover about 32 percent of the total expenditures of the households in our sample. In addition, monthly expenditures are only from one umbrella chain, while a household may

[5]To calculate unit prices, we need to determine the number of units of a product (e.g., the number of kilos or liters) from the product's name. We drop transactions of products that have a different measure of unit in their name than the mode of the category (e.g., products whose name describes the amount of liters while the mode unit of measurement of the category is kilos). We also exclude products where the product name does not contain information about the number of units.

[6]We exclude months with zero expenditure because many households appear in our data well into the sample period, presumably because they were not members of the frequent buyer program at the beginning of the sample period.

[7]In January 2013, the price of one USD was 5.56 NOK (monthly exchange rates from The Central Bank of Norway).

visit more than one umbrella chain in a given month. Turning to the number of stores visited, the average (across households) of the average (within household) number of distinct stores visited is 2.30, again only counting months where a given household visited at least one store. The months active variable indicates that on average the households made purchases in about 40 of the 66 months in the sample period, reflecting the fact that many households are not present in the data in the beginning of the sample period. Among the households present in the first quarter of the sample period, the average of the months active variable is about 54.

In the subsequent analysis, we keep only observations where we have information about the municipality of residence of the household, and where the household is registered as living in the same local market as the store. This is to avoid transactions where a customer no longer lives (and works) in the registered local market, and transactions made while travelling. We define local markets by local labor market regions. The labor market regions are defined by Statistics Norway using data on commuting patterns [Bhuller, 2009]. The 46 labor market regions nest the municipalities in Norway.[8] The reason for defining local markets by labor market regions rather than by municipalities is that consumers may live in one municipality but do much of their grocery shopping in neighboring municipalities. From Table 1, we see that this is indeed the case. The mean share of total expenditure that households spend in their home municipality is 0.73, while the mean share households spend in their home region is 0.87. Furthermore, 75 percent of the households spend 88 percent or more of their total expenditure in their home labor market region, while the corresponding figure for the home municipality is only 59 percent. As we will be analyzing households' willingness to switch to cheaper stores when economic conditions worsen, defining local markets by local labor market regions can be especially important in situations where the umbrella chain has few (if any) stores in a household's home municipality. While the umbrella chain has stores in all 46 labor markets, it is during our sample period never present in more than 370 municipalities. Furthermore, 75 municipalities have only one store from the umbrella chain (during the sample period), and 58 municipalities have only two stores, implying that the umbrella chain has two or fewer stores in about 45 percent of the municipalities.[9]

[8] In the beginning of our sample period there were 428 municipalities in Norway. At the end of our sample period, mergers had reduced the number of municipalities to 423.

[9] In addition, the umbrella chain is represented by either zero or one chain concepts in almost 40 percent of the municipalities. Since substituting toward cheaper stores typically involves substituting toward cheaper

Turning now to the store-level variables, we see that the average (across stores) of the average (within store) monthly revenue is about 1,175,937 NOK, which corresponded to about 211,499 USD at the start of our sample period.[10] The mean number of distinct months a store is active is about 44, and the median is 56.

chain concepts, this reinforces the impression that defining the relevant market by municipality is too narrow.

[10]Note that this is only the revenue coming from the subset of categories we consider in the subsequent analysis. The monthly revenue is calculated using the data set with weekly sales and quantities at the product–store level, so it covers revenue from all customers, not only the sample included in our transaction-level data set.

Table 1: Customer and store characteristics

	Mean	Median	Std. dev.	Observations
Households				
Monthly expenditure	733.79	498.51	730.72	100261
Stores visited	2.30	2.02	1.15	100261
Chains visited	1.72	1.59	0.60	100261
Stores in home municipality	29.05	9.00	48.80	100261
Stores in home region	159.55	53.44	169.42	100261
Chains in home municipality	4.30	4.00	2.52	100261
Chains in home region	8.08	8.00	2.87	100261
Home municipality share	0.73	0.87	0.32	100260
Home region share	0.87	0.97	0.24	100260
Months active	40.01	42	22.51	100261
Stores				
Monthly revenue	1175937	1019418	965686	2339
Months active	43.92	56	24.57	2339

Notes: Monthly expenditure is the average (within household) monthly expenditure in NOK, counting only months with expenditure above zero and only the categories considered in the subsequent analysis (see Table 8 in Appendix C). Stores visited is the average (within household) number of stores visited, counting only months with expenditure above zero. Chains visited is equivalently defined. Months active is the number of months where a household had expenditure above zero. Age is the age of a household's primary member. Monthly revenue is store-level revenue in NOK counting only the categories considered in the subsequent analysis. Months active is the number of months with revenue above zero. All household-level variables are calculated using the transaction-level data set. All store-level variables are calculated using the weekly store-level data set.

4 Household and store behavior over the business cycle

Aguiar and Hurst [2007] and Nevo and Wong [2019] argue that variation in the opportunity cost of time can induce households to increase effort to find items at lower prices. Furthermore, wealth effects may make households more price sensitive and more willing to substitute toward goods on sale. Wealth effects can also induce substitution toward generic brands, items bought in bulk, and lower priced stores. In Appendix B, we outline a theoretical framework based on Aguiar and Hurst [2007] and Nevo and Wong [2019]. This framework illustrates how business cycle variation in the opportunity cost of time can induce households to spend more time looking for items on sale.

As discussed earlier, stores may also adjust their behavior in response to an economic downturn. If households become more willing to hunt for bargains, stores may find it more profitable to run campaigns. A negative income shock that shifts the demand downwards may also induce price reductions by the stores. Finally, if the households become more inclined to buying generic brands or bulk items, stores may find it beneficial to give such items more exposure, e.g., through shelf space allocation. In this section, we will study how households and stores adjust their behavior along these dimensions over the business cycle. We will use simple reduced form fixed effects regressions to analyze the effect of changes in the unemployment rate on carefully designed variables measuring changes in household and store behavior.

We will start at the household-level. Table 2 reports descriptive statistics for a number of household-level measures that may be affected by the business cycle. We also report descriptive statistics on the unemployment rate.

Table 2: Household-level variables

	Mean	Median	75th pct.	25th pct.	Std. dev.
Generic PL share	0.0499	0.0052	0.0607	0.0000	0.0983
Sales share	0.0512	0.0000	0.0422	0.0000	0.1228
Bulk share	0.1910	0.1776	0.2520	0.1022	0.1464
Low price retailers share	0.3262	0.1004	0.6967	0.0000	0.3868
High price retailers share	0.0983	0.0000	0.0380	0.0000	0.2354
Unemployment rate	0.0275	0.0270	0.0333	0.0210	0.0086

Notes: The unit of observation is household-quarter. The number of observations with nonmissing values of all variables is 1,376,188. There are 97,379 distinct households. Markets are defined by labor market regions. The sample period is 2013q1 to 2018q2.

Generic PL share is the share of total expenditures that involved the umbrella chain's low-cost private label. Sales share is the share of total expenditures made on sale. To obtain the Bulk share, we follow Griffith et al. [2009] and rank all product (defined by EAN numbers) within each product category by size. For each category, we then calculate the share of purchases a given household makes that are in the top quartile of the category distribution.

To investigate whether households substitute towards low price stores when economic conditions worsen, we follow Coibion et al. [2015] and construct an aggregate measure of a store's price level, relative to the median price level in a given market and time period.[11] High price retailer share is the share of expenditure a consumer allocates to stores in the top quartile of the store distribution, while Low price retailer share is the share of expenditure the consumers allocate to stores in the bottom quartile of the store distribution.

Even though all these variables are measured at the household-level, some of them may

[11] First, we calculate for each product j in category c and local market m the log-difference, denoted $R_{mscj,t}$, between the average price at store s, calculated as total sales amount divided by the total quantity bought, and the median price of the product in the market in that time period. The average relative price of store s is given by $R_{ms,t} = \sum_c \Omega_{c,t} \sum_j \omega_{mscj,t} R_{mscj,t}$, where $\omega_{mscj,t}$ is product j's share of the expenditure in the category in the given market and time period, and $\Omega_{c,t}$ is category c's share of the total expenditure in the time period. We calculate $R_{ms,t}$ using only products that are sold by at least 90 percent of the stores in the market. We then rank the stores in a market by price level.

also reflect strategic decisions by the stores. A household's sales share may for example be affected by the local stores' sales campaign strategies. In addition, a household's bulk and private label shares may rise if the local stores give such items increased exposure through their shelf space and assortment decisions. However, low and high price retailer shares are less likely to be systematically affected by store-side responses.[12] For each of the household-level variables, we estimate a model of the following form,

$$Y_{hm,t} = \alpha_{hm} + \beta UR_{hm,t} + \lambda_t + \epsilon_{hm,t}, \tag{1}$$

where $Y_{hm,t}$ is the dependent variable of interest, α_{hm} are household fixed effects, $UR_{hm,t}$ is the unemployment rate in the home municipality of the household, and λ_t are time fixed effects. Table 3 reports the results for the household-level regressions.

[12] However, to the extent that there is variation in the economic conditions *within* the labor market regions and local store strategies are sensitive to this, the households' store shares could be systematically affected by store-side responses.

Table 3: Household-level regressions

	Unemployment rate
Generic PL share	0.109***
	(0.020)
Sales share	0.482***
	(0.041)
Bulk share	0.157***
	(0.030)
Low price retailers share	0.361***
	(0.078)
High price retailers share	−0.483***
	(0.056)
Observations	1376188
Households	97379

Notes: This table reports results from fixed effects estimation of models of the form specified in (1). The variables in the first column are dependent variables with the coefficients showing the effect of the unemployment rate on the dependent variable in question. The unit of observation is household-quarter. In the regressions, we only use observations with nonmissing values for all variables in the table. The standard errors reported in parentheses are clustered at the household-level. Markets are defined by labor market regions.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

All variables are sensitive to the local business conditions as measured by the unemployment rate, and all coefficients have the expected signs. The private label, sale, and bulk shares increase significantly when local unemployment increases. Likewise, the low price retailer share increases and the high price retailer share decreases.

What is the economic significance of these results? Let us consider an increase in the unemployment rate of five percentage points to get a better understanding of our results. Such an increase is estimated to increase the private label share by 0.6 percentage points, implying a increase relative to the average reported in Table 2 of about 11 percent. Similarly, the sales share is estimated to increase by 2.4 percentage points, which is an increase of about 47 percent relative to the average. The expenditure share of bulk items is estimated to increase by roughly 0.8 percentage points, which is about four percent relative to the mean. The expenditure share allocated to low price stores is estimated to increase by nearly two percentage points, but because the average low price retailer share is above 32 percent, the relative increase is relatively modest at about five percent. The high price retailer share is estimated to fall by roughly 2.5 percentage points, which relative to the average share is about 25 percent.

In summary, we find both statistically significant and economically important effects from an increase in the local unemployment rate, suggesting that households do indeed adjust their behavior when hit by unemployment. Next we consider the price levels at the stores, and see whether we can find similar evidence of cyclicality. Table 4 reports descriptive statistics for two store-level price measures that may be affected by the business cycle.

Table 4: Store-level variables

	Mean	Median	75th pct.	25th pct.	Std. dev.
Chain deviation	−0.0025	−0.0015	0.0014	−0.0072	0.0134
Total deviation	−0.0093	−0.0271	0.0284	−0.0430	0.0418

Notes: The unit of observation is store-quarter. The number of observations with non-missing values for both variables is 33,830. There are 2313 distinct stores. The sample period is 2013q1 to 2018q2.

The variables Chain deviation and Total deviation measure the price level of a store, compared with the price level of the other stores in the store chain and all stores in the sample, respectively.[13] Even though these variables are measured at the store level, they

[13] The Chain deviation variable is constructed as follows. First, we calculate for each product j in category c

are constructed to also capture changes in household shopping behavior. Households may drive down the average price paid for a particular product in a particular store in a given time period (e.g., quarter) by concentrating their purchases in weeks when the product is relatively cheap, e.g., by taking advantage of sales campaigns.

For the two store-level variables, we estimate a model of the following form,

$$Y_{sm,t} = \alpha_{sm} + \beta UR_{sm,t} + \lambda_t + \epsilon_{sm,t}, \tag{2}$$

where $Y_{sm,t}$ is the dependent variable of interest, α_{sm} are store fixed effects, $UR_{sm,t}$ is the unemployment rate in the municipality of the store, and λ_t are time fixed effects.

Table 5 reports the results of the store-level regressions.

---

and chain k the log-difference, denoted $R_{kmscj,t}$, between the average price at store s in market m, calculated as total expenditure in period t divided by total quantities, and the median price of the product in the chain in that time period. The Chain deviation of store s is given by $R_{sm,t} = \sum_c \Omega_{c,t} \sum_j \omega_{kcj,t} R_{kmscj,t}$, where $\omega_{kcj,t}$ is product j's share of the monthly expenditure in category c in the given chain and time period, and $\Omega_{c,t}$ is category c's share of the expenditure in the given time period. We calculate $R_{sm,t}$ using only products that are sold by at least 90 percent of the stores in the chain. The variable Total deviation is defined in the same way, but here we are comparing the price level of the store with all the stores in the sample (rather than only the stores from the same chain).

Table 5: Store-level regressions

	Unemployment rate
Chain deviation	−0.028**
	(0.014)
Total deviation	−0.080***
	(0.024)
Observations	33830
Stores	2313

Notes: This table reports the results from fixed-effects estimation of the models of the form specified in (2). The variables in the first column are dependent variables with the coefficients showing the effect of the unemployment rate on the dependent variable in question. The unit of observation is store-quarter. In the regressions, only observations with nonmissing values of both variables are used. The standard errors reported in parentheses are clustered at the store level. Markets are defined by labor market regions.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

We see from the table that average prices are indeed countercyclical. An increase in the unemployment rate of five percentage points is estimated to reduce Chain deviation by roughly 0.002, which is about 0.13 standard deviations. A similar increase in the unemployment rate is estimated to reduce Total deviation by roughly 0.05, which corresponds to about 0.11 standard deviations.

As mentioned above, this cyclicality in the store prices may reflect both household- and store-side responses, which was also the case for several of the household-level variables. In the next section, we propose a decomposition of changes in the average prices households pay in given categories which will allow us to better separate the relative contributions stemming from the stores and households.

5 Decomposing price changes

The previous section has indicated that both households and stores respond to changes in the local economic conditions. In this section, we develop a new framework for analyzing and decomposing the cyclicality of the average prices the households pay for goods in a given category, such as skimmed milk or filter coffee.

Let j refer to products (e.g., one liter of a specific brand of skimmed milk) and s to stores. In order to normalize prices across categories, we do the following. For household h in market m, we measure the log-difference, denoted $r_{hmscj,t}$, between the average price the household pays for product j belonging to category c in store s in period t, and the average price paid for products in category c, where the average is taken over all products, stores, households and time periods. We measure the category price as the share-weighted average of the normalized prices, which for a household in a given market for products in a given category and time period is given by

$$p_{hcm,t} = \sum_j \sum_s \alpha_{hmscj,t} r_{hmscj,t}, \tag{3}$$

where $\alpha_{hmscj,t} \geq 0$ is the proportion of total units bought in the category in period t the household allocated to product j in store s.

Within a time period such as a quarter, purchases of a given product in a given store can occur at different prices. By exploiting temporary price reductions, bundling or quantity discounts, a household may pay less than average for a given product in a given store in a given time period. Define

$$\delta_{hmscj,t} = r_{hmscj,t} - r_{mscj,t}, \tag{4}$$

where $r_{mscj,t}$ is the average price paid for product i in store j in the period in question. We can now write a household's category price as follows.

$$p_{hcm,t} = \sum_j \sum_s \alpha_{hmscj,t}(r_{mscj,t} + \delta_{hmscj,t}) \tag{5}$$

This average price can be decomposed as follows.

$$\begin{aligned} p_{hcm,t} &= \sum_j \sum_s \alpha_{hmscj,t}(r_{mscj,t} + \delta_{mscj,t}) \\ &= \frac{1}{2}\sum_j \alpha_{hmcj,t} r_{mcj,t} + \frac{1}{2}\sum_s \alpha_{hmsc,t} r_{msc,t} + \sum_j \sum_s \alpha_{ij}(r_{mscj,t} - \frac{r_{mcj,t} + r_{msc,t}}{2}) \\ &+ \sum_j \sum_s \alpha_{hmscj,t}\delta_{hmscj,t}, \end{aligned} \tag{6}$$

where $\alpha_{hmcj,t} = \sum_s \alpha_{hmscj,t}$ is the volume share of product j in period t (summed across stores), $\alpha_{hmsc,t} = \sum_j \alpha_{hmscj,t}$ is the volume share of store s in period t (summed across products), and $r_{hmcj,t}$ and $r_{hmsc,t}$ are the average prices in period t, market m and category c of product j and store s, respectively.

The first two terms of the last expression in (6) are weighted averages of the price levels of stores and products, where the weights are the volume shares the household allocates to each store and product. The third term accounts for the fact that some product–store combinations may be cheaper (or more expensive) than expected, based on the general price level of the store and the product. The fourth term accounts for the fact that not all purchases of a given product in a given store in a given time period take place at the same price. Equation (6) illustrates that a household can reduce its average price by buying products that in general are cheap (the first term), by buying at stores that in general are cheap (the second term), by choosing product–store combinations that, relative to the general price level of the store and the product, are cheap (the third term), and finally, by exploiting temporary price reductions and other special offers such as bundling or quantity discounts (the fourth term).

We are interested in the cyclicality of prices. Therefore, let us now consider the change in the average price from one period to the next. Note that we can write the category price paid by the household in period t as follows.

$$p_{hcm,t} = \sum_j \sum_s \alpha_{hmscj,t}(r_{mscj,t} + \delta_{hmscj,t}) \tag{7}$$
$$= \sum_j \sum_s (\alpha_{hmscj,t-1} + \Delta^{\alpha}_{hmscj,t})(r_{mscj,t-1} + \Delta^{r}_{mscj,t}) + \sum_j \sum_s \alpha_{hmscj,t}\delta_{hmscj,t},$$

where $\Delta^{\alpha}_{hmscj,t} = \alpha_{hmscj,t} - \alpha_{hmscj,t-1}$ and $\Delta^{r}_{mscj,t} = r_{mscj,t} - r_{mscj,t-1}$. Subtracting $p_{hc,t-1}$ from (7) gives us the change in the category price as follows.

$$\begin{aligned} p_{hcm,t} - p_{hcm,t-1} &= \sum_j \sum_s (\alpha_{hmscj,t-1} + \Delta^{\alpha}_{hmscj,t})(r_{mscj,t-1} + \Delta^{r}_{mscj,t}) + \sum_j \sum_s \alpha_{hmscj,t}\delta_{hmscj,t} \\ &- \sum_j \sum_s \alpha_{hmscj,t-1}(r_{mscj,t-1} + \delta_{hmscj,t-1}) \\ &= \sum_j \sum_s \alpha_{hmscj,t-1}\Delta^{r}_{mscj,t} + \sum_j \sum_s \Delta^{\alpha}_{hmscj,t} r_{mscj,t-1} + \sum_j \sum_s \Delta^{\alpha}_{hmscj,t}\Delta^{r}_{mscj,t} \\ &+ \sum_j \sum_s (\alpha_{hmscj,t}\delta_{hmscj,t} - \alpha_{hmscj,t-1}\delta_{hmscj,t-1}) \end{aligned} \tag{8}$$

The first term in the last expression, $\sum_j \sum_s \alpha_{hmscj,t-1}\Delta^{r}_{mscj,t}$, is the change in the average category price that would result purely from changes in product–store prices (if the household did not reallocate consumption). The second term, $\sum_j \sum_s \Delta^{\alpha}_{hmscj,t} r_{mscj,t-1}$, is the change in the category price that would result purely from changes in volume shares (if prices were unchanged). The third term, $\sum_j \sum_s \Delta^{\alpha}_{hmscj,t}\Delta^{r}_{mscj,t}$, captures the interaction between price changes and volume changes. If the household reallocates toward products that have become relatively cheaper this term will be negative. The last term, $\sum_j \sum_s (\alpha_{hmscj,t}\delta_{hmscj,t} - \alpha_{hmscj,t-1}\delta_{hmscj,t-1})$, captures changes in the households' willingness and ability to take advantage of temporary price changes and other special offers.

To obtain the decomposition that we will take to the data, we write the change in the average price as follows.

$$
\begin{aligned}
p_{hcm,t} - p_{hcm,t-1} = & \overbrace{\sum_j \sum_s \alpha_{hmscj,t-1} \Delta^r_{mscj,t}}^{\Delta^{Laspeyre}} \qquad (9) \\
& + \overbrace{\frac{1}{2} \sum_j \Delta^\alpha_{hmcj,t} r_{mcj,t-1}}^{\Delta^{Products}} + \overbrace{\frac{1}{2} \sum_s \Delta^\alpha_{hmsc,t} r_{msc,t-1}}^{\Delta^{Stores}} \\
& + \overbrace{\sum_j \sum_s \Delta^\alpha_{hmscj,t} (r_{mscj,t-1} - \frac{r_{mcj,t-1} + r_{msc,t-1}}{2})}^{\Delta^{Shopping}} + \overbrace{\sum_j \sum_s \Delta^\alpha_{hmscj,t} \Delta^r_{mscj,t}}^{\Delta^{Interaction}} \\
& + \overbrace{\sum_j \sum_s (\alpha_{hmscj,t} \delta_{hmscj,t} - \alpha_{hmscj,t-1} \delta_{hmscj,t-1})}^{\Delta^{Discounts}}
\end{aligned}
$$

The average price a household pays for products in a given category may decrease because the prices of the products it buys decrease ($\Delta^{Laspeyre}$), because the household substitutes toward products and stores that in general are cheaper ($\Delta^{Products}$ and Δ^{Stores}), and because the household's shopping intensity has increased (the last three terms in (9)). $\Delta^{Shopping}$ captures changes in the household's propensity to choose combinations of products and stores that cost less than their individual product and store shares would indicate. $\Delta^{Interaction}$ tells us something about the household's willingness to take advantage of changing relative prices by substituting toward products that have become relatively cheaper, while $\Delta^{Discounts}$ captures changes in the changes in the household's willingness and ability to take advantage of temporary price changes and other special offers.

6 The cyclicality of grocery prices

Our main empirical specification is as follows

$$
Y_{hcm,t} = \theta_{hcm} + \beta UR_{hm,t} + \lambda_t + \epsilon_{hcm,t}, \qquad (10)
$$

where h, c, m, and t index households, categories, markets, and time period, respectively.

$Y_{hcm,t}$ is the variable of interest, $UR_{hm,t}$ is the unemployment rate in the home municipality of the household, θ_{hcm} denotes fixed effects at the household-category level, and λ_t denotes time fixed effects.

First differencing (10) gives us the following equation

$$Y_{hcm,t} - Y_{hcm,t-1} = \beta(UR_{hm,t} - UR_{hm,t-1}) + (\lambda_t - \lambda_{t-1}) + (\epsilon_{hcm,t} - \epsilon_{hcm,t-1}). \tag{11}$$

OLS estimation of (11) with the change in household-level category price, $p_{hcm,t} - p_{hcm,t-1}$, on the left-hand side gives us an estimate of the cyclicality of average category prices. Furthermore, by estimating (11) with each of the terms on the right-hand side of (9) as the dependent variable, we can decompose the cyclicality of the prices into the different components described in the previous section.

To calculate $p_{hcm,t}$, we use the average prices a household paid for each product–store combination in category c in period t. The average prices are calculated as the number of units bought divided by sales expenditure, including any discounts. We use quarters as time periods. When calculating the terms on the right hand side of (9), we need a measure of the general price of product j in store s in quarter t. Our measure is the (unweighted) average of the weekly product–store prices in the quarter, where the weekly price is sales value divided by the total number of units sold. When calculated in this way, the product–store prices will only to a limited extent be affected by household side responses. If we had calculated the quarterly price by dividing the total sales amount by the total number of units sold, the price would be responsive to the households' willingness and ability to concentrate their purchases of the product to the weeks where the price is relatively low.[14]

We now turn to the terms of the decomposition, and discuss to what extent each term captures household-side or store-side responses.[15]

[14]There are two ways the household still could affect the average price as we define it here. First, the average price would be reduced if the households exploit price variation at the product–store level *within* weeks, by concentrating their purchases in days where the price is relatively low. However, because the umbrella chain's sales campaigns tend to follow a weekly pattern, we believe that any such effects are limited. Second, households could reduce this average price by increasing their propensity to take advantage of special offers that are always available, such as quantity discounts. It should be noted, however, that the largest chain associated with the umbrella chain has an explicit policy of not offering quantity discounts, so we believe that this channel is of limited importance.

[15]In order to decompose the change in the category price according to (9), we need to know the (average) price in period t of all product–store combinations bought by the customer in period $t-1$, and likewise the

$\Delta^{Laspeyre}$ is calculated holding product–store shares fixed. As we argue above, the quarterly product–store price should not be much affected by household behavior, therefore, we view $\Delta^{Laspeyre}$ as measuring store-side responses to the business cycle. The variable will pick up price reductions stemming both from reductions in the regular price and increases in campaign activity at the store level. As Δ^{Stores} and $\Delta^{Shopping}$ are calculated holding prices fixed, they are unaffected by any cyclical pricing strategies at the store level. These two variables are therefore driven entirely by household-side responses. $\Delta^{Products}$ is also calculated holding prices fixed, but could to some extent be affected by store behavior, if for example, stores reacted to changing economic conditions through assortment and shelf space adjustments. We still believe that this variable is best viewed primarily as measuring household-side responses. $\Delta^{Interaction}$ measures the household's willingness and ability to reallocate consumption toward products that have become relatively cheaper. This variable is therefore entirely a measure of household-side response.

Finally, $\Delta^{Discounts}$ measures the change in the household's ability to take advantage of temporary price reductions, and thereby pay a lower price for product j in store s than the average price for the product in the store. Note that any cyclical variation in this variable will reflect an increase in the households' tendency to concentrate their purchases in weeks where the product is available at a relatively low price, e.g., by taking advantage of temporary sales campaigns. Increased propensity of households in local markets experiencing an economic downturn to take account of special offers that are available throughout the time period, such as quantity discounts, would not affect the variable because this would have the effect of reducing the average price. It should be noted that while it is natural to view this variable as primarily capturing a household-side response, cyclical variation in the households' willingness to exploit sales campaigns may be amplified by store-side responses, because, e.g., more frequent sales campaigns may make it easier for the households to reduce the price they pay for a given product in a given store (compared with the average price of the product in the store).

Table (6) reports our main empirical results. The first column of Table 6 is our preferred

(average) price in period $t-1$ of all product–store combinations bought by the customer in period t. Average prices at the product–store level are calculated using the store level data set with weekly sales and quantity information. We will therefore have a measure of the average product–store price in a given quarter, as long as the product was sold in the given store in the given time period, even if the product was not bought by any of the households in our transaction-level data set.

specification. We see that the category prices indeed are countercyclical: a five percentage point increase in the unemployment rate leads to a decrease in the category price of about 0.008,[16] Given that the (within-panel) standard deviation of the category price is about 0.21 this may seem like a relatively small effect. One should however keep in mind that while not all consumers in a given local market are (equally) affected by an economic downturn, the effect estimated in Table 6 is an average effects over all households. Among the households directly affected by an economic downturn, e.g., the ones becoming unemployed, the effect is likely to be greater.

Turning to the decomposition, we observe that these sum to the total effect and that all coefficients are negative. The component with the largest contribution to the decrease in the category price is $\Delta^{Discounts}$, which accounts for about 57 percent of the total effect. This indicates that customers are more willing and able to take advantage of temporary price reductions when local unemployment increases. The second most substantial component, $\Delta^{Laspeyre}$ is statistically significant at the five percent level. This component accounts for about 12 percent of the decrease in the category price. As discussed above, we interpret $\Delta^{Laspeyre}$ as capturing store-side responses, and the negative sign of the coefficient indicates that stores do in fact respond to an economic downturn by reducing their prices. The parameter for Δ^{Stores}, which measures a household-side effect, is statistically significant at the one percent level, and represents about 12 percent of the total effect.

These findings are well aligned with the results reported in Table 3 and Table 5. In Table 3, we found that the share of expenditures involving sales increased when the unemployment rose. This is reflected directly in the negative sign of $\Delta^{Discounts}$, and also potentially in the negative sign of $\Delta^{Laspeyre}$, because this variable reflects both reductions in ordinary prices and price reductions due to more frequent or more substantial sales campaigns. The negative sign of Δ^{Stores} reflects the finding reported in Table 3 that households shift their trade from high-price stores to low-price stores when economic conditions worsen. Table 5 established that the price levels of the stores were cyclical, when average prices were calculated as quarterly expenditure divided by quarterly volume. This finding is reflected in the negative signs of $\Delta^{Laspeyre}$ and $\Delta^{Discounts}$. The negative sign and magnitude of $\Delta^{Discounts}$ indicates

[16] We choose to estimate Equation 10 by first differences rather than by fixed effects because this allows us to decompose the cyclicality of the average price. Estimating the model with fixed effects on the same samples as in Table 6 gives us nearly indistinguishable estimates of the main effect of unemployment on the category price.

Table 6: Cyclicality of category prices

	Category price	Category price	Category price	Category price
Unemployment rate	−0.14262***	−0.16083***	−0.16673***	−0.17479***
	(0.04038)	(0.04235)	(0.03941)	(0.04136)
Decomposition				
$\Delta^{Laspeyre}$	−0.01819**	−0.01872**	−0.01440*	−0.01489*
	(0.00772)	(0.00755)	(0.00811)	(0.00793)
$\Delta^{Products}$	−0.00198	−0.00158	−0.01054	−0.00582
	(0.01685)	(0.01624)	(0.01766)	(0.01704)
Δ^{Stores}	−0.01753***	−0.01340***	−0.02061***	−0.01520***
	(0.00542)	(0.00417)	(0.00571)	(0.00440)
$\Delta^{Shopping}$	−0.01338	−0.01966	−0.02480	−0.02730
	(0.01809)	(0.01740)	(0.01896)	(0.01826)
$\Delta^{Interaction}$	−0.00956	−0.00331	−0.00984	−0.00313
	(0.00715)	(0.00676)	(0.00751)	(0.00709)
$\Delta^{Discounts}$	−0.08199***	−0.11006***	−0.08064***	−0.10845***
	(0.02031)	(0.02044)	(0.02125)	(0.02139)
Observations	8,303,161	8,432,761	7,271,425	7,397,597
Panels	1,640,337	1,611,499	1,257,110	1,235,174
Households	87,300	87,165	54,211	54,206
Household set	Full	Full	Restricted	Restricted
Product set	Full	Restricted	Full	Restricted
Market span	Labor market	Labor market	Labor market	Labor market

Notes: The standard errors reported in parentheses are clustered at the household-level. Panels is the number of distinct household category combinations. The restricted household set only includes customers who were active in at least half of the months in the sample period. The restricted product set is derived as follows: we rank the products in each category (in descending order) by total expenditure in the entire sample period, and keep all products until the cumulative expenditure share reaches 0.95. Market is defined by labor market regions.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

that the reduction in store prices to a large degree reflects that the households are more willing and able to concentrate their purchases of a given product in weeks where the price is relatively low. However, the negative sign of $\Delta^{Laspeyre}$ indicates that part of the cyclicality of the store prices are also driven by the stores themselves, through reductions in ordinary prices or through increased campaign activity.

While both household and store responses to business cycles have been studied in the literature, our detailed data and our new decomposition allows us to clearly disentangle and quantify the two responses. In sum, our results show a clear result: grocery prices are countercyclical. When unemployment increases, prices are reduced. When we decompose this cyclicality, we find that the aggregate effect is driven by both household-side and store-side responses, and that most of the cyclicality is driven by changes in the households' propensity to take advantage of sales campaigns.

To investigate the robustness of our results, we estimate several alternative specifications. First, households that buy most of their groceries from other chains may be a less reliable source of variation in category prices, because the category price calculated using transactions from the umbrella chain we have data from may differ substantially from the household's true average category price. In Column 3 and Column 4 of Table 6, we only include households that were active in at least half of the months in the sample period. This removes from the estimation sample households that only sporadically visited the umbrella chain's stores. Second, products that are infrequently bought may not be a reliable source of variation in prices because the weekly (and quarterly) prices at the store level may be based on few transactions and therefore be a noisy measure of the price at which the product is available in the store in the given period. In Column 2 and Column 4 of Table 6, we therefore exclude the least frequently bought products in each category when calculating and decomposing the average category prices. More specifically, we rank the products in each category (in descending order) by total expenditure in the entire sample period, and keep all products until the cumulative expenditure share reaches 0.95.

Comparing the results in Columns 2–4 with Column 1, we see that the results are qualitatively and quantitatively similar. The overall effects is similar, although the magnitude is slightly larger in the alternative specifications than in the Column 1. $\Delta^{Discounts}$ has the largest contribution in all specifications. $\Delta^{Laspeyre}$ and Δ^{Stores} still stands out among the other components, although $\Delta^{Laspeyre}$ is only borderline statistically significant in the specifications with the restricted household set.

Finally, we have re-estimated each model reported in Table 6 after dropping extreme observations. Specifically, when constructing the household-level average prices we drop transactions where the log-difference between the average quarterly price at the household-product-store level and the category-level average (across all products, stores, households and time periods) exceed two. This is to ensure that our results are not driven by a small number of transactions with extremely low (or high) prices. As can be seen from Table 7 in Appendix A, the results are both qualitatively and quantitatively similar to those reported in Table 6.

7 Conclusion

We utilize two data sets on household- and store-level grocery prices and sales to uncover how consumers' shopping behavior was affected by local economic downturns following the large drop in oil prices in 2014. The reduction in oil prices affected the Norwegian labor market very differently across regions, increasing local unemployment rates substantially in some areas.

We start by presenting reduced form evidence suggesting that both households and stores reacted to the economic downturn. Store prices are reduced when unemployment increases, and consumers react by reallocating expenditure toward cheaper products (more private label products, more bulk items) and stores.

We then develop a novel decomposition of changes in average category prices at the household-level. The decomposition captures changes in the prices charged by the stores (holding the choices of the households unchanged), changes in the store shares and product shares (holding prices charged by the stores unchanged), and changes in the households' shopping intensity. This decomposition allows us to incorporate household and store responses within the same framework, and thus measure also their relative contributions. We find that most of the cyclicality in prices are determined by household responses, but more than ten percent of the cyclicality in the average price is determined by stores' regional responses to the economic downturn. The single most important factor, accounting for more than half of the total effect, is the households' willingness to take advantage of temporary price reductions.

The results are consisitent with findings in the literature and indicate that knowledge of households' shopping behavior and the effect on prices can play a crucial role in understanding how shocks are transmitted in the economy (as in e.g, Jaimovich et al. [2019] and Kaplan and Menzio [2016]). The findings in the current paper are relevant for several important issues, such as how to measure consumption expenditures, and how local consumer responses affect the measurement of the aggregated real interest rate in an economy. Finally, the understanding of the scope for consumers to respond to economic shocks has implications for the measurement of consumption inequality and purchasing power in an economy.

It is important to note that while not all consumers in a given local market are (equally) affected by an economic downturn, the effects estimated in our paper are average effects over all households. An interesting venue for future research would be to combine detailed household-level data on shopping behavior with household-level data on employment status. This would allow a more direct measurement of the ways becoming unemployed affects shopping behavior.

Appendix A Alternative specification

Table 7: Cyclicality of category prices – extreme values dropped

	Category price	Category price	Category price	Category price
Unemployment rate	−0.13847***	−0.15163***	−0.16427***	−0.16765***
	(0.03964)	(0.04155)	(0.03882)	(0.04074)
Decomposition				
$\Delta^{Laspeyre}$	−0.01899**	−0.01990***	−0.01533*	−0.01620**
	(0.00768)	(0.00751)	(0.00807)	(0.00789)
$\Delta^{Products}$	−0.00358	−0.00315	−0.00920	−0.00427
	(0.01651)	(0.01593)	(0.01728)	(0.01670)
Δ^{Stores}	−0.01461***	−0.01074**	−0.01688***	−0.01242***
	(0.00530)	(0.00441)	(0.00559)	(0.00465)
$\Delta^{Shopping}$	−0.01526	−0.02203	−0.02401	−0.02660
	(0.01763)	(0.01704)	(0.01845)	(0.01786)
$\Delta^{Interaction}$	−0.01055	−0.00394	−0.01047	−0.00365
	(0.00709)	(0.00670)	(0.00744)	(0.00702)
$\Delta^{Discounts}$	−0.07549***	−0.10452***	−0.07573***	−0.10450***
	(0.02021)	(0.02034)	(0.02116)	(0.02130)
Observations	8,378,469	8,501,788	7,339,874	7,460,478
Panels	1,644,486	1,615,344	1,259,854	1,237,755
Households	87,307	87,172	54,211	54,206
Household set	Full	Full	Restricted	Restricted
Product set	Full	Restricted	Full	Restricted
Market span	Labor market	Labor market	Labor market	Labor market

Notes: The standard errors reported in parentheses are clustered at the household-level. Panels is the number of distinct household category combinations. The restricted household set only includes customers who were active in at least half of the months in the sample period. The restricted product set is derived as follows: we rank the products in each category (in descending order) by total expenditure in the entire sample period, and keep all products until the cumulative expenditure share reaches 0.95. Market is defined by labor market regions. We drop observations where the log-difference between the average quarterly price price at the household-product-store level and the category-level average (across all products, stores, households and time periods) exceeds two.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Appendix B Theoretical Framework

To organize thinking about the transmission mechanism from local economic conditions to shopping behavior, we present the model from Aguiar and Hurst [2007] and Nevo and Wong [2019] used for the study of life-time prices and shopping behavior over the business cycle respectively. The underlying assumption is that business cycle variation in the opportunity cost of time induces households to spend more time looking for lower prices, and that unemployment induces substitution in the consumption bundle. These mechanisms are captured in the comparative statics of s and Q with respect to C and μ below.

Within a period the household minimizes the cost of reaching a consumption level, C, at a given cost of time, μ. To reach the desired level of consumption the household exerts effort, h, to enhance inputs purchased in the market, Q, in order to produce the final consumption good. Furthermore, the household can exert effort, s, to search for lower prices, $p(s, \mathbb{N})$. We assume that the marginal gross return to search is always positive and declining in search effort, i.e., $\partial p(s, \mathbb{N})/\partial s < 0$ and $\partial^2 p(s, \mathbb{N})/\partial s^2 > 0$. As in Aguiar and Hurst [2007] and Nevo and Wong [2019] the price vector can be described by aspects other than price, these are captured in $\mathbb{N}$. Among the properties are the product itself, Q. We assume that the conditions for an interior maximum are satisfied. This implies that η is a positive Lagrange multiplier measuring the marginal cost of consumption. The described problem results in the following optimization problem and first-order conditions

$$\begin{aligned} \underset{Q,h,s}{\text{minimize}} \quad & p(s, \mathbb{N})Q + \mu\,(h+s) \\ \text{subject to} \quad & f(Q,h) = C \end{aligned}$$

$$-\frac{\partial p}{\partial s}Q = \mu \tag{12}$$

$$\frac{\partial f}{\partial h}\eta = \mu \tag{13}$$

$$p(s, \mathbb{N}) + \frac{\partial p}{\partial Q}Q = \frac{\partial f}{\partial Q}\eta \tag{14}$$

The optimal allocation of time is described by the agent equating the marginal returns to shopping and household production to the opportunity cost of time, μ. In the following I assume that $\partial p/\partial Q = 0$. Dividing equation 13 by equation 14 gives the familiar result that the inputs to production are chosen such that their marginal rate of transformation equals their relative price.

$$\frac{\partial f/\partial h}{\partial f/\partial Q} = \frac{\mu}{p(s)} \tag{15}$$

Business Cycle: Comparative Statics with respect to μ and C

μ

If the opportunity cost of time decreases, we would expect the household to spend more time to produce the same level of consumption. However, whether both time in home production and search effort increase is not obvious. For prices to decrease when the opportunity cost of time decreases, time and market goods must be sufficiently "unsubstitutable" in home production. To see why, assume that the household does not change its search effort such that the price of market goods $p(s)$ is unchanged. By equation 15, the household increases the use of time relative to market goods in production. This will come about as an increase in h and a decrease in Q. When the purchased quantity of market goods falls, the marginal benefits of search decline. However, there is a direct effect of the opportunity cost of time on search effort which will tend to increase the effort spent looking for lower prices. Hence, the substitutability of time and market goods in home production versus the elasticity of the price with respect to search effort is crucial in determining the effect of changed opportunity cost of time on prices paid by households.

C

Assume that the desired level of final consumption falls. Holding time spent searching for low prices constant, this reduces the time needed in home production and the amount of goods purchased in the market. This in turn reduces the returns to search for low prices and we would expect to see a decline in search effort and higher prices. A higher price of market goods will lead to substitution toward time in home production, further reducing the incentives to search for low prices.

Sources of Business Cycle Variation in μ and C

We consider variation in household income and available time to be the main sources of variation in the opportunity cost of time and consumption over the business cycle. Here we consider how changes in current and future employment prospects might affect the within-period opportunity cost of time and desired final consumption. We first consider the case when labor supply is along the intensive margin and then along the extensive margin. In both cases we abstract from potential search effort in the labor market as a consequence of being unemployed.

To understand the potential sources of business cycle variation in the opportunity cost of time and consumption, we embed the home production model of Aguiar and Hurst [2007] and Nevo and Wong [2019] in an intertemporal setting as follows. Assume that the household derives utility from final consumption and leisure and can save in a bond. If the employment is along the extensive margin, hours worked and income are given by $n_t = \bar{n}\mathbb{I}_t, y_t = \bar{y}\mathbb{I}_t$, where $\mathbb{I}_t = 1$ and $\mathbb{I}_t = 0$ if unemployed. If employment is along the extensive margin, the household chooses hours optimally given a wage rate w_t and labor income $w_t n_t$. This results in the following maximization problem

$$max \qquad \sum_{t=0}^{\infty} \beta^t u\left(c_t, l_t\right) \tag{16}$$

$$s.t. \qquad p\left(s_t\right) q_t + b_t = R b_{t-1} + y_t \qquad (\lambda_t) \tag{17}$$

$$c_t = f\left(h_t, q_t\right) \qquad (\kappa_t) \tag{18}$$

$$l_t = 1 - n_t - s_t - h_t$$

The variables q, p, s and h have the same interpretation as previously. b_t is the amount saved in period t, y_t is labor income, and n_t is the share of the time endowment devoted to market work. The problem has the following first-order conditions

$$b_t : \quad \lambda_t = R\beta\lambda_{t+1} \tag{19}$$

$$c_t : \quad \frac{\partial u}{\partial c_t} = \kappa_t \tag{20}$$

$$n_t : \quad \frac{\partial u}{\partial l_t} = w_t\lambda_t \tag{21}$$

$$q_t : \quad \left[p\left(s_t\right) + \frac{\partial p}{\partial q_t}q_t\right]\lambda_t = \frac{\partial f}{\partial q_t}\kappa_t \tag{22}$$

$$s_t : \quad -\frac{\partial p}{\partial s_t}q_t\lambda_t = \frac{\partial u}{\partial l_t} \tag{23}$$

$$h_t : \quad \frac{\partial f}{\partial h_t}\kappa_t = \frac{\partial u}{\partial l_t} \tag{24}$$

Define $\eta_t \equiv \kappa_t/\lambda_t$ and $\mu_t \equiv \frac{\partial u/\partial l_t}{\lambda_t}$ such that equations 22, 23, and 24 can be rewritten as

$$p\left(s_t\right) + \frac{\partial p}{\partial q_t}q_t = \frac{\partial f}{\partial q_t}\eta_t$$
$$-\frac{\partial p}{\partial s_t}q_t = \mu_t$$
$$\frac{\partial f}{\partial h_t}\eta_t = \mu_t$$

Conditional on a value of c_t and μ_t these equations along with equation 18 make up a system of four equations in four unknowns (q_t, h_t, s_t, η_t), mirroring the first-order conditions of the cost minimization problem. Intuitively, maximizing life-time utility implies minimizing costs within periods. The intertemporal problem allows us to consider how employment status and real wages affect the within-period consumption level and opportunity cost of time.

When labor supply is along the intensive margin, the opportunity cost of time is equal to the real wage. That is, μ moves one-for-one with the real wage in each period. Based on the comparative statics above, we would predict lower real wages, ceteris paribus, lead to greater search effort and lower transaction prices for the affected households. Depending on how strong the effect of temporary real wage changes are on labor supply, and therefore life-time income, the effect on transaction prices might be undone through effects on desired consumption. A decline in desired consumption reduces purchases of market goods and therefore reduces the marginal benefit of looking for lower prices. For this channel to dominate, the decline in income would have to be long-lasting and/or uninsured.

For households that determine labor supply on the extensive margin, the opportunity cost of time is given by the marginal rate of substitution between leisure and market goods. That is, the ratio of marginal utility of leisure to the marginal utility of market income. Assume that a household is employed and expects to be employed at the same salary for the foreseeable future. The household then becomes unemployed. Becoming unemployed increases time available, allowing for more leisure. Holding the marginal utility of market income/wealth constant and assuming leisure increases, the marginal utility of leisure falls and the opportunity cost of home production/search falls. In addition, job loss will tend to decrease life-time income, which in turn will increase the marginal utility of market income and lead to a further decline in the opportunity cost of time. As before, the decline in consumption of market goods will reduce the returns to search in product markets and the effect on transaction prices might be ambiguous.

To conclude, the two models have similar predictions regarding business cycle fluctuations in final consumption, but they differ in how the opportunity cost of time is determined. This might be clearer if we consider the response to an anticipated future reduction in real wages or expected transition to unemployment. When labor supply is determined along the intensive margin, there is no change in the opportunity cost of time in response to the news of lower future wages as today's opportunity cost is equal to the current real wage. We would therefore expect to see an increase in transaction prices as final consumption is reduced. In contrast, a household that supplies labor along the extensive margin will reduce final consumption and experience a fall in the opportunity cost of time.

Appendix C Product categories

The table lists the categories included in the analysis. The Total column reports the expenditure share of the category in the transaction-level data set (including all categories), while Included column reports the expenditure share of the category in the data set used for the main analyses.

Table 8: Product categories

Product category	**Total**	**Cum. total**	**Included**	**Cum. included**
Beer	0.0477	0.0477	0.1472	0.1472
Soft drinks	0.0351	0.0828	0.1083	0.2555
White cheese, semi-hard	0.0221	0.1049	0.0681	0.3236
Milk, low-fat	0.0192	0.1240	0.0592	0.3828
Beef, minced	0.0137	0.1378	0.0424	0.4252
Ham	0.0132	0.1510	0.0408	0.4661
Eggs	0.0117	0.1627	0.0361	0.5022
Coffee, ground	0.0103	0.1730	0.0316	0.5338
Pizza, frozen	0.0099	0.1828	0.0304	0.5643
Chocolate, bars	0.0095	0.1923	0.0293	0.5936
Bread, whole grain	0.0090	0.2013	0.0278	0.6214
Chicken, raw fillets	0.0089	0.2102	0.0275	0.6488
Orange juice	0.0086	0.2188	0.0265	0.6754
Potato chips	0.0085	0.2273	0.0263	0.7016
Beef, steaks	0.0080	0.2354	0.0248	0.7264
Sausages	0.0065	0.2419	0.0201	0.7465
Toilet tissue	0.0058	0.2477	0.0178	0.7643
Fish, fresh	0.0057	0.2534	0.0176	0.7819
Bread, semi whole-grain	0.0053	0.2586	0.0163	0.7982
Sour cream	0.0052	0.2638	0.0160	0.8142
Milk, full	0.0043	0.2682	0.0134	0.8276
Chocolate, snack bars	0.0041	0.2723	0.0126	0.8402

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Table 8 – continued from previous page

Product category	Total	Cum. total	Included	Cum. included
Yoghurt, fruit	0.0039	0.2762	0.0121	0.8523
Butter	0.0031	0.2793	0.0096	0.8619
Mackerel, tinned	0.0030	0.2822	0.0092	0.8711
Milk, skimmed	0.0029	0.2852	0.0091	0.8801
Toothpaste	0.0027	0.2879	0.0085	0.8886
Fish, frozen salmon and trout	0.0026	0.2906	0.0081	0.8967
Carbonated water, flavoured	0.0024	0.2930	0.0074	0.9041
Tortillas	0.0024	0.2953	0.0073	0.9114
Diapers	0.0023	0.2976	0.0071	0.9186
Pork, steaks	0.0022	0.2998	0.0068	0.9253
Fish, frozen whitefish	0.0019	0.3017	0.0057	0.9311
Coffee, instant	0.0018	0.3034	0.0054	0.9365
Dishwasher detergent, tablets	0.0017	0.3052	0.0053	0.9418
Shampoo	0.0017	0.3068	0.0051	0.9470
Laundry detergent, liquid	0.0016	0.3084	0.0049	0.9518
Breakfast cereals	0.0015	0.3099	0.0046	0.9565
Beer, alcohol free	0.0015	0.3114	0.0046	0.9611
Carbonated water, not flavoured	0.0015	0.3129	0.0046	0.9657
Laundry detergent, powder	0.0015	0.3144	0.0045	0.9702
Ketchup	0.0013	0.3156	0.0039	0.9741
Müsli	0.0012	0.3168	0.0037	0.9778
Salsa	0.0011	0.3179	0.0034	0.9812
Dishwasher detergent, powder	0.0011	0.3190	0.0033	0.9845
Tomatoes, tinned	0.0009	0.3199	0.0029	0.9874
Still water, not flavoured	0.0008	0.3208	0.0026	0.9900
Sanitary napkins	0.0008	0.3216	0.0026	0.9926
Pantyliners	0.0008	0.3224	0.0026	0.9951
Spaghetti	0.0007	0.3232	0.0022	0.9973
Still water, flavoured	0.0006	0.3237	0.0018	0.9991

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Table 8 – continued from previous page

Product category	Total	Cum. total	Included	Cum. included
Laundry detergent, tablets	0.0003	0.3240	0.0009	1.0000

Appendix D Business cycle measures

Table 9: County-level unemployment

County	Month	Unemployment
Akershus	2013m1	2.3
Aust-Agder	2013m1	3.5
Buskerud	2013m1	2.5
Finnmark	2013m1	3.7
Hedmark	2013m1	2.9
Hordaland	2013m1	2.1
Møre og Romsdal	2013m1	2.1
Nord-Trøndelag	2013m1	2.5
Nordland	2013m1	3.1
Oppland	2013m1	2.6
Oslo	2013m1	3.4
Østfold	2013m1	3.6
Rogaland	2013m1	1.8
Sogn og Fjordane	2013m1	2.0
Sør-Trøndelag	2013m1	2.5
Telemark	2013m1	3.6
Troms	2013m1	2.3
Vest-Agder	2013m1	3.1
Vestfold	2013m1	3.2
Akershus	2016m1	2.7
Aust-Agder	2016m1	4.7
Buskerud	2016m1	3.1
Finnmark	2016m1	3.8
Hedmark	2016m1	2.6
Hordaland	2016m1	3.5
Møre og Romsdal	2016m1	3.3

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Table 9 – continued from previous page

County	Month	Unemployment
Nord-Trøndelag	2016m1	2.9
Nordland	2016m1	2.9
Oppland	2016m1	2.4
Oslo	2016m1	3.6
Østfold	2016m1	3.6
Rogaland	2016m1	4.8
Sogn og Fjordane	2016m1	2.4
Sør-Trøndelag	2016m1	3.0
Telemark	2016m1	4.0
Troms	2016m1	2.3
Vest-Agder	2016m1	4.1
Vestfold	2016m1	3.3
Akershus	2018m6	1.8
Aust-Agder	2018m6	2.5
Buskerud	2018m6	2.3
Finnmark	2018m6	2.7
Hedmark	2018m6	1.7
Hordaland	2018m6	2.5
Møre og Romsdal	2018m6	2.2
Nordland	2018m6	1.7
Oppland	2018m6	1.4
Oslo	2018m6	2.4
Østfold	2018m6	2.6
Rogaland	2018m6	2.6
Sogn og Fjordane	2018m6	1.3
Telemark	2018m6	2.4
Troms	2018m6	1.5
Trøndelag	2018m6	1.9
Vest-Agder	2018m6	2.4

Continued on next page

Table 9 – continued from previous page

County	Month	Unemployment
Vestfold	2018m6	2.7

Table 10: Municipality-level unemployment in Rogaland

Municipality	**Month**	**Unemployment**
Bjerkreim	2013m1	0.7
Bokn	2013m1	1.4
Eigersund	2013m1	1.5
Finnøy	2013m1	0.7
Forsand	2013m1	2.5
Gjesdal	2013m1	1.8
Hå	2013m1	1.8
Haugesund	2013m1	2.8
Hjelmeland	2013m1	0.7
Karmøy	2013m1	2.3
Klepp	2013m1	1.5
Kvitsøy	2013m1	1.9
Lund	2013m1	1.7
Randaberg	2013m1	1.1
Rennesøy	2013m1	1.0
Sandnes	2013m1	1.9
Sauda	2013m1	1.7
Sokndal	2013m1	1.2
Sola	2013m1	1.5
Stavanger	2013m1	1.6
Strand	2013m1	1.8
Suldal	2013m1	1.6
Time	2013m1	1.7
Tysvær	2013m1	1.6
Utsira	2013m1	0.8
Vindafjord	2013m1	1.7
Bjerkreim	2016m1	3.1
Bokn	2016m1	3.1

Continued on next page

Table 10 – continued from previous page

Municipality	Month	Unemployment
Eigersund	2016m1	5.2
Finnøy	2016m1	2.1
Forsand	2016m1	3.3
Gjesdal	2016m1	4.8
Hå	2016m1	3.2
Haugesund	2016m1	6.2
Hjelmeland	2016m1	3.0
Karmøy	2016m1	4.9
Klepp	2016m1	4.5
Kvitsøy	2016m1	2.1
Lund	2016m1	9.3
Randaberg	2016m1	4.4
Rennesøy	2016m1	3.4
Sandnes	2016m1	5.6
Sauda	2016m1	2.7
Sokndal	2016m1	4.3
Sola	2016m1	5.1
Stavanger	2016m1	5.0
Strand	2016m1	4.9
Suldal	2016m1	0.9
Time	2016m1	4.0
Tysvær	2016m1	2.7
Utsira	2016m1	NA
Vindafjord	2016m1	2.6
Bjerkreim	2018m6	1.2
Bokn	2018m6	1.4
Eigersund	2018m6	2.8
Finnøy	2018m6	1.4
Forsand	2018m6	2.3

Continued on next page

Table 10 – continued from previous page

Municipality	Month	Unemployment
Gjesdal	2018m6	2.6
Hå	2018m6	2.1
Haugesund	2018m6	2.8
Hjelmeland	2018m6	1.3
Karmøy	2018m6	2.3
Klepp	2018m6	2.2
Kvitsøy	2018m6	1.4
Lund	2018m6	1.0
Randaberg	2018m6	2.3
Rennesøy	2018m6	2.5
Sandnes	2018m6	3.0
Sauda	2018m6	1.4
Sokndal	2018m6	1.4
Sola	2018m6	3.0
Stavanger	2018m6	2.9
Strand	2018m6	2.4
Suldal	2018m6	0.7
Time	2018m6	2.2
Tysvær	2018m6	1.5
Utsira	2018m6	NA
Vindafjord	2018m6	2.8

Table 11: Additonal business cycle measures

Municipality	**Year**	**Disposable income**	**Gross product**	**Wage cost**
Akershus	2013	536000	224537	143125
Aust-Agder	2013	462000	33750	22398
Buskerud	2013	465000	94282	62130
Finnmark	2013	454000	26063	17659
Hedmark	2013	430000	59093	38156
Hordaland	2013	488000	226218	141186
Møre og Romsdal	2013	480000	108996	65959
Nord-Trøndelag	2013	462000	41824	27878
Nordland	2013	452000	83443	52057
Oppland	2013	436000	56313	36562
Oslo	2013	410000	459605	273353
Østfold	2013	442000	81475	54222
Rogaland	2013	532000	226278	150557
Sogn og Fjordane	2013	486000	40746	25338
Sør-Trøndelag	2013	463000	123555	79044
Telemark	2013	442000	55764	35318
Troms	2013	457000	59616	38158
Vest-Agder	2013	468000	68798	43063
Vestfold	2013	455000	74917	50452
Akershus	2016	573000	255988	165857
Aust-Agder	2016	489000	37728	24074
Buskerud	2016	500000	105219	68259
Finnmark	2016	493000	31874	18995
Hedmark	2016	463000	68471	43283
Hordaland	2016	517000	244246	149038
Møre og Romsdal	2016	509000	113118	70447
Nord-Trøndelag	2016	497000	48397	30307
Nordland	2016	485000	98737	57447

Continued on next page

Table 11 – continued from previous page

Municipality	**Year**	**Disposable income**	**Gross product**	**Wage cost**
Oppland	2016	472000	65780	41868
Oslo	2016	446000	516690	308924
Østfold	2016	477000	93495	60838
Rogaland	2016	547000	231403	158615
Sogn og Fjordane	2016	516000	48187	28429
Sør-Trøndelag	2016	500000	143387	88442
Telemark	2016	473000	62445	38737
Troms	2016	493000	71758	44217
Vest-Agder	2016	495000	71959	45866
Vestfold	2016	489000	86107	56465

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