Gauging the Effects of the German COVID-19 Fiscal Stimulus Package*

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Abstract

To alleviate the economic costs of the COVID-19 pandemic, the German government set up a huge fiscal stimulus package. Simulations in a dynamic New Keynesian multi-sector general equilibrium model indicate that it notably stabilizes output and consumption. Cumulated over 2020-2022, output can be stabilized by over 4 PP. On average, the welfare costs of the pandemic are reduced by around 5% and by 20% for liquidity-constrained households. The long-run present value output multiplier amounts to around 0.2. The reduction of consumption taxation and direct transfers to households notably back consumption by liquidity-constrained consumers and stabilize output in both the short and the medium run. Subsidies for firms prevent defaults and also stabilize the economy in the medium run, but are quite costly. Public investment is the most cost-effective measure, but pays off rather in the long run. The paper sheds light on the question as to which fiscal measures have so far helped to mitigate the impact of the crisis and may provide guidance for possible future fiscal stimulus packages.

Keywords: Fiscal Policy, COVID-19, DSGE Modelling, Sectoral Heterogeneity

JEL classification: E1, E2, E62, H2, H30

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1 Introduction

The COVID-19 pandemic and the resulting lockdown measures have caused a major economic recession around the world, and also weighed heavily on the German economy. To alleviate its impact, fiscal policy makers in Germany set up a large stabilization and stimulus package, including transfers to households and firms, easy access to publicly subsidized credit, tax relief and higher public (investment) spending. In this paper, we take a look at the core elements of these measures through the lens of a dynamic New Keynesian multi-sector general equilibrium model. To do so, we compare how key macroeconomic variables are expected to evolve after the COVID-19 pandemic (i.) without and (ii.) with the fiscal stimulus package. We also analyze the impact of each individual measure as well as fiscal multipliers and welfare implications.

Our analytical framework is based on a New Keynesian multi-sector general equilibrium model along the lines of Bouakez, Rachedi, and Santoro (2018, 2020) featuring multiple interrelated production sectors that vary in their degree of price rigidity, factor intensities, use of intermediate inputs, and contribution to final demand. Since Germany is an export-oriented country, we introduce international trade following Bergholt and Sveen (2014). Hence, the different sectors do not only trade goods with each other, but can also trade with firms abroad. As a simplification, we model Germany as a small open economy. The seven sectors included follow the NACE classification and comprise agriculture, forestry and fishing, mining and carrying, energy and water supply and manufacturing. combination of trade, transporting, storage, accomodation and food service activities forms the fourth sector, followed by IT and communication, professional, scientific and technical as well as administrative and support service activities, and art, entertainment and recreation, including other services activities. To evaluate the impact of fiscal measures on firms, the effects on their survival probabilities might be of importance. We thus allow for firms defaulting, following Agnor, Pierre-Richard and Bratsiotis, George J. and Pfajfar, Damjan (2014) by introducing a working capital channel and assuming that firms can default on loans previously granted. In our setup, sector-specific default rates differ, and so do the corresponding loan credit spreads. To evaluate the effects of transfers to households, we choose a TANK (two-agent New Keynesian) model specification. Hence, we allow for two different types of agents, liquidity-constrained consumers (also called rule-of-thumb (RoT) agents) and optimizers who own firms, banks and physical capital.

The economic effects of the COVID-19 pandemic are assessed by performing a conditional forecast based on the (projected) evolution of key macroeconomic variables (such as consumption, working hours, exports, etc.). To obtain a baseline pandemic scenario without fiscal intervention, we keep the identified COVID-19 shocks and exclude the fiscal shocks. Hence, we refrain from explicitly combining an epidemic and an economic model (as in, for example, Atkeson (2020), and Eichenbaum, Rebelo, and Trabandt (2020)). Moreover, we neither contribute to the discussion about the extent to which the economic recession is driven by the pandemic itself or by lockdowns and how this might affect the impact of fiscal interventions (see e.g. Auray and Eyquem (2020)). Nor do we touch upon the debate about the design of containment measures (see e.g. Berger, Herkenhoff, Huang, and Mongey (2020) and Chari, Kirpalani, and Phelan (2020)) or potential adverse economic side effects of lockdowns.[1]

According to our simulation, the pandemic leads to a drop in aggregate output by around 17% relative to the steady-state when ignoring fiscal interventions. Consumption falls by around 13%, capital investment by 21% and hours worked by around 13%. These numbers are similar to results for Germany found by Chudik, Mohaddes, Pesaran, Raissi, and Rebucci (2020) in a threshold-augmented global VAR analysis. We additionally identify significant sectoral differences. The manufacturing, cultural as well as trade, transport, accomodation and food services sector face the largest losses in output with up to 22%. Especially the cultural sector is hit quite persistently due to repeated and prolonged lockdown measures.

As regards stabilization, the German fiscal stimulus measures are able to mitigate aggregate output losses by up to 4 percentage points (PP) cumulated over 2020-2022, ignoring additional effects from automatic stabilizers, equity injections and credit guarantees. On the firm side, subsidies essentially decrease operating costs, partly by preventing firm defaults, which in turn reduces loan interest rates. On the household side, disposable income and consumption is stabilized by lower consumption and labor taxes as well as transfers. Specifically liquidity-constrained households benefit substantially due to stabilized consumption. However, the stimulus measures are quite costly, implying that, in 2020 and 2021, they amount to 4.6% of GDP in total. In 2021/22, the debt-to-GDP ratio increases by around 5 PP more (to 72%) relative to a scenario without fiscal interventions.

In terms of sectoral differences, we find that, relative to the sectoral drops in output without fiscal intervention and to the other sectors, the mining, energy and water supply sector benefits most, while the professional scientific and technical services as well as the cultural sector come off worst in 2020. This is partly due to the fact that the latter is rarely used as an intermediate input and, hence, positive effects in other sectors do not spill over. However, it is also because of what we impose on the distribution of transfers and subsidies. In our baseline simulation, we assume that subsidies are granted to the different sectors according to their steady-state shares in production. This might be subject to change once we have more detailed information on who exactly asks for (and is granted) subsidies and who is not. The more subsidies are granted to a sector, the better off is this sector (in relative terms).

The simulation-implied present value output multiplier peaks at about 0.26 in the second half of 2020 and reaches 0.2 in the long run. In terms of a cost-benefit analysis (by comparing the impact of the primary deficits of the measure and its impact on output), we find that increasing public investment is by far the most effective measure driven by the assumption of private-sector productivity enhancing public capital.

[1] However, the need for restrictions to fight the pandemic appears to be widely acknowledged in the literature. See, for example, Alvarez, Argente, and Lippi (2020), Banerjee, Pasea, Harris, Gonzalez-Izquierdo, Torralbo, Shallcross, Noursadeghi, Pillay, Sebire, Holmes, Pagel, Wong, Langenberg, Williams, Denaxas, and Hemingway (2020), Boissay, Rees, and Rungcharoenkitkul (2020), Dehning, Zierenberg, Spitzner, Wibral, Neto, Wilczek, and Priesemann (2020), Glogowsky, Hansen, and Schächtele (2020), and Quaas, Meya, Schenk, Bos, Drupp, and Requate (2020). Furthermore, Eichenbaum et al. (2020) and Farboodi, Jarosch, and Shimer (2020) show that the economic costs could have been almost just as high without lockdown measures, especially if it is assumed that the public health care system would have been overwhelmed without these measures (and mortality rates would have been significantly higher). The reason for this is a "voluntary lockdown/distancing" by rational agents (see also Born, Dietrich, and Müller, 2020, for a discussion).

Our simulations indicate that households in our model would be willing to give up over 3% of their steady-state consumption on average in order to avoid the COVID-19 recession. Bearing in mind that the costs of business cycles are typically less than 1% of steady-state consumption (see Gali, Gertler, and Lopez-Salido, 2007, and Imrohoroglu, 2008, for a discussion), this shows that the current recession is truly a major challenge to society. The fiscal package set up by the German government reduces these costs on average by around 5% according to our model simulations, while the welfare losses of liquidity-constrained households can be decreased by 20%. Kaplan, Moll, and Violante (2020) find an even larger value for the US economy in a HANK model that features more heterogeneity than our TANK economy does. Hacıoğlu-Hoke, Känzig, and Surico (2021) also report that low-income households have benefited most from government support in the UK.

Our paper is closely related to the literature studying the effects of economic policy responses to the current pandemic crisis, including, amongst others, Bayer, Born, Luetticke, and Müller (2020), Elenev, Landvoigt, and Van Nieuwerburgh (2020), e Castro (2021), Kaplan et al. (2020), Pfeiffer, Roeger, and in't Veld (2020) and Boscá, Doménech, Ferri, García, and Ulloa (2021). These first four papers analyze the impacts of various fiscal measures as a response to the COVID-19 crisis in the United States. The latter two investigate the effects of short-term work allowances and liquidity guarantees in the European Union and the stabilizing effects of the Spanish fiscal response to the Covid-19 crisis. Arellano, Bai, and Mihalache (2020) and Hürtgen (2020) address fiscal stability issues due to the pandemic, which we entirely ignore in this analysis (as they are, most likely, less important in Germany). Christl, Poli, Hufkens, Peichl, and Ricci (2021) analyse the effects of short-time working scheme and discretionary measures on household income, relying on a micro-level approach and find the one-off payments to be a beneficial tool to support poorer households. That the pandemic affected different sectors differently is documented e.g. in Baqaee and Farhi (2020) and Darougheh (2021). To the best of our knowledge, our paper is the first to focus on the effects of Germany's discretionary policy responses to the pandemic (including the adopted fiscal stimulus package) using a multi-sector general equilibrium model.

It should be stressed that the results presented in this paper are based on available data from the national accounts including 2021:Q1 and on (projections) of fiscal data issued in June 2021, which still includes a large amount of uncertainty, especially concerning the speed of the recovery (see e.g. also Rees, 2020). As indicated in Keeling, Guyver-Fletcher, Holmes, Dyson, Tildesley, Hill, and Medley (2020) and Linden, Dehning, Mohr, Mohring, Meyer-Hermann, Pigeot, Schöbel, and Priesemann (2020) for the second wave, the economy was hit by another wave of pandemic shocks, and additional lockdown measures were already undertaken. Does this mean that our analysis is outdated? Quite the contrary. It highlights which fiscal policy measures help mitigate the pandemic losses to what extent so far and, hence, gives guidance on how to set up potentially additional fiscal stimulus programs. Moreover, future research on the effects of the pandemic should also focus on the long-term consequences (as discussed in, for example, Jordà, Òscar and Singh, Sanjay R and Taylor, Alan M, 2020) and the question of whether fiscal policy is capable of stabilizing the economy in the long run, too (see also Priesmeier and Stähler, 2011).

The rest of the paper is organized as follows. In Section 2, we present the model.

The calibration of the model is detailed in Section 3. The simulation design is laid out in Section 4. Section 5 discusses the results. Section 6 concludes.

2 The model

In this section, we lay out the structure of our multi-sector general equilibrium framework. After a description of the household sector, we describe how labor and capital are distributed to the various sectors. Next, we detail the firm and the banking sectors, the fiscal authorities and the (international) market clearing conditions. While the model resembles to a large extent a prototypical New Keynesian small open economy model, it is the multi-sector production structure which stands out in our framework. The interlinked sectors show heterogeneity along several dimensions (price setting, factor intensities, use of intermediate inputs and contribution to aggregate demand). Furthermore, we allow for sector-specific firm default. Unless otherwise indicated, we express model variables in per-capita terms. Total population size is normalized to one.

2.1 Households

Following Gali, Lopez-Salido, and Valles (2007), we assume that the economy is populated by a share $\mu \in [0,1)$ of liquidity-constrained households (rule-of-thumb consumers), who do not participate in asset markets and consume their entire income each period, and a remaining share $(1-\mu)$ of capital and firm owners (optimizers). They are labeled by the superscript $i = o, r$ for optimizing and rule-of-thumb households, respectively. The utility function of each type of representative household in group i at time t is given by

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\epsilon_t^C \frac{{C_t^i}^{1-\sigma}}{1-\sigma} - \kappa_N \epsilon_t^{\kappa_N} \frac{{N_t^i}^{1+\zeta}}{1+\zeta} \right], \tag{1}$$

where C_t^i denotes consumption of a type-i household and N_t^i labor supply. The parameter $\sigma \leqslant 0$ denotes the inverse of the elasticity of intertemporal substitution for consumption, while $\zeta \geqslant 0$ is the inverse of the Frisch elasticity of labor supply, and κ^N measures the relative weight of the disutility of labor. E_0 is the expectations operator E_t at time $t = 0$, ϵ_t^C a consumption preference shock, and $\epsilon_t^{\kappa N}$ a labor disutility shock, which we describe in detail later.

Optimizing households consume, supply labor, invest in physical capital, K_t, which pays a return r_t^k, buy public debt, B_t^o, and deposit interest-bearing savings, D_t^o, with banks to maximize their utility (1) for $i = o$ subject to the CPI-deflated real budget constraint

$$\begin{aligned}(1+\tau_t^c) C_t^o + B_t^o + D_t^o + \frac{P_t^I}{P_t^C} I_t^o + \frac{P_t^I}{P_t^C} S\left(I_t^o, K_{t-1}^o\right) K_{t-1}^o + T_t^o = (1-\tau_t^w) w_t N_t^o \\ + R_{t-1}^d \frac{D_{t-1}^o}{\pi_t^C} + R_{t-1} \frac{B_{t-1}^o}{\pi_t^C} + \left[\left(1-\tau_t^k\right) r_t^k + \delta^k \tau_t^k\right] K_{t-1}^o + TR_t^o + \Pi_t^o + \Psi_t. \end{aligned} \tag{2}$$

While P_t^C denotes the consumer price index (CPI), which will be derived in detail later, $\pi_t^C = P_t^C / P_{t-1}^C$ is CPI inflation, w_t is the real wage rate, R_t^d represent real gross interest payments on outstanding deposits, R_t are real interest payments on outstanding public debt, TR_t^o (T_t^o) are per-capita lump-sum transfers (taxes), Π_t^o denote firm profits and Ψ_t are bank dividends stemming from the ownership of firms and banks. τ_t^c, τ_t^k and τ_t^w are consumption, capital income and labor income tax rates, respectively. Returns on physical capital net of depreciation allowances are taxed at rate τ_t^k. Moreover, we introduce convex capital accumulation costs of the form $S(I_t^o, K_{t-1}^o) = \kappa^I/2\left(I_t^o/K_{t-1}^o - \delta^k\right)^2$ (see, e.g., Ireland, 2003).

The law of motion for physical capital is given by:

$$K_t^o = (1-\delta^k)K_{t-1}^o + I_t^o. \tag{3}$$

We define $p_t^i = P_t^I/P_t^C$ as the relative price of investment in terms of consumption goods (because investment and consumption baskets may differ in our model). The optimization problem yields the standard first-order conditions.

Rule-of-thumb households also maximize (1) for $i = r$ with respect to labor supply subject to their real CPI-deflated budget constraint

$$(1+\tau_t^c)\,C_t^r = (1-\tau_t^w)\,w_t N_t^r + TR_t^r. \tag{4}$$

Economy-wide per-capita consumption and labor supply is calculated as $C_t = (1-\mu)C_t^o + \mu C_t^r$ and $N_t = (1-\mu)N_t^o + \mu N_t^r$, respectively. Aggregate transfers from the public to the household sector are given by $TR_t = (1-\mu)TR_t^o + \mu TR_t^r$. Household-specific variables for optimizers and rule-of-thumbers X_t^i are aggregated as $X_t = (1-\mu)X_t^o$ or $X_t = \mu X_t^r$, respectively.

Due to the multi-sector structure, we need to derive how much of aggregate consumption and investment spending $X_t \in \{C_t, I_t\}$ is channeled towards each sector $z \in Z$. In this respect, we follow Bouakez et al. (2020), and assume that households' consumption and investment goods preferences across all Z sectors in our economy are given by

$$X_t = \left[\sum_{z=1}^{Z} \psi_{x,z}^{1-\sigma_x} X_{z,t}^{\sigma_x}\right]^{\frac{1}{\sigma_x}},$$

where $X \in \{C, I\}$. Moreover, $\psi_{x,z} \in [0,1]$ for $x \in \{c, i\}$ depicts the consumption utility value (for $x = c$) and the weight in the investment goods basket (for $x = i$) attached to a good produced in sector z. The parameter $\sigma_x \in (-\infty, 1)$ governs the elasticity of substitution between these goods, which equals $1/(1-\sigma_x)$. It holds that $\sum_{z=1}^{Z} \psi_{x,z} = 1$. Given $P_{z,t}^X$ as the consumer/investor price for goods of sector z, the household aims to minimize total consumption/investment spending

$$\min_{X_{z,t}} P_t^X \left[\sum_{z=1}^{Z} \psi_{x,z}^{1-\sigma_x} X_{z,t}^{\sigma_x}\right]^{\frac{1}{\sigma_x}} - \sum_{j=1}^{Z} P_{j,t}^X \epsilon_t^{X_z} X_{j,t},$$

which implies that the consumption/investment demand of sector-z goods is determined by

$$X_{z,t} = \psi_{x,z} \left(\frac{\epsilon_t^{X_z} P_{z,t}^X}{P_t^X} \right)^{-\left(\frac{1}{1-\sigma_x}\right)} X_t, \tag{5}$$

and the consumer/investor price index can be written as

$$P_t^X = \left[\sum_{z=1}^{Z} \psi_{x,z} \left(\epsilon_t^{X_z} P_{z,t}^X \right)^{-\frac{\sigma_x}{(1-\sigma_x)}} \right]^{-\frac{(1-\sigma_x)}{\sigma_x}}, \tag{6}$$

where $\epsilon_t^{X_z}$ is a cost shifter for sector-z goods that we use to describe the loss in demand for specific goods as a result of the pandemic (either because of preferences or because of policy measures, similar to the preference shifter described in Baqaee and Farhi, 2020, and e Castro, 2021). As long as $\psi_{c,z} \neq \psi_{i,z}$ and/or $\sigma_c \neq \sigma_i$, it follows that $P_t^C \neq P_t^I$ and thus $p_t^i \neq 1$.

We additionally have to take into account that goods can be traded internationally. Hence, domestic consumers and capital investors need to decide not only which sectoral goods to purchase, but also whether to buy these goods at home or from abroad. We assume that households make this decision for each sectoral good separately. Specifically, we employ a CES aggregator for any sectoral good $X_{z,t} \in \{C_{z,t}, I_{z,t}\}$:

$$X_{z,t} = \left[hb_{x,z}^{1-\sigma_{hb,x}} X_{z,h,t}^{\sigma_{hb,x}} + (1 - hb_{x,z})^{1-\sigma_{hb,x}} X_{z,f,t}^{\sigma_{hb,x}} \right]^{\frac{1}{\sigma_{hb,x}}},$$

where $hb_{x,z}$ denotes the home bias for goods of sector z produced domestically, $\sigma_{hb,x} \in (-\infty, 1)$ determines the elasticity of substitution between those goods produced domestically or abroad, $X_{z,h,t}$ denotes the domestically produced good and $X_{z,f,t}$ the corresponding good produced abroad. Given sectoral producer prices at home and abroad, $P_{z,h,t}^X$ and $P_{z,f,t}^X$, cost minimization of $P_{z,t}^X X_{z,t} - P_{z,h,t}^X X_{z,h,t} - \epsilon_t^{z,f} P_{z,f,t}^X X_{z,f,t}$ yields

$$X_{z,h,t} = hb_{x,z} \left(\frac{P_{z,h,t}^X}{P_{z,t}^X} \right)^{-\left(\frac{1}{1-\sigma_{hb,x}}\right)} X_{z,t},$$

and

$$X_{z,f,t} = (1 - hb_{x,z}) \left(\frac{\epsilon_t^{z,f} P_{z,f,t}^X}{P_{z,t}^X} \right)^{-\left(\frac{1}{1-\sigma_{hb,x}}\right)} X_{z,t} \tag{7}$$

as the consumption/investment demand for goods of sector z produced at home or abroad. Hence, when taking into account international trade, the corresponding consumer/investor price for goods of sector z is given by

$$P_{z,t}^X = \left[hb_{x,z} \, P_{z,h,t}^X{}^{-\frac{\sigma_{hb,x}}{(1-\sigma_{hb,x})}} + (1 - hb_{x,z}) \left(\epsilon_t^{z,f} P_{z,f,t}^X \right)^{-\frac{\sigma_{hb,x}}{(1-\sigma_{hb,x})}} \right]^{-\frac{(1-\sigma_{hb,x})}{\sigma_{hb,x}}}. \tag{8}$$

Again, we allow for the home bias and the elasticity of substitution to differ across consumption and investment goods, and $\epsilon_t^{z,f}$ denotes a cost push shock on foreign goods governing losses in import demand due to the pandemic.

2.2 Labor and capital agencies

To determine the labor and capital supply that goes to each sector $z \in Z$ of our model economy, assume that perfectly competitive, representative labor and capital agencies hire the total amount of labor N_t at the real wage w_t and rent the total amount of capital K_t at the real rate r_t^k, selling it in turn to intermediate goods producers operating in Z different sectors (see also Bouakez et al., 2020). It is assumed that labor/capital input cannot perfectly move across sectors, so that

$$X_t = \left[\sum_{z=1}^{Z} \omega_{X,z}^{1-\nu_X} X_{z,t}^{\nu_X} \right]^{\frac{1}{\nu_x}},$$

for $X \in \{N, K\}$, where $\omega_{X,z}$ is the weight attached to labor/capital provided to sector z, and the elasticity of substitution of labor/capital across sectors can be derived from $\nu_X \in (-\infty, 1)$. Hence, this parameter captures the degree of labor/capital mobility between sectors. The labor agencies' optimization problem can be written as

$$\max_{X_{z,t}} \sum_{z=1}^{Z} x_{z,t} X_{z,t} - x_t \left[\sum_{z=1}^{Z} \omega_{X,z}^{1-\nu_X} X_{z,t}^{\nu_X} \right]^{\frac{1}{\nu_X}},$$

where $x_{z,t} = w_{z,t}$ and $x_t = w_t$ for $X = N$ and $x_{z,t} = r_{z,t}^k$ and $x_t = r_t^k$ for $X = K$, which leads to the following first-order condition characterizing the sector-specific demand for labor/capital:

$$X_{z,t} = \omega_{X,z} \left(\frac{x_{z,t}}{x_t} \right)^{-\left(\frac{1}{1-\nu_X}\right)} X_t. \tag{9}$$

By plugging this expression into the constant elasticity of substitution aggregator of labor/capital goods, we obtain the aggregate wage/capital interest index

$$x_t = \left[\sum_{z=1}^{Z} \omega_{X,z} x_{z,t}^{-\frac{\nu_X}{(1-\nu_X)}} \right]^{-\frac{(1-\nu_X)}{\nu_X}}. \tag{10}$$

Again, we allow for $\nu_K \neq \nu_N$ and $\omega_{K,z} \neq \omega_{N,z}$, i.e. capital and labor substitutability as well as their weights may differ.

2.3 Firms

There is a continuum of producers that combine labor, capital, and a bundle of intermediate inputs to produce differentiated varieties of goods. We assume this to hold in each sector. These varieties are aggregated into a single good in each sector by a representative wholesaler who sells these to households and investors according to the consumption/investment baskets previously described.[2] We assume that intermediate goods producing firms face convex price adjustment costs following Rotemberg (1982).

Operating under perfect competition, the representative wholesaler in sector z maximizes profits

$$\max_{y_{z,h,t}(j)} P_{z,h,t}Y_{z,h,t} - \int_0^1 P_{z,h,t}(j)y_{z,h,t}(j)dj, \tag{11}$$

subject to the production technology $Y_{z,h,t} = \left(\int_0^1 y_{z,h,t}(j)^{(\theta_{p,z}-1)/\theta_{p,z}}dj\right)^{\theta_{p,z}/(\theta_{p,z}-1)}$, where $\theta_{p,z} > 1$ determines the elasticity of substitution between varieties in each sector, $y_{z,h,t}(j)$ is the retailer's demand for each differentiated input $j \in [0,1]$, and $P_{z,h,t}(j)$ is the producer price of each input. The first-order condition for the problem is given by

$$y_{z,h,t}(j) = \left(\frac{P_{z,h,t}(j)}{P_{z,h,t}}\right)^{-\theta_{p,z}} Y_{z,h,t}, \tag{12}$$

capturing the demand for intermediate goods. By plugging the latter into the CES aggregator, we obtain $P_{z,h,t} = \left(\int_0^1 P_{z,h,t}(j)^{1-\theta_{p,z}}dj\right)^{1/(1-\theta_{p,z})}$, which is the producer price index for the home country.

Each intermediate goods producer $j \in [0,1]$ in sector z faces the technology

$$y_{z,h,t}(j) \leqslant \varepsilon_{z,t}\varrho_t(j)\; {K^g_{t-1}}^{\eta_{K^g,z}} \left(N_{z,t}(j)^{\alpha_{N,z}}K_{z,t-1}(j)^{1-\alpha_{N,z}}\right)^{\alpha_{H,z}} \left(H_{z,t}(j)\right)^{1-\alpha_{H,z}}, \tag{13}$$

where $\varepsilon_{z,t}$ is an aggregate productivity shock common to all sectors and $\varrho_t(j)$ is an ideosyncratic productivity uniform shock, distributed over the interval $(\underline{\varrho}, \overline{\varrho})$. The public capital stock is denoted by K^g_t, which is assumed to be productivity-enhancing along the lines of Leeper, Walker, and Yang (2010). The sector-specific parameter $\eta_{K^g,z} \geqslant 0$ determines how influential public capital is on sector-specific private production (see Bom and Ligthart, 2014, for a discussion).[3] $\alpha_{N,z} \in [0,1]$ and $\alpha_{H,z} \in [0,1]$ are factor intensities, and $H_{z,t}(j)$ depicts intermediate goods needed in the production process.

We introduce a working capital channel (Christiano, Trabandt, and Walentin, 2010) and assume that firms need to pay wages, interest on capital input and intermediate goods purchases *before* their own production has taken place. To do so, firm j has to take out a loan amounting to $L^f_{z,t}(j) = (1+\tau^{sc}_t)w_{z,t}N_{z,t}(j) + r^k_{z,t}K_{z,t-1}(j) + P^H_{z,t}H_{z,t}(j)$ at the beginning of the period, which it pays back with interest at the end of the period. We follow Stähler and Thomas (2012) and Gadatsch, Hauzenberger, and Stähler (2016), among others, and assume that firms have to pay social security contributions at rate τ^{sc}_t for all workers.[4] Along the lines of Agnor, Pierre-Richard and Bratsiotis, George J. and Pfajfar, Damjan (2014), some firms will default on their loans. The sector-specific interest rate for the loans, $R^l_{z,t}$, will therefore depend on the default probability within

[2]An analogous basket is assumed for government consumption and investment spending as well as for exports (all of which we will derive in more detail below).

[3]We also ran the simulations assuming that public and private capital are connected via a CES aggregator along the lines of Coenen, Straub, and Trabandt (2013). The results remain pretty much unchanged.

[4]In Germany, social security payments are split between workers and firms (see Enders, Groll, and Stähler, 2020). We assume that the part borne by workers is included in τ^w_t, while the part borne by firms is given by τ^{sc}_t.

this sector. The profit function of firm j in sector z in nominal terms is, therefore, given by

$$\begin{aligned} P_t^C \Pi_{z,t}(j) &= P_{z,h,t}(j) y_{z,h,t}(j) - R_{z,t}^l P_t^C L_{z,t}^f(j) + S_{z,t} - FC_z \\ &\quad - \frac{\kappa_z^p}{2} \left(\frac{P_{z,h,t}(j)}{P_{z,h,t-1}(j)} - 1 \right)^2 P_{z,h,t}(j) y_{z,h,t}(j), \end{aligned} \tag{14}$$

where $S_{z,t}$ are subsidies received from government, and the last term on the right-hand side of this equation depicts quadratic price adjustment costs with $\kappa_z^p \geqslant 0$. FC_z are fixed costs in sector z. Maximizing profits with respect to labor, capital and other intermediate inputs yields

$$R_{z,t}^l P_t^C w_t (1 + \tau_t^{sc}) = \alpha_{H,z} \alpha_{N,z} mc_{z,t} \frac{P_{z,h,t} y_{z,t}}{N_{z,t}}, \tag{15}$$

$$R_{z,t}^l P_t^C r_t^k = \alpha_{H,z} (1 - \alpha_{N,z}) mc_{z,t} \frac{P_{z,h,t} y_{z,t}}{K_{z,t-1}}, \tag{16}$$

$$R_{z,t}^l P_t^C P_{z,t}^H = (1 - \alpha_{H,z}) mc_{z,t} \frac{P_{z,h,t} y_{z,t}}{H_{z,t}}, \tag{17}$$

where we have dropped the index j due to the assumption of symmetry and $mc_{z,t}$ denotes real marginal costs. Optimal prices are derived from

$$\begin{aligned} &\beta E_t \left\{ \frac{\lambda_{t+1}^o}{\lambda_t^o} \kappa_z^p \left(\frac{P_{z,h,t+1}}{P_{z,h,t}} - 1 \right) \left(\frac{P_{z,h,t+1}}{P_{z,h,t}} \right)^2 \left(\frac{Y_{z,h,t+1}}{Y_{z,h,t}} \right) \left(\frac{P_t^C}{P_{t+1}^C} \right) \right\} \\ &+ 1 - \theta_{p,z} + (1 - \theta_{p,z}) mc_{z,t} = \kappa_z^p \left(\frac{P_{z,h,t}}{P_{z,h,t-1}} - 1 \right) \frac{P_{z,h,t}}{P_{z,h,t-1}}. \end{aligned} \tag{18}$$

A firm chooses to default whenever

$$\varrho_t(j) < \frac{P_t^C R_{z,t}^l L_{z,t}^f + FC_z - S_{z,t} + \frac{\kappa_z^p}{2} \left(\frac{P_{z,h,t}}{P_{z,h,t-1}} - 1 \right)^2 P_{z,h,t}(j) y_{z,h,t}(j)}{P_{z,h,t} \varepsilon_{z,t} \, {K_{t-1}^g}^{\eta_{Kg}} \left(N_{z,t}^{\alpha_{N,z}} K_{z,t-1}^{1-\alpha_{N,z}} \right)^{\alpha_{H,z}} (H_{z,t})^{1-\alpha_{H,z}}}. \tag{19}$$

This implies that an intermediate good producer declares default if its revenue after materialization of the idiosyncratic productivity shock is not high enough to cover its costs. The constraint may be alleviated by a government subsidy $S_{z,t}$. The default threshold in sector z is thus given by $\bar{\varrho}_{z,t}$, which we obtain when equation (19) holds with equality.

In order to derive the sector-specific demand for intermediate inputs of sector z, we assume that it is determined by the CES aggregator,

$$H_{z,t} = \left[\sum_{\tilde{z}=1}^{Z} \psi_{z,\tilde{z}}^{1-\sigma_z} H_{z,\tilde{z},t}^{\sigma_z} \right]^{\frac{1}{\sigma_z}},$$

where $H_{z,\tilde{z},t}$ is the demand for intermediate good $\tilde{z}$ in sector z, with $\psi_{z,\tilde{z}}$ as the weight in the basket and $\sigma_z \in (-\infty, 1)$ determining the elasticity of substitution. Hence, we get

$$H_{z,\tilde{z},t} = \psi_{z,\tilde{z}} \left(\frac{P^H_{z,\tilde{z},t}}{P^H_{z,t}} \right)^{-\left(\frac{1}{1-\sigma_z}\right)} H_{z,t}, \tag{20}$$

and

$$P^H_{z,t} = \left[\sum_{\tilde{z}=1}^{Z} \psi_{z,\tilde{z}} \, {P^H_{z,\tilde{z},t}}^{-\frac{\sigma_z}{(1-\sigma_z)}} \right]^{-\frac{(1-\sigma_z)}{\sigma_z}}. \tag{21}$$

Since firms in sector z can also decide on whether to purchase the goods from sector $\tilde{z}$ at home or from abroad, we additionally have

$$H_{z,\tilde{z},h,t} = hb_{z,\tilde{z}} \left(\frac{P^H_{z,\tilde{z},h,t}}{P^H_{z,\tilde{z},t}} \right)^{-\left(\frac{1}{1-\sigma_{hb,z}}\right)} H_{z,\tilde{z},t},$$

and

$$H_{z\tilde{z},f,t} = (1 - hb_{z,\tilde{z}}) \left(\frac{P^H_{z,\tilde{z},f,t}}{P^H_{z,\tilde{z},t}} \right)^{-\left(\frac{1}{1-\sigma_{hb,z}}\right)} H_{z,\tilde{z},t} \tag{22}$$

as the intermediate goods demand for goods of sector z produced at home or abroad, where $H_{z,\tilde{z},t} = \left[hb_{z,\tilde{z}}^{1-\sigma_{hb,z}} H^{\sigma_{hb,z}}_{z,\tilde{z},h,t} + (1 - hb_{z,\tilde{z}})^{1-\sigma_{hb,z}} H^{\sigma_{hb,z}}_{z,\tilde{z},f,t} \right]^{1/\sigma_{hb,z}}$ with $hb_{z,\tilde{z}}$ denoting the home bias of sector z towards goods produced in sector $\tilde{z}$ and $\sigma_{hb,z} \in (-\infty, 1)$ representing the elasticity of substitution. The corresponding intermediate goods price in sector z for goods of sector $\tilde{z}$ when taking into account international trade is thus given by

$$P^H_{z,\tilde{z},t} = \left[hb_{z,\tilde{z}} \, {P^H_{z,\tilde{z},h,t}}^{-\frac{\sigma_{hb,H}}{\left(1-\sigma_{hb,H}\right)}} + (1 - hb_{z,\tilde{z}}) \, {P^H_{z,\tilde{z},f,t}}^{-\frac{\sigma_{hb,H}}{\left(1-\sigma_{hb,H}\right)}} \right]^{-\frac{\left(1-\sigma_{hb,H}\right)}{\sigma_{hb,H}}}. \tag{23}$$

2.4 Banks

At the beginning of each period, the bank receives deposits from optimizers and gives loans to firms. Imposing that no reserves are required, the aggregate balance sheet of the bank is $(1 - \mu)D^o_t = \sum_{z=1}^{Z} L^f_{z,t}$. We assume that the bank faces the refinancing (policy) rate R_t. No reserve requirement and perfect competition in the deposit market, both of which are assumed for reasons of simplicity,[5] imply that $R^d_t = R_t$. Hence, optimizers receive the policy rate on their deposits from banks.

Next, we derive the sector-specific lending rate of loans granted to firms. The bank

[5] This simplification is not critical as long as it is assumed that the current COVID-19 crisis will not also have an effect on financial markets. However, if one believes that the economic crisis could generate a financial crisis, a more complex banking sector should be modeled, for example along the lines of Clerc, Derviz, Mendicino, Moyen, Nikolov, Stracca, Suarez, and Vardoulakis (2015). In this paper, we abstract from a potential financial crisis and leave this for future research.

is exposed to default risk as firms' final output is subject to idiosyncratic shocks. Let $(1-\chi_z)$, with $\chi_z \in (0,1)$, be the fraction of firms' sales $P_{z,h,t}(j)y_{z,t}(j)$ that is lost in the event of a default (as in Agnor, Pierre-Richard and Bratsiotis, George J. and Pfajfar, Damjan, 2014). Then, the bank's expected income from lending to a firm j in sector z is

$$EI_{z,t}(j) = \int_{\bar{\varrho}_{z,t}}^{\infty} R^l_{z,t}(j)L^f_{z,t}(j)\, f\left(\varrho_{z,t}\right) d\varrho_{z,t}$$
$$+ \int_{\underline{\varrho}}^{\bar{\varrho}_{z,t}} \left[\underbrace{\chi_z \frac{P_{z,h,t}(j)}{P^C_t} y_{z,t}(j) + \frac{S_{z,t}}{P^C_t} - \frac{FC_z}{P^C_t} - \frac{\kappa^p_z}{2}\left(\frac{P_{z,h,t}}{P_{z,h,t-1}} - 1\right)^2 \frac{P_{z,h,t}(j)}{P^C_t} y_{z,t}(j)}_{=\tilde{y}_{z,t}(j)} \right] f\left(\varrho_{z,t}\right) d\varrho_{z,t} \quad ,$$

where $f\left(\varrho_{z,t}\right)$ is the density function for the idiosyncratic productivity shock $\varrho_{z,t}$, where $\underline{\varrho}$ is the lowest support for the productivity value. Whenever the idiosyncratic productivity shock exceeds the default threshold, the firm repays its loan. If it does not, the bank can seize the firms' profits. However, $(1-\chi_z)P_{z,h,t}(j)y_{z,t}(j)$ is lost in this case. Using equation (19) and dropping the index j because of symmetry, we can re-write this as

$$\begin{aligned} EI_{z,t} &= R^l_{z,t}L^f_{z,t} - \int_{\underline{\varrho}}^{\bar{\varrho}_{z,t}} \left[R^l_{z,t}L^f_{z,t} - \tilde{y}_{z,t}\right] f\left(\varrho_{z,t}\right) d\varrho_{z,t}, \\ &= \left[R^l_{z,t} - \rho^l_{z,t}\right], L^f_{z,t}, \end{aligned} \tag{24}$$

where

$$\begin{aligned} \rho^l_{z,t} = \frac{1}{L^f_{z,t}} \frac{P_{z,h,t}(j)}{P^C_t} \varepsilon_z\, {K^g_{t-1}}^{\eta_{K^g}} \left(N^{\alpha_{N,z}}_{z,t} K^{1-\alpha_{N,z}}_{z,t-1}\right)^{\alpha_{H,z}} \left(H_{z,t}\right)^{1-\alpha_{H,z}} \left[1 - \frac{\kappa^p_z}{2}\left(\frac{P_{z,h,t}}{P_{z,h,t-1}} - 1\right)^2\right] \\ \cdot \int_{\underline{\varrho}}^{\bar{\varrho}_{z,t}} \left[\bar{\varrho}_{z,t} - \chi_z \varrho_{z,t}\right] f\left(\varrho_{z,t}\right) d\varrho_{z,t} \end{aligned} \tag{25}$$

is the expected loss from lending to a defaulting sector-z firms. As we will see below, this expression turns out to be the finance premium charged on top of the policy rate when lending to firms. The bank's decision is thus to maximize profits by choosing how much to lend to each sector z. It does so by maximizing

$$\Pi^{bank}_t = \sum_{z=1}^{Z} R^l_{z,t}L^f_{z,t} - R_t(1-\mu)D^s_t \tag{26}$$

subject to the aggregate balance sheet described at the beginning of this section.Hence, the optimal interest on loans charged in sector z is given by

$$R^l_{z,t} = R_t + \rho^l_{z,t}. \tag{27}$$

2.5 The government

The fiscal authority's budget constraint in CPI-deflated real terms is given by

$$B_t = R_{t-1}\frac{B_{t-1}}{\pi_t^c} + PD_t, \tag{28}$$

with

$$\begin{aligned} PD_t = & \frac{P_t^G}{P_t^C}G_t + \frac{P_t^{I^g}}{P_t^C}I_t^g + TR_t - \tau_t^c C_t - \left(\tau_t^w + \tau_t^{sc}\right) w_t N_t \\ & -\tau_t^k\left(r_t^k - \delta^k\right)K_{t-1} - (1-\mu)T_t^s, \end{aligned} \tag{29}$$

as the primary deficit. Hence, the government must finance real government consumption and investment expenditures, $P_t^G/P_t^C G_t$ and $P_t^{I^g}/P_t^C I_t^g$, transfers to the household sector, TR_t, and interest payments on outstanding debt, $R_{t-1}B_{t-1}/\pi_t^c$, by taxing labor income (including social security contributions), capital returns and consumption, the issuance of new debt and lump-sum taxes. We follow Stähler and Thomas (2012) and Gadatsch, Stähler, and Weigert (2016), among others, and assume full home bias in government consumption. This assumption is based on the observation that the import share in government consumption is, in general, significantly lower than in private consumption or investment (Brülhart and Trionfetti, 2001, 2004, and Trionfetti, 2000). However, it has to be determined how fiscal authorities spend across sectors. We assume a CES aggregator for public consumption and investment similar to the one used for the private sector, bearing in mind that no goods are purchased from abroad. For $\{X, x\} \in \{G, I^g\}$, this yields

$$X_{z,t} = \psi_{x,z}\left(\frac{P_{z,h,t}}{P_t^X}\right)^{-\left(\frac{1}{1-\sigma_x}\right)} X_t, \tag{30}$$

as the demand for sector-z products from the public sector. The price index for public consumption/investment can be written as

$$P_t^X = \left[\sum_{z=1}^{Z}\psi_{x,z}\, P_{z,h,t}{}^{-\frac{\sigma_x}{(1-\sigma_x)}}\right]^{-\frac{(1-\sigma_x)}{\sigma_x}}, \tag{31}$$

with the usual definitions for $\psi_{x,z}$ and σ_x. We assume that the public-sector capital stock evolves according to $K_t^g = (1-\delta^k)K_{t-1}^g + I_t^g$.

For $X \in \{G_t, I^g, TR, \tau^w, \tau^{sc}, \tau^c, \tau^k\}$, fiscal policy variables are assumed to be given by $X_t = \bar{X} + \epsilon_t^X$, where the bar indicates steady-state values and ϵ_t^X is a shock with a mean of zero. Hence, (most) fiscal variables are set to their steady-state values unless they are hit by a shock. However, to guarantee stationarity, a fiscal rule along the lines of Schmitt-Grohé and Uribe (2007) and Kirsanova and Wren-Lewis (2012) is included in our model (see also Mitchell, Sault, and Wallis, 2000, for a discussion). We assume that this role is taken by the non-distortionary lump-sum tax levied on optimizers, which follows the process

$$\hat{T}_t^o = \rho^{fp}\hat{T}_{t-1}^o + \zeta^{debt}\hat{B}_{t-1}, \tag{32}$$

where $\hat{T}_t^o = \log\left(T_t^o/\bar{T}^o\right)$, $\hat{B}_t = \log\left(B_t/(\omega^{debt}Y_t)\right)$, ρ^{fp} is an autocorrelation parameter and ζ^{debt} a sensitivity parameter that determines how strongly the fiscal rule reacts to deviations of the public debt-to-GDP ratio from the target, ω^{debt}. Aggregate output, Y_t, is derived in the next section.

Regarding monetary policy, we assume that the central bank behaves accomodative over the simulation horizon, i.e. the nominal interest rate stays unchanged.

2.6 International linkages and market clearing

In each sector z, product market clearing in nominal terms implies

$$\begin{aligned} P_{z,h,t}Y_{z,t} - P_t^C P_{z,t}^H H_{z_t} &= P_{z,t}^C C_{z,t} + P_{z,t}^I I_{z,t} + TB_{z,t} \\ &+ P_{z,h,t}\left(G_{z,t} + I_{z,t}^g\right) + \frac{\kappa_z^p}{2}\left(\frac{P_{z,h,t}}{P_{z,h,t-1}} - 1\right)^2 P_{z,h,t}Y_{z,t}, \end{aligned} \tag{33}$$

where the sectoral trade balance (see also Bergholt and Sveen, 2014) is given by

$$TB_{z,t} = P_{z,h,t}\epsilon_t^{Exp,z} Exp_{z,t} - \epsilon_t^{z,f} P_{z,f,t}\left[C_{z,f,t} + I_{z,f,t} + \sum_{\tilde{z}=1}^{Z} H_{z,\tilde{z},t}\right]. \tag{34}$$

Given the small open economy assumption, exports, $Exp_{z,t}$, and prices for foreign goods, $P_{z,f,t}$, are assumed to be exogenously given. They may be shocked and follow an AR(1) process, however, where $\epsilon_t^{Exp,z}$ denotes the export shock.

Following Bouakez et al. (2020) and defining aggregate output as gross value added, we get

$$\begin{aligned} P_t^C Y_t &= \sum_{z=1}^{Z}\left(P_{z,h,t}Y_{z,t} - P_t^C P_{z,t}^H H_{z_t} - \frac{\kappa_z^p}{2}\left(\frac{P_{z,h,t}}{P_{z,h,t-1}} - 1\right)^2 P_{z,h,t}Y_{z,t}\right) \\ &= P_t^C C_t + P_t^I I_t + P_t^G G_t + P_t^{I^g} I_t^g + PC_t TB_t, \end{aligned}$$

where $PC_t TB_t = \sum_{z=1}^{Z} TB_{z,t}$. Given that we have a small open economy and, at the same time, assume a balanced trade balance per sector in each period, the policy rate equals the world interest rate $R_t = R$ (see also Bergholt and Sveen, 2014). Any exogenous shock follows an AR(1) process, which completes the model description.

Since the model is nonlinear, and generally no exact analytical closed-form solution can be derived, we approximate a solution by computing the steady-state, log-linearizing the system around the steady-state, and then applying a complex generalized Schur decomposition to solve the linear difference model under rational expectations (see Klein, 2000).

3 Calibration

In this section, we determine the steady-state calibration of the model. It consists of common parameters that describe the aggregate economy and that are standard in the literature, and sector-specific parameters that we need to describe the heterogenous production side and inter-sectoral linkages in our economy. General economic parameters are described in Table 1, sector-specific parameters are summarized in Table 2.

Table 1: Baseline calibration of general parameters

Variable/Parameter	Symbol	Value
Discount factor	β	0.992
Share of rule-of-thumb households	μ	0.450
Elasticity of intertemporal substitution	σ	1.500
Inverse of Frisch elasticity of lab. supply	ζ	2.000
Labor disutility scaling	κ^N	6.331
Capital depreciation rate	δ^k	0.025
Capital adjustment costs	κ^I	25
Density function of idiosyncratic productivity shock	$f(\varrho_{z,t})$	$U(0.5, 1.5)$
Substitution elasticities:		
Elasticity of substitution, consumption	σ_C	0.5000
Elasticity of substitution, investment	σ_I	0.5000
Elasticity of substitution, government consumption	σ_G	0.5000
Elasticity of substitution, government investment	σ_{I^g}	0.5000
Elasticity of substitution, labor	ν_N	1-1/5
Elasticity of substitution, capital	ν_K	1-1/5
Elasticity of substitution, intermediates	$\sigma_{H,z}$	1-1/0.1
Elasticity of substitution, home vs. foreign	$\sigma_{hb,x}, x \in \{C, I, H\}$	1/3
Government spending-to-GDP ratio	G/Y	0.200
Government investment-to-GDP ratio	I^g/Y	0.020
Consumption tax rate	$\bar{\tau}^c$	0.183
Labor tax rate	$\bar{\tau}^n$	0.304
Capital gains tax rate	$\bar{\tau}^k$	0.214
Social security contribution rate	$\bar{\tau}^{sc}$	0.167
Transfer to borrowers	$\overline{TR}^b$	0.266
Lump-sum tax	$\bar{T}^s$	-0.015
AR(1) coefficient lump-sum tax	ρ_{fp}	0.900
Debt-reaction coefficient lump-sum tax	ζ_{debt}	0.005
AR(1) coefficients pandemic shocks		0.900

Notes: The table shows calibrated values for general parameters as described in the main text.

Calibration is at a quarterly frequency. The discount factor is set to $\beta = 0.992$ to match an annual interest rate of roughly 3.3%. The intertemporal elasticity of substitution is set to $\sigma_c = 1.5$, which is close to the mode estimates in Smets and Wouters (2003). We opt for a Frisch elasticity of labor supply of 0.5 (i.e. $\Psi = 2$) following Coenen et al. (2013). To match a targeted aggregate labor supply of $\bar{N} = 0.33$, we set $\kappa_N = 6.3307$. Capital depreciates at a rate of $\delta^k = 0.025$, see Cooley and Prescott (1995), implying an annual depreciation rate of 10%. Setting the share of liquidity-constrained consumers to 45% is in line with Ziegelmeyer, Porpiglia, Teppa, Le Blanc, and Zhu (2015). The capital adjustment cost parameter is set to 25, which is in line with estimates found in the literature (see, e.g., Ireland, 2003). Substitution elasticities for goods produced in the different sectors are set as follows. With 0.5 for the (government) consumption and investment baskets, we choose similar values to the ones of Bouakez et al. (2020). For the intermediate inputs, we also follow Bouakez et al. (2020) (and Atalay (2017)), by selecting a value of 0.1. Concerning the substitution elasticities of labor and capital, Bouakez et al. (2020) assume perfect substitutability. We do not go that far, but also assume a high substitutability and set the value to 5. As regards the substitutability between home and foreign (consumption/ investment/ intermediate) goods $\sigma_{hb,x}$, $x \in \{C, I, H\}$, we assume an equal value of 1/3 for all sectors.

As regards the fiscal parameters, we rely on Gadatsch et al. (2016), who estimate a fiscal DGSE model for Germany. Following Iacoviello (2005), we assume that, in steady-state, optimizers and rule-of-thumb households consume the same. This is achieved by the government paying a transfer $\overline{TR}^r = 0.5775$ to liquidity-constrained households (the direct transfer to savers is assumed to be zero as it would only increase the lump-sum tax accordingly; see also Gali et al., 2007, and Forni, Monteforte, and Sessa, 2009, for a discussion). Targeting a debt-to-GDP ratio at an annual frequency of 60% (which is more or less the current value and corresponds to the Maastricht criteria), we get a lump-sum tax $\bar{T}^o = 0.549$ that closes the government budget constraint in steady-state. Following Schmitt-Grohé and Uribe (2007), we assume an autocorrelation parameter of 0.8 and a small debt reaction parameter of 0.005 for the fiscal rule. The share of a bank's equity that is paid out to households amounts to $\nu^{bank} = 0.047$, which we derive endogenously from closing the bank's equity condition. We also derive the bank capital-to-loan ratio endogenously such that capital costs for banks are zero in steady-state. The adjustment cost parameter ζ^{bank} is set to 20 (Benes and Kumhof, 2015). All parameter values are in the range of values commonly chosen in the literature, and results are not very sensitive to changes in them.

For the multi-sector production part of our model, we distinguish between $Z = 7$ sectors, relying on the standard broad NACE classification[6] The first sector represents agriculture, forestry and fishing (A), the second is a conglomerate of mining and carrying, energy and water supply (B-D-E), and the third refers to manufacturing (C). The combination of trade, transporting, storage, accomodation and food service activities forms the fourth sector (G-H-I), followed by IT and communication (J), professional, scientific and technical as well as administrative and support service activities (M-N) and art, entertainment and recreation, including other services activities (R-S). Sticking to the NACE structure allows us to calibrate and match available disaggregated data. The calibration of the sector-specific parameters is mainly based on the most recent World Input Output Database (WIOD), providing sectoral data for the years 2000-2014 (see Timmer, Dietzenbacher, Los, Stehrer, and De Vries (2015)).[7] It encompasses data on socioeconomic

[6]Note that we exclude the construction sector (F), financial and real estate activities (K-L), the public sectors (O-Q) as well as activities of households as employers; undifferentiated goods- and services-producing activities of households for own use (T) and activities of extraterritorial organizations and bodies (U).

[7]Our steady state calibration refers to mean values over this period. In order to extract and aggregate

accounts as well as input-output tables for 56 sectors and 43 countries.
The sectors in the model differ along several dimensions. First, they can be distinguished by their labor and capital supply, provided by the respective agency. The labor and capital weights, $\omega_{N,z}$ and $\omega_{K,z}$, respectively, are calculated based on WIOD's socioeconomic accounts. Specifically, we first add up the number of persons engaged and the nominal capital stock over all sectors, and then compute the sector-specific shares. Second, the technology of intermediate goods producers differs across sectors in the sense that we distinguish factor intensities for capital, labor and intermediate inputs as well as the productivity enhancement of public capital. The shares of intermediate inputs in total sectoral gross output $1 - \alpha_{H,z}$ and the labor intensity implied by $\alpha_{N,z}$ match corresponding data within WIOD's input-output tables. By dividing the amount of intermediate inputs by gross output per industry, we can pin down the factor intensities for intermediate inputs, $1 - \alpha_{H,z}$. The parameters $\alpha_{N,z}$ are then derived by dividing the share of compensation of labor in total sectoral gross output by $\alpha_{H,z}$.
The input-output tables also allow us to model detailed inter-sectoral trade shares of intermediate inputs, $\psi_{z,\tilde{z}}$, as presented in Table 3, as well as the contributions to the final consumption, $\psi_{C,z}$, investment, $\psi_{I,z}$ and government consumption, $\psi_{G,z}$, goods. Due to the lack of data, we assume the shares of the public investment good $\psi_{IG,z}$ to be the same as for government consumption. The productivity of public capital is based on Bom and Ligthart (2014), whose meta-regression yields an average output elasticity of 0.106, while core public capital (such as roads, railways and so on) yields a larger short-run estimate of 0.131. Therefore, we assume that the Professional scientific and technical services sector is the one that profits most from public capital.
Concerning the international dimension, we compute the home biases with respect to consumption $hb_{C,z}$, investment $hb_{I,z}$ and intermediate goods $hb_{z,\tilde{z}}$ (shown in Table 4) by aggregating WIOD data of the remaining 42 countries to one *Rest of the world* counterpart of Germany and determine the respective shares of goods produced abroad and at home.
Furthermore, the sectors differ in price setting and default probabilities. Mark-ups θ^p_z for the different sectors stem from Christopoulou and Vermeulen (2012), and price duration is in line with Bouakez, Cardia, and Ruge-Murcia (2009) and Hoffmann and Kurz-Kim (2006).[8] From the price duration, we can compute the Calvo parameters and translate them into Rotemberg price adjustment costs parameters κ^p_z along the lines of Keen and Wang (2007). The default probabilities from which we then extract the default threshold $\bar{\varrho}_z$ rely on business closing rates provided by Destatis for 2017.[9]

WIOD data, we set up a quite flexible calibration routine that allows for a custom choice of years, country and sector specifications.

[8]Note that data are only available for the five sectors agriculture, mining, durables, nondurables and services; data for more disaggregated NACE sectors are not.

[9]See https://www-genesis.destatis.de/genesis//online?operation=table&code=52111-0011&bypass=true&levelindex=0&levelid=1601033242933

Table 2: Baseline calibration of sector-specific parameters

Variable/Parameter	Symbol	Value
Labor weight:	$\omega_{N,z}$	
Agriculture	$\omega_{N,1}$	0.0263
Mining, Energy, Water Supply	$\omega_{N,2}$	0.0146
Manufacturing	$\omega_{N,3}$	0.2876
Trade, Transport & Storage, Accomod. and Food Services	$\omega_{N,4}$	0.3651
IT and Communication	$\omega_{N,5}$	0.0451
Professional Scientific and Technical Services	$\omega_{N,6}$	0.1819
Art, Entertainment, Recreation	$\omega_{N,7}$	0.0794
Capital weight:	$\omega_{K,z}$	
Agriculture	$\omega_{K,1}$	0.0598
Mining, Energy, Water Supply	$\omega_{K,2}$	0.1061
Manufacturing	$\omega_{K,3}$	0.3061
Trade, Transport & Storage, Accomod. and Food Services	$\omega_{K,4}$	0.2453
IT and Communication	$\omega_{K,5}$	0.0499
Professional Scientific and Technical Services	$\omega_{K,6}$	0.1516
Art, Entertainment, Recreation	$\omega_{K,7}$	0.0842
Labor & capital factor intensity:	$\alpha_{H,z}$	
Agriculture	$\alpha_{H,1}$	0.4069
Mining, Energy, Water Supply	$\alpha_{H,2}$	0.4334
Manufacturing	$\alpha_{H,3}$	0.3303
Trade, Transport & Storage, Accomod. and Food Services	$\alpha_{H,4}$	0.5167
IT and Communication	$\alpha_{H,5}$	0.5161
Professional Scientific and Technical Services	$\alpha_{H,6}$	0.5971
Art, Entertainment, Recreation	$\alpha_{H,7}$	0.6740
Labor factor intensity:	$\alpha_{N,z}$	
Agriculture	$\alpha_{N,1}$	0.7044
Mining, Energy, Water Supply	$\alpha_{N,2}$	0.4125
Manufacturing	$\alpha_{N,3}$	0.6662
Trade, Transport & Storage, Accomod. and Food Services	$\alpha_{N,4}$	0.7006
IT and Communication	$\alpha_{N,5}$	0.5641
Professional Scientific and Technical Services	$\alpha_{N,6}$	0.5624
Art, Entertainment, Recreation	$\alpha_{N,7}$	0.6441
Productivity of public capital:	$\eta_{K^g,z}$	
Agriculture	$\eta_{K^g,1}$	0.1000
Mining, Energy, Water Supply	$\eta_{K^g,2}$	0.0900
Manufacturing	$\eta_{K^g,3}$	0.0800
Trade, Transport & Storage, Accomod. and Food Services	$\eta_{K^g,4}$	0.1200

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Variable/Parameter	Symbol	Value
IT and Communication	$\eta_{K^g,5}$	0.0500
Professional Scientific and Technical Services	$\eta_{K^g,6}$	0.1000
Art, Entertainment, Recreation	$\eta_{K^g,7}$	0.0900
Share in consumption good:	$\psi_{C,z}$	
Agriculture	$\psi_{C,1}$	0.0247
Mining, Energy, Water Supply	$\psi_{C,2}$	0.0640
Manufacturing	$\psi_{C,3}$	0.2780
Trade, Transport & Storage, Accomod. and Food Services	$\psi_{C,4}$	0.4234
IT and Communication	$\psi_{C,5}$	0.0905
Professional Scientific and Technical Services	$\psi_{C,6}$	0.0367
Art, Entertainment, Recreation	$\psi_{C,7}$	0.0827
Share in investment good:	$\psi_{I,z}$	
Agriculture	$\psi_{I,1}$	0.0026
Mining, Energy, Water Supply	$\psi_{I,2}$	0.0225
Manufacturing	$\psi_{I,3}$	0.6841
Trade, Transport & Storage, Accomod. and Food Services	$\psi_{I,4}$	0.0827
IT and Communication	$\psi_{I,5}$	0.0943
Professional Scientific and Technical Services	$\psi_{I,6}$	0.1086
Art, Entertainment, Recreation	$\psi_{I,7}$	0.0052
Share in government consumption and investment good:	$\psi_{x,z}$, $x \in \{G, I^G\}$	
Agriculture	$\psi_{x,1}$	0.0002
Mining, Energy, Water Supply	$\psi_{x,2}$	0.0070
Manufacturing	$\psi_{x,3}$	0.3181
Trade, Transport & Storage, Accomod. and Food Services	$\psi_{x,4}$	0.3070
IT and Communication	$\psi_{x,5}$	0.0053
Professional Scientific and Technical Services	$\psi_{x,6}$	0.0517
Art, Entertainment, Recreation	$\psi_{x,7}$	0.3108
Price adjustment costs:	κ_z	
Agriculture	κ_1	23.9620
Mining, Energy, Water Supply	κ_2	77.0530
Manufacturing	κ_3	29.3420
Trade, Transport & Storage, Accomod. and Food Services	κ_4	476.6780
IT and Communication	κ_5	114.3870
Professional Scientific and Technical Services	κ_6	476.5490
Art, Entertainment, Recreation	κ_7	121.5360
Mark-up:	θ_z	
Agriculture	θ_1	1.01/0.01

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Variable/Parameter	Symbol	Value
Mining, Energy, Water Supply	θ_2	1.35/0.35
Manufacturing	θ_3	1.15/0.15
Trade, Transport & Storage, Accomod. and Food Services	θ_4	1.35/0.35
IT and Communication	θ_5	1.85/0.85
Professional Scientific and Technical Services	θ_6	1.76/0.76
Art, Entertainment, Recreation	θ_7	1.80/0.80
Default probability (in %):	$\bar{\varrho}_z$	
Agriculture	$\bar{\varrho}_1$	5.4000
Mining, Energy, Water Supply	$\bar{\varrho}_2$	5.7000
Manufacturing	$\bar{\varrho}_3$	6.7000
Trade, Transport & Storage, Accomod. and Food Services	$\bar{\varrho}_4$	8.1000
IT and Communication	$\bar{\varrho}_5$	11.9000
Professional Scientific and Technical Services	$\bar{\varrho}_6$	10.5000
Art, Entertainment, Recreation	ϱ_7	10.2
Home bias consumption:	$hb_{C,z}$	
Agriculture	$hb_{C,1}$	0.3936
Mining, Energy, Water Supply	$hb_{C,2}$	0.9100
Manufacturing	$hb_{C,3}$	0.6367
Trade, Transport & Storage, Accomod. and Food Services	$hb_{C,4}$	0.9341
IT and Communication	$hb_{C,5}$	0.8793
Professional Scientific and Technical Services	$hb_{C,6}$	0.9295
Art, Entertainment, Recreation	$hb_{C,7}$	0.9876
Home bias investment:	$hb_{I,z}$	
Agriculture	$hb_{I,1}$	0.9662
Mining, Energy, Water Supply	$hb_{I,2}$	0.9733
Manufacturing	$hb_{I,3}$	0.5525
Trade, Transport & Storage, Accomod. and Food Services	$hb_{I,4}$	0.8421
IT and Communication	$hb_{I,5}$	0.8948
Professional Scientific and Technical Services	$hb_{I,6}$	0.9494
Art, Entertainment, Recreation	$hb_{I,7}$	0.9548

Notes: The table shows calibrated values for sector-specific parameters as described in the main text.

4 Simulation design

In this section, we describe the simulation design of our analysis. The general idea is to match selected economic time series from 2020:Q1-2021:Q1 by different structural shocks. Specifically, in the first step, we include various types of COVID-19 as well as fiscal shocks. In the second step, we keep the identified COVID-19 shocks of the first step, but exclude the fiscal shocks to obtain a baseline pandemic scenario (without fiscal intervention), that

Table 3: Input-Output Matrix, $\psi_{z,\tilde{z}}$

	Consumer z						
Producer $\tilde{z}$	A	B-D-E	C	G-H-I	J	M-N	R-S
A	0.1459	0.0524	0.3087	0.2018	0.0077	0.2768	0.0067
B-D-E	0.0015	0.4387	0.2299	0.1517	0.0222	0.1455	0.0105
C	0.0034	0.0681	0.6467	0.1528	0.0187	0.1060	0.0043
G-H-I	0.0039	0.0374	0.1665	0.5513	0.0515	0.1765	0.0129
J	0.0002	0.0156	0.1654	0.1044	0.5097	0.1607	0.0440
M-N	0.0026	0.0203	0.0780	0.0700	0.1502	0.6458	0.0330
R-S	0.0039	0.0494	0.1343	0.1279	0.1004	0.1832	0.4009

Notes: This table reports the share of total intermediates (in expenditure terms) used by the consuming sector z that comes from the producing sector $\tilde{z}$. (For example, 10.60% of the total intermediates used by the IT sector (J) stem from the manufacturing sector (C).) The values were computed by the authors based on the World Input Output Database, taking an average over the years 2000-2014.

Table 4: Home Bias Matrix, $hb_{z,\tilde{z}}$

	Consumer z						
Producer $\tilde{z}$	A	B-D-E	C	G-H-I	J	M-N	R-S
A	0.7606	0.8194	0.5835	0.9017	0.8723	0.9541	0.9787
B-D-E	0.7576	0.6642	0.7096	0.7922	0.8629	0.8834	0.9901
C	0.7758	0.4347	0.6017	0.8254	0.8534	0.8870	0.9629
G-H-I	0.7284	0.7943	0.6631	0.9088	0.8861	0.9354	0.9887
J	0.7344	0.8443	0.6062	0.8901	0.9036	0.9267	0.9919
M-N	0.7823	0.8684	0.7083	0.8683	0.8885	0.9159	0.9933
R-S	0.7626	0.8714	0.6116	0.8722	0.8927	0.9501	0.9994

Notes: This table reports the share of intermediates (in expenditure terms) used by the consuming sector z that comes from the producing sector $\tilde{z}$ and is produced domestically. (For example, 58.35% of the intermediates used by the manufacturing sector (C) stemming from the agriculture sector (A) are domestically produced.) The values were computed by the authors based on the World Input Output Database, taking an average over the years 2000-2014.

can be compared to the scenario with fiscal intervention.[10]
Concerning the nature of the COVID-19 shock, there seems to be consensus in the growing body of economics literature that it represents a combination of demand and supply shocks (see e.g. Eichenbaum et al., 2020, Pfeiffer et al., 2020, Bayer et al., 2020, Guerrieri, Lorenzoni, Straub, and Werning, 2020, Brinca, Pedro and Duarte, Joao B and Faria-e-Castro, Miguel, 2020, and Balleer, Zorn, Link, and Menkhoff, 2020). Baqaee and Farhi (2020) show that the decomposition of the shock also differs across sectors which especially holds for the cultural sector, for example. Hence, we also use different shocks to replicate effects of the pandemic on selected variables. The endogenous variables we match comprise sectoral output, sectoral export and import[11], aggregate consumption, hours worked and wage income. All corresponding time series are part of Germany's national accounts published by Destatis.[12]
Regarding the pandemic shocks, we allow for six types. First, a sector-specific shock to the costs of consumption ($\varepsilon_t^{C,z}$) reduces consumption demand, which may differ per sector. During the lockdown, consumption was either prohibited by regulations or more costly because of the containment measures. Second, we include a general consumption preference shock (ε_t^{C}) that is meant to capture peoples' behaviour of postponing consumption due to increased uncertainty. Third, a labor disutility shock ($\varepsilon_t^{\kappa_N}$) reduces aggregate labor supply. It can also be interpreted as a proxy for people staying at home to avoid risks of infection while commuting, or rules restricting contacts at work. Fourth, a common shock to total factor productivity, mirroring possible restrictions concerning the production process. Fifth, we allow for sector-specific exports shocks ($\varepsilon_t^{Exp,z}$) that are supposed to match the fall in exports shown in the national accounts. An analogous sector-specific shock on import prices ($\varepsilon_t^{f,z}$) is used to reduce imports. The intention here is to mirror, for example, the international dimension of the crisis with disrupted supply chains and a general reduction in world trade and travel.
The German government has responded to the COVID-19 crisis with various expansionary fiscal measures. In terms of amounts, we rely on (projected) values described in Bundesbank (2021).[13] In total, the fiscal measures included amount to 2.6 % and 2.0 % of trend GDP in 2020 and 2021, respectively, and 0.3 % in the following two years each. Hence, we observe a large (COVID-19 related) expansionary fiscal stimulus between 2020 and 2023

[10]In an earlier version of the paper, we started with a baseline pandemic scenario by matching selected variables of the first half of 2020 using COVID-19 shocks only, adding fiscal shocks afterwards. The new approach identifies the different shocks more precisely, since fiscal measures were already in place since March 2020 and might have affected the observed variables. We thank Benjamin Born for pointing that out.

[11]We can only distinguish between goods and services with respect to these categories due to data availability.

[12]See https://www.destatis.de/EN/Themes/Economy/National-Accounts-Domestic-Product/Publications/Downloads-National-Accounts-Domestic-Product/seasonally-adjusted-quarterly-results-xlsx.xlsx?__blob=publicationFile

[13]Note that we do not include measures earmarked specifically for health-related support such as expenses for additional intensive care beds, additional financial resources for hospitals, and other expenses for pandemic containment since we do not model a separate health care sector. As part of the fiscal stimulus package, the government also announced a large future investment package of 1.7% of GDP including programs tackling issues like digitalization, climate change and health care. However, since details on the timing of implementation are lacking in some cases, and the package is supposed to have a longer-run impact, we do not include it in our analysis.

of about 5 %. Roughly 65 % of it stems from the actual fiscal stimulus package adopted in June 2020. The remaining part contains the block of measures that were established at the beginning of the crisis.

Regarding the intra-annual profiles, we assume that the first block of measures is split across the second to fourth quarter with weights of 0.6, 0.3 and 0.1, respectively. We choose to fade the weights out across the quarters in order to reflect the emergency assistance character of these measures. The fiscal stimulus package (from June) is split equally across the third and fourth quarters in the simulation. The intra-annual profiles in 2021-2023 are also assumed to be flat. Note that we only consider measures that affect the national accounts' deficit (except for tax deferrals). Hence, we do not include equity injections and credit guarantees, which affect public debt but not the deficit. These measures may have a significant additional stabilization impact (see also Bundesbank, 2020a,b).[14]

Table 5 provides more detailed information on the composition of the fiscal shocks that we implement in our model. As this table shows, the emergency assistance fiscal measures primarily support firms. Almost 90% of the fiscal stimulus was aimed at firms. Transfers to small and medium-sized businesses, and to the self-employed, make up the largest share. Direct transfers to theaters and other cultural institutions are also included (which we model as a sector-specific transfer to sector 7). Additionally, support was provided to firms by shifting the tax burden over time. Since these measures are intended to provide liquidity support, we model these as firm subsidies, S_t. Moreover, on the household side, social transfers other than in kind were expanded by more generous unemployment benefits, compensation of loss of earnings due to child care and higher replacement rates for short-time working arrangements. Further, a bonus payment for people employed in the nursing sector was agreed upon.

The second part of the fiscal measures was advertised by the government as the actual fiscal stimulus package. Roughly 70 % of it is aimed at households, where the VAT reduction accounts for the largest share, followed by a bonus transfer of 300 euro per child and tax reliefs for single parents. Firms, on the other side, benefit mainly from direct assistance, investment grants and subsidies. Income tax-related measures, such as an increased threshold for tax loss carrybacks and degressive depreciation rates for moveable assets, are further targeting a reduction of business costs in order to provide liquidity. We therefore model them as subsidies for firms. Furthermore, the government promises to keep the rate for social security contributions below 40 % until the end of 2021 by providing federal subsidies, which we model as a reduction in the contribution rate relative to the steady-state. Additionally, the fiscal stimulus package includes a public investment component with a focus on child care facilities, school renovations and constructions. Concerning the distribution of transfers and subsidies across sectors, we use steady-state shares in aggregate output due to the lack of more detailed information.

Of course, the exact fiscal stimulus package and its effect can only be approximated by the model. For example, full pass-through of the VAT reductions by firms is uncertain,

[14] Moreover, it should be noted that a further stabilizing effect results from the automatic stabilizers of the government budget. They lead to an additional deficit increase via lower tax revenues and higher unemployment-related expenditure (not least via short-time working benefits). Moreover, there are several other expansionary fiscal measures in place that are not related to the COVID-19 crisis like e.g. the abolition of the solidarity surcharge. Here, we only focus on COVID-19 related measures.

Table 5: Composition of the German COVID-19 Fiscal Stimulus Measures

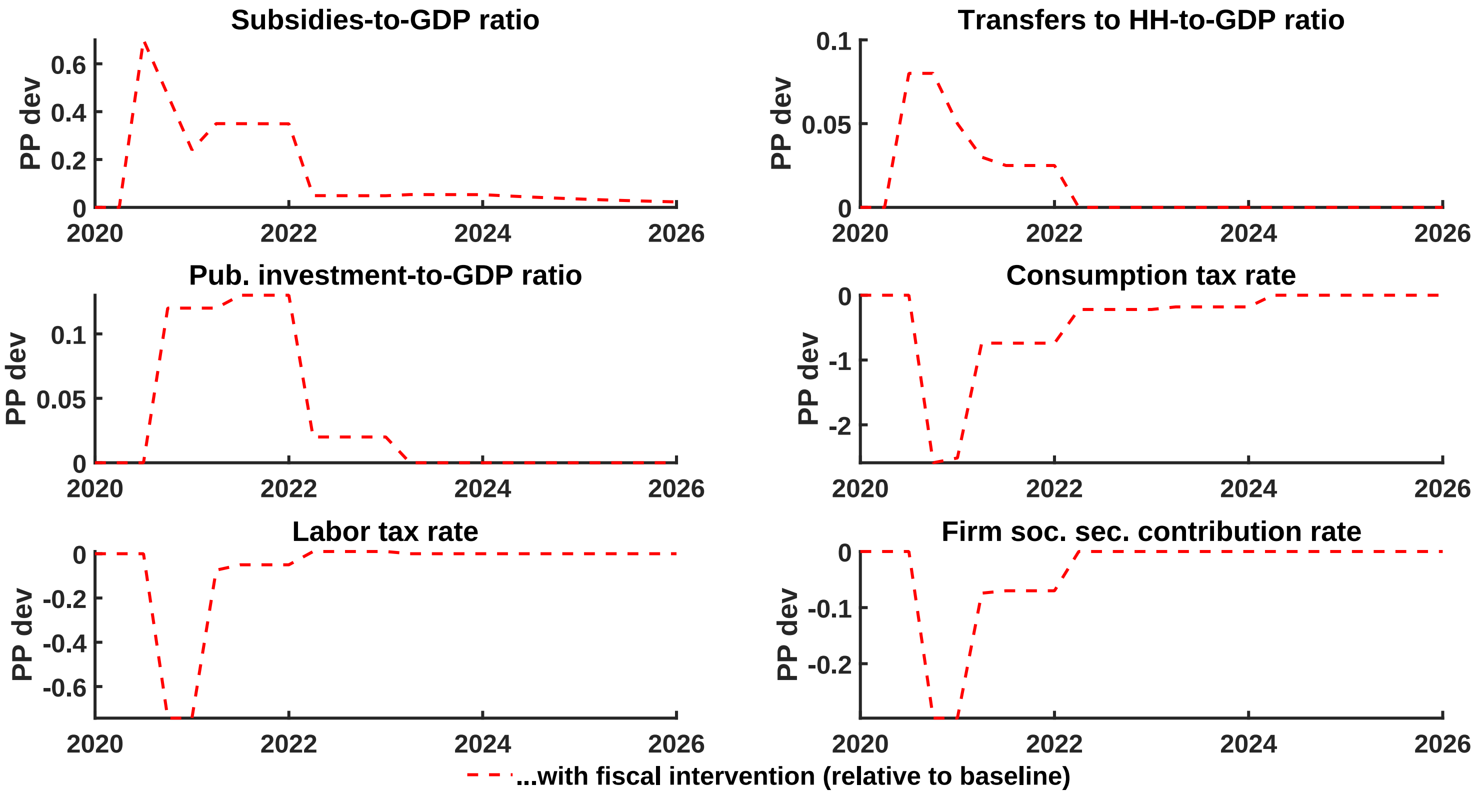
Stimulus Measure	2020	2021	2022	2023	Fiscal instruments
Emergency assistance					
Measures aimed at households:					
Transfers	0.1	0.1	0.0	0.0	TR
Measures aimed at firms:					
Liquidity support	1.1	0.4	0.0	0.0	S
Indirect taxes	0.0	0.1	0.0	0.0	τ^c
Fiscal stimulus package					
Measures aimed at households:					
Transfers	0.1	0.0	0.0	0.0	TR
Direct taxes	0.2	0.0	0.0	0.0	τ^w
Indirect taxes	0.7	0.3	0.1	0.1	τ^c
Measures aimed at firms:					
Liquidity support	0.3	1.0	0.2	0.2	S
Social security contributions	0.1	0.0	0.0	0.0	τ^{sc}
Public investment	0.1	0.1	0.0	0.0	I^g

Notes: Fiscal stimulus measures are expressed as a percentage of trend GDP. A positive (negative) sign denotes an expansionary (contractionary) stimulus. Note, that with the exception of tax deferrals, we only consider measures that affect the national accounts' deficit. Automatic stabilizers, equity injections and credit guarantees are not included.

and some measures concerning direct assistance depend on actual take-up rates in specific sectors, which were not available at the time the projections were made. Nevertheless, we believe that the simulations broadly mirror the actual COVID-19 fiscal stimulus measures. To find the structural shocks needed to match the constrained paths of the endogenous variables previously described, we apply a conditional forecast. This is done using the reduced-form first-order state-space representation of the model $y_t = Ty_{t-1} + R\varepsilon_t$, where y_t includes pre- and non-predetermined variables, and ε_t are the structural shocks just described. The representation can be split into a controlled and uncontrolled part and then solved algebraically for the controlled shocks. Note that only the controlled variables of the first two quarters are fixed. Starting with the third quarter, all variables move freely, driven by the shock propagation.

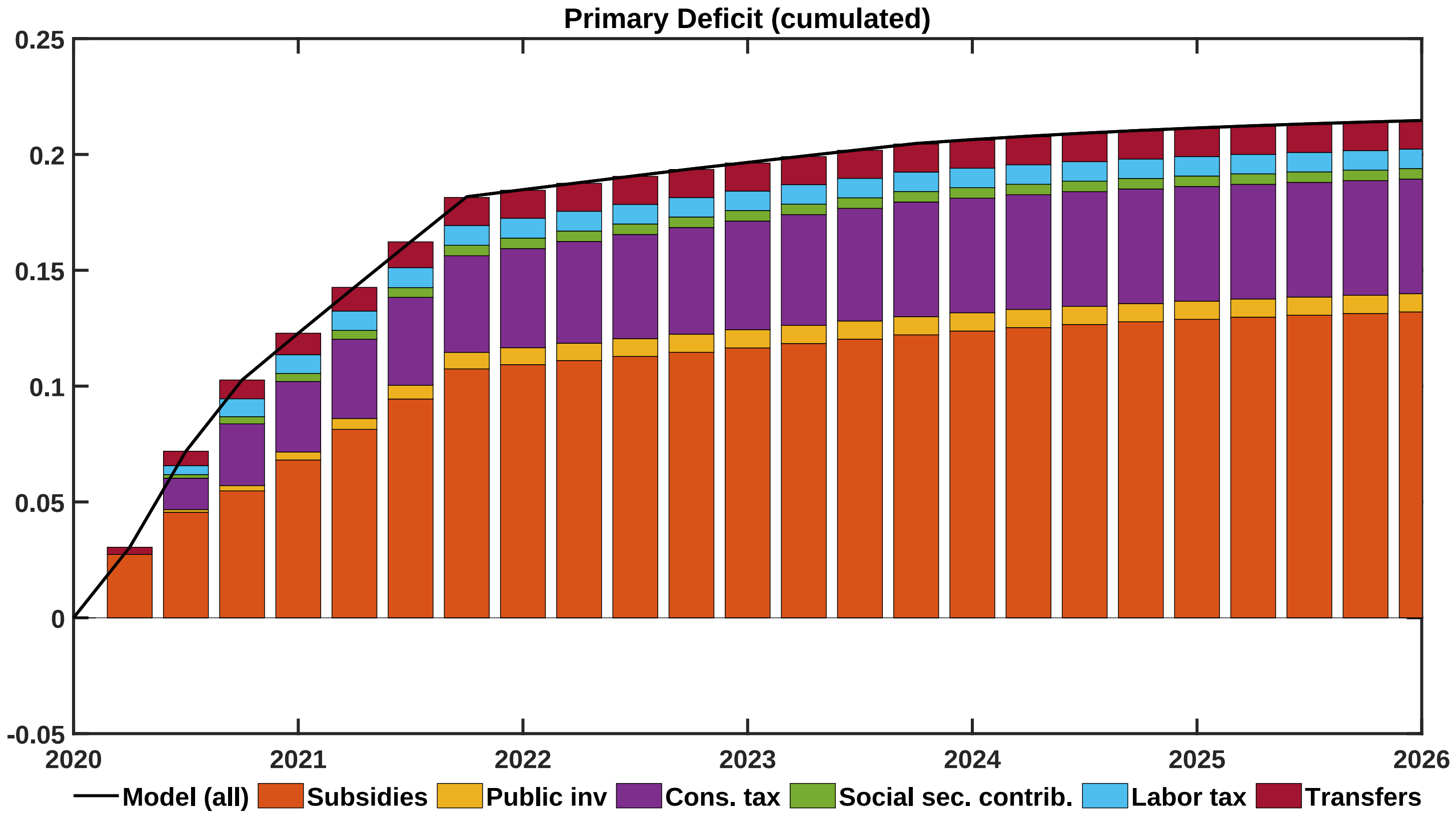
In Figure 1, we visualize the fiscal measures just described in order to get a feeling for the timing of events. Note that we plot the ratios (to GDP) of firm subsidies, transfers to households and public investment-to-GDP as deviations from the steady-state. In Figure 2, we plot the evolution of the cumulated primary deficit-to-GDP ratios after the fiscal package, and the contribution of each measure to this development (colored bars as indicated in figure). The contributions are plotted relative to steady-state GDP. Hence, changes can be attributed to the policy change alone. We can see that subsidies constitute the largest share followed by consumption tax.

Figure 1: The Fiscal Stimulus Packages



Notes: Figure plots (projected) paths of selected fiscal variables after COVID-19 pandemic shocks including fiscal measures (red dashed line) relative to the baseline pandemic scenario without fiscal intervention.

Figure 2: Percentage Point Increase in Cumulated Primary Deficit-to-GDP Ratios



Notes: Figure plots (projected) increase of primary deficit-to-GDP ratios after the fiscal stimulus program and the contribution of each fiscal measure to these developments (colored bars as indicated).

5 Results

In this section, we first discuss the macroeconomic developments of selected key macroeconomic variables. Then, we derive multipliers and analyse the welfare effects.

5.1 Macroeconomic developments

The evolution of key macroeconomic variables is shown in Figures 3. The blue solid line depicts the impact of the shocks representing the baseline pandemic scenario in our model economy. The dashed red line shows the evolution of variables when the fiscal stimulus package described above is also included.

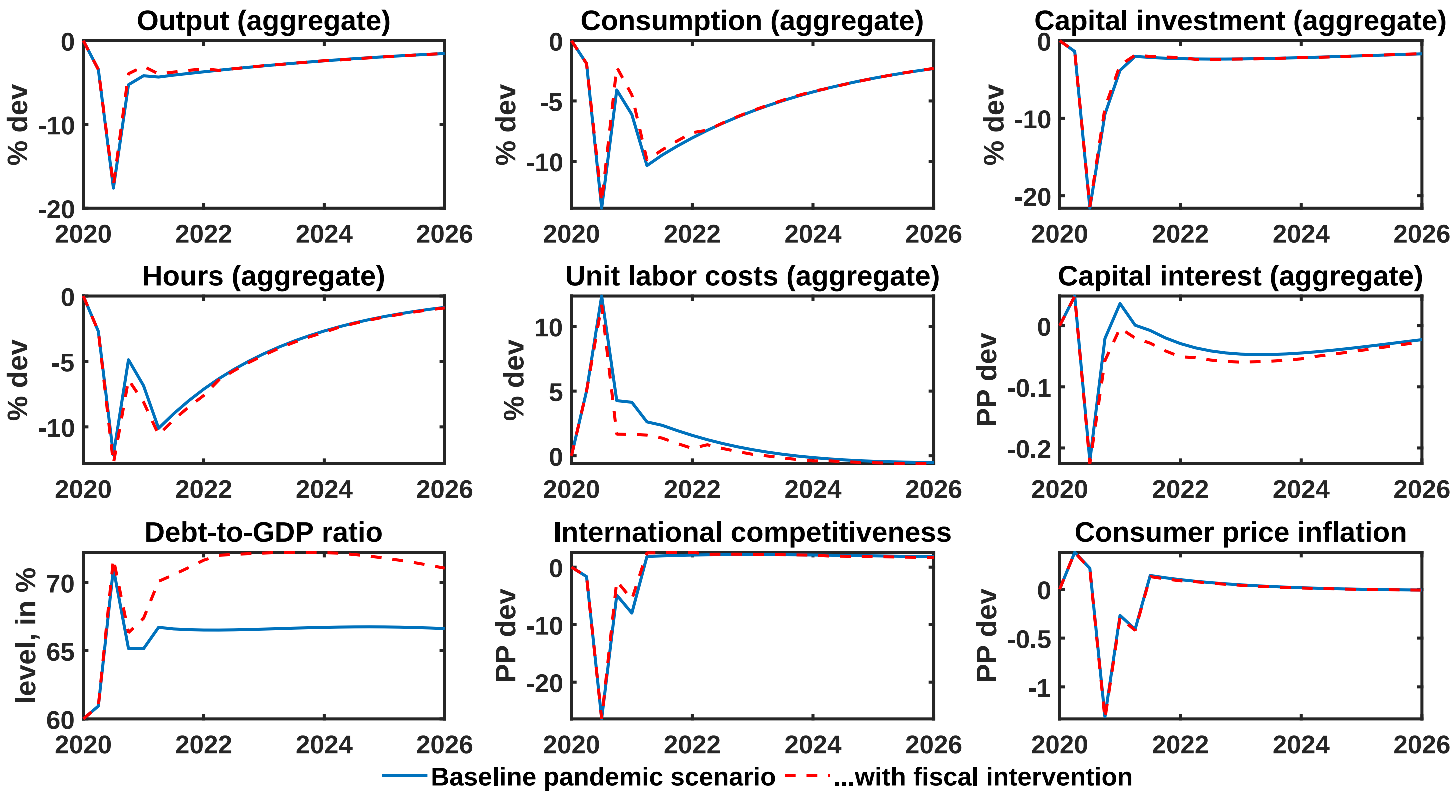
The shocks describing the COVID-19 pandemic significantly reduce private consumption and hours worked as well as net exports. Higher import prices also increase production costs by driving up the prices for intermediate inputs. Unit labor costs also increase. This results in a significant fall in aggregate output and capital investment (which further dampens aggregate demand). German international competitiveness deteriorates, and consumer price inflation increases. According to our model simulations, the German debt-to-GDP ratio increases from 60% in the initial steady-state to over 70% because of the pandemic (even without any fiscal intervention).

The effects of the COVID-19 shocks also differ across sectors, as can be seen in Figure 4. While most of the sectors share a large drop in output in the second quarter of 2020, the agricultural sector as well as the IT and communication sector perform well and even above steady state during the crisis. The latter benefitted from the crisis due to the increased demand for home office solutions and virtual meetings. The three sectors hit hardest at the trough are manufacturing, art, entertainment and recreation as well as trade, transport, accomodation and food services with drops in output of -24%, -20% and -15%, respectively. Increases in unit labor costs and drops in hours worked are also pronounced for these sectors. The pandemic hit the manufacturing sector hard in the beginning through disrupted supply chains and a general reduction in world trade. Still, we observe a quite quick recovery of value added of the manufacturing sector, driven also by a come back of exports, while the other two sectors and the professional, scientific and technical services sector experience negative rebounds in 2021 due to further lockdown measures.[15] The manufacturing sector shows a large decrease in capital investment, which also affects heavily aggregate capital investment, since manufacturing makes up for the largest share in the investment good bundle with almost 70 % (see 2).

The increase in production costs and fall in demand has pushed up firm default rates. Unsurprisingly, this happens most in the cultural sector (sector 7) (which is hit longest and hardest, as just described), where default rates rise by over 10 PP, and less so in the agricultural and IT sectors, where we even observe decreases below the steady state level of between -1 to 2 PP in 2021 (see Figure 5).

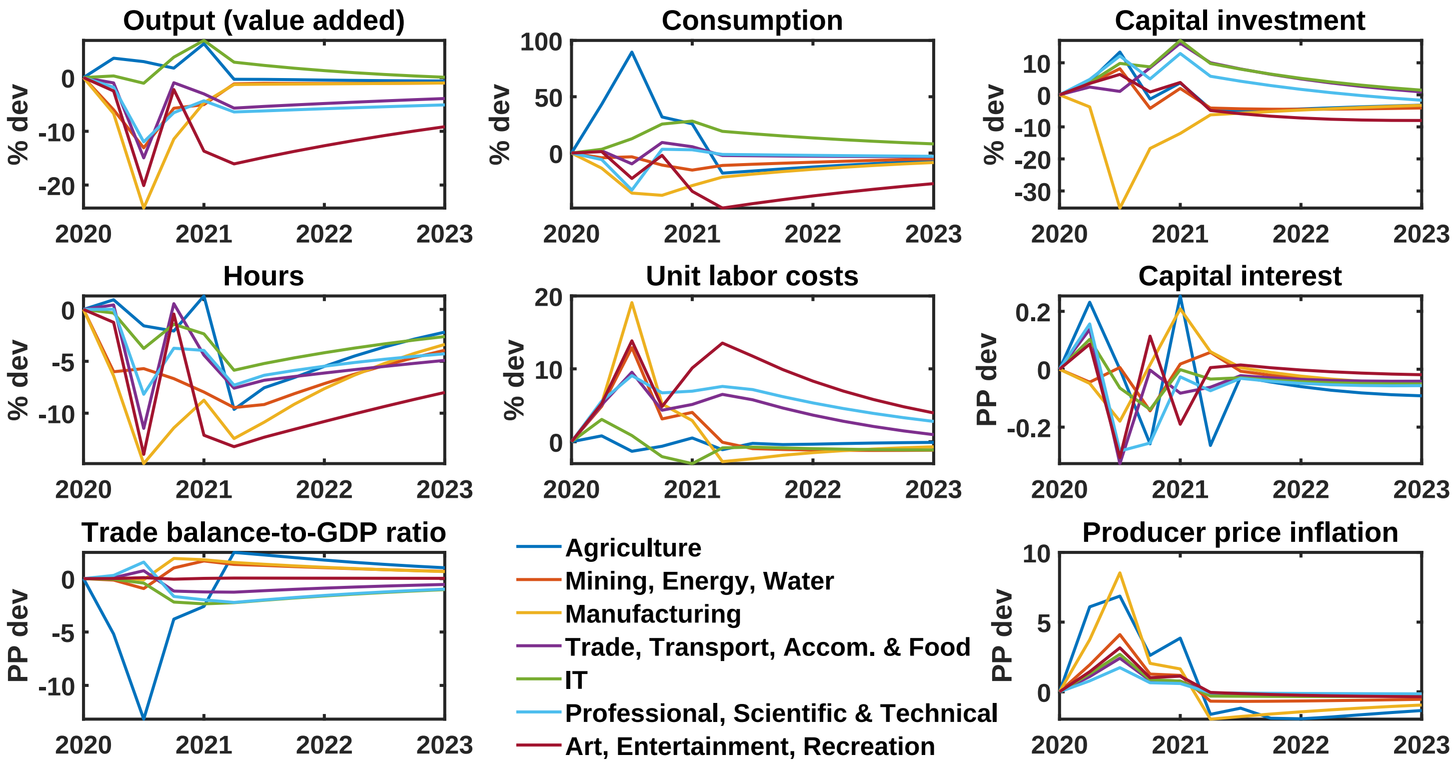
[15] Note, that we cannot distinguish between trade, transport and accomodation and food services due to the lack of data. While trade and transport (except for passenger transport) recovered quickly in the third quarter of 2020, hotels and gastronomy certainly suffered larger losses comparable to the art, entertainment and recreaction sector.

Figure 3: Implications of COVID-19 pandemic and fiscal stimulus package for key macro variables (aggregate)



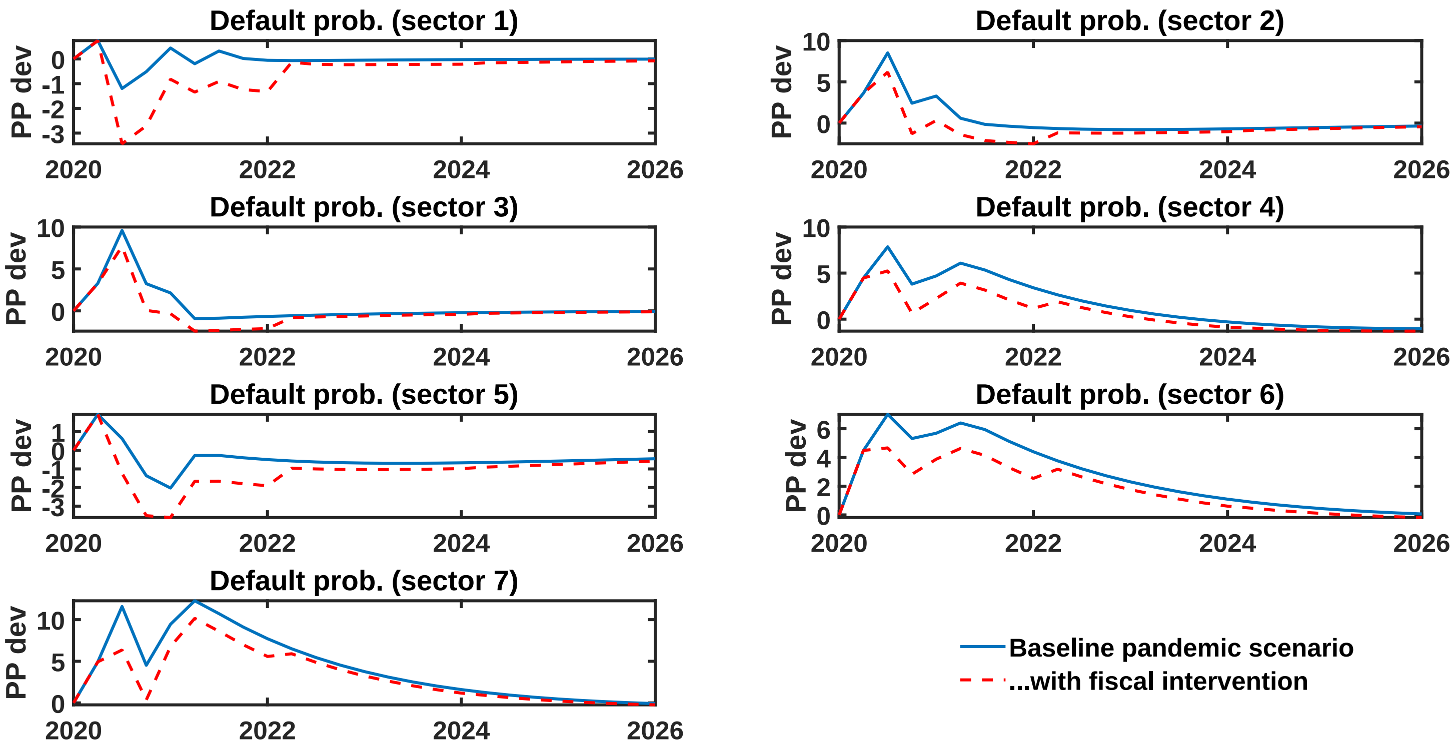
Notes: Figure plots (projected) path of selected aggregated macroeconomic variables after COVID-19 pandemic shocks without fiscal intervention (blue solid line) and with the fiscal stimulus package (red dashed line).

Figure 4: Sectoral implications of COVID-19 pandemic



Notes: Figure plots (projected) paths of selected sectoral macroeconomic variables without fiscal intervention (baseline pandemic scenario) for each sector as indicated by the colored lines.

Figure 5: Implications of COVID-19 pandemic and fiscal stimulus package for sectoral default probabilities



Notes: Figure plots (projected) path of selected sectoral default probabilities after COVID-19 pandemic shocks without fiscal intervention (blue solid line) and with the fiscal stimulus package (red dashed line).

The fiscal package helps to mitigate the negative impact of the pandemic (see Figure 6). While it can not prevent the large drop in output in the second quarter of 2020, it stabilizes consumption and reduces unit labor costs for firms from the third quarter on through 2021. The effect on consumption amounts to almost 2 PP at the peak. Capital investment is increased by 0.8 PP. Together, this leads to a stabilisation of output by about 1.3 PP in the second half of 2020. It comes at the cost of an additional increase in the debt-to-GDP ratio by around 5 PP. Cumulated over the first 3 years, the fiscal package stabilizes output by 4 PP as can be seen from Figure 7. Concerning distributional aspects, it heavily backs consumption of liquidity-constrained households with an cumulated effect of 10 PP, which is roughly 5 times larger than the cumulated effect on optimizer's consumption.

What are the mechanisms behind these results? Figure 7 also plots the contribution of each fiscal measure of the entire fiscal stimulus to (cumulated) developments in output, investment and household type-specific consumption relative to a scenario where only the pandemic is simulated.

First, the reduction in consumption taxes and transfers to households increase disposable income. This stabilizes consumption demand, especially for rule-of-thumb consumers, who spend their entire income each period. However, higher debt-financed transfers to all households crowd out investment and consumption demand of optimizing households. The reason is that the transfer-implied increase in consumption of rule-of-thumb households reduces their labor supply because consumption and leisure are normal goods. To increase production (in relative terms), real wages must increase. This reduces firm profits and income of optimizers.[16] Second, as subsidies for firms stabilize firm income per period, they allow a larger fraction of firms to cover the fixed costs of production after the idiosyncratic productivity shocks. This significantly reduces the probability of default (see Figure 5), and default-implied output losses decrease. At the same time, lower probabilities of default imply lower loan interest rates. This is how firms' operating costs can be decreased (working capital channel). Lower default rates and operating costs stabilize wage income of households because marginal labor productivity does not fall as much.[17] This fosters demand.

In addition, lower labor income taxation augments net wage income, and lower social security contributions levied on firms reduces operating costs further. The reduction in labor income taxation has two output-increasing effects. First, it directly raises net wage income of households, which fosters demand. Second, because of the tax reduction, house-

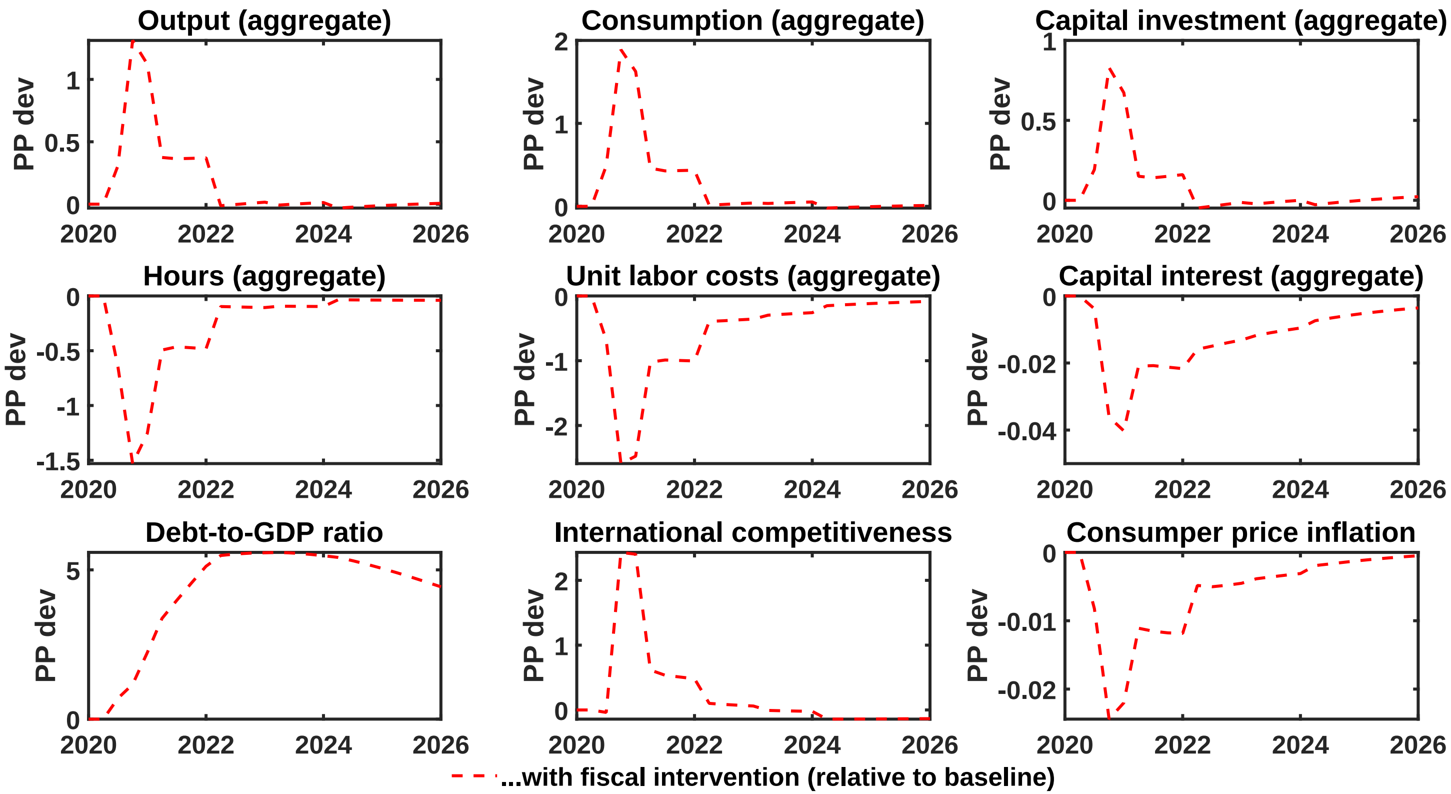
[16]We assume that optimizers and rule-of-thumb households individually determine their labor supply while, at the same time, assuming the wage rate to be equal (determined by equation (15)). As transfers affect consumption of rule-of-thumb households more positively (see also Figure A.8 in the Appendix), and because consumption and leisure are normal goods, their labor supply decreases relative to the simulation of the pandemic without any fiscal intervention. This, plus the relatively high increase in wages, which reduces profits and thus disposable income for optimizers, implies that an increase in transfers has smaller output effects than if we had assumed that the labor supply of rule-of-thumb households was determined by the decision of optimizers, too. Then, the detrimental labor market effects of the fiscal package would be less severe, and we would generate a larger positive output effect by increasing transfers (as in, for example, Born et al., 2020). The more transfers are (solely) paid to rule-of-thumb households with a high marginal propensity to consume, the more this holds true (Spector, 2020).

[17]The initial drop in hours worked relative to a scenario where only the pandemic is simulated, see Figure 6, can be explained by the fact that the fiscal package stabilizes consumption. As consumption and leisure are normal goods, households also want to enjoy more leisure (work less) for any given wage. Whenever consumption stabilization fades out, hours worked start to increase again.

holds are willing to accept lower gross wages (as they primarily care about their net labor income). The reduction in gross wages has a cost-dampening effect for firms, who are willing to increase employment and reduce prices in relative terms. The latter additionally fosters demand. The former increases the marginal product of capital and, thus, augments investment. In a similar way, the reduction in the social security contributions reduces firms' labor costs and has analogous effects. Because households demand higher gross wages when social security contributions fall (given that wages reflect, in some way, the share of firm profits workers obtain), labor income also rises by this measure and households increase consumption (see also Attinasi, Prammer, Stähler, Tasso, and van Parys, 2019, and Enders et al., 2020, for an in-depth discussion).

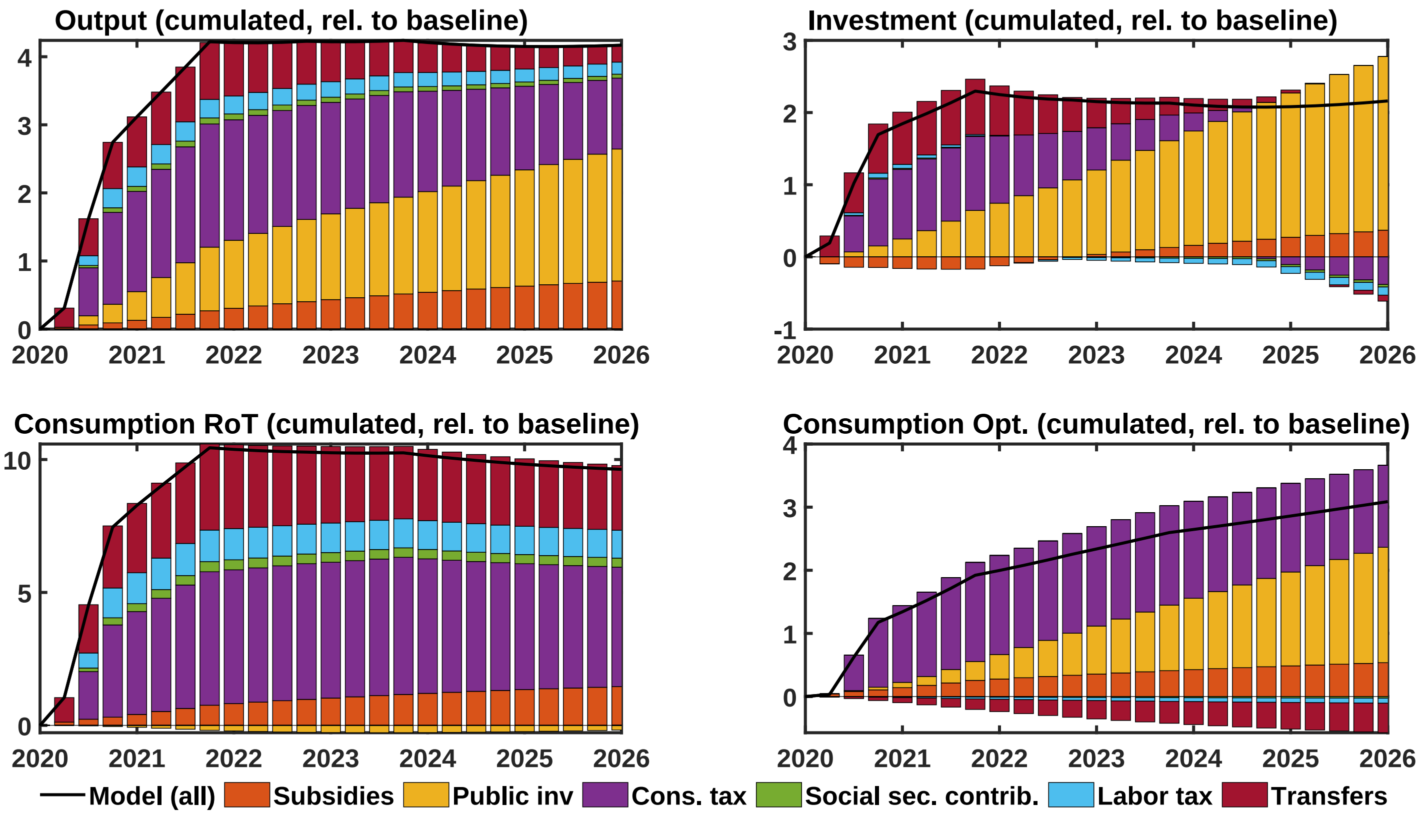
The most effective measure in the longer run is the increase in public capital investment. It fosters output on impact through an increase in aggregate demand as investment goods are bought by the government from the private sector. Given that public investment increases the public capital stock, which affects private-sector productivity positively, private investment demand starts to increase eventually. The positive policy-induced "productivity" shock generates effects that are similar to a pure technology shock (see also Leeper et al., 2010, and Gadatsch et al., 2016, for a more detailed discussion). We nicely see that, as the productivity effect starts to kick in, the positive impact of the increase in public investment rises. It is noteworthy that the size of the effect very much depends on the productivity-enhancing impact of public capital, captured by the parameter $\eta_{K^g,z}$. If the productivity-enhancing impact is zero, we only observe a small positive impulse on impact (due to higher demand) that fades out quickly. If we differentiate productivity by sector (or assume that a single sector does not benefit from the type of public investment undertaken), different sectors would also be affected very differently by this shock (see also Bom and Ligthart, 2014, for a discussion). Hence, the extent public investment positively affects aggregate and sectoral output certainly very much depends on the degree of productivity-enhancement we assign to it. Future research should certainly address which sectors benefit from which type of public investment.

Figure 6: Paths of key macro variables with fiscal stimulus packages relative to baseline scenario (aggregate)



Notes: Figure plots (projected) paths of selected aggregated macroeconomic variables with the fiscal package (red dashed line) relative to the baseline scenario without fiscal intervention.

Figure 7: Cumulated impact of fiscal measures on key macroeconomic variables



Notes: Figure plots (projected) impact of different fiscal measures on selected macroeconomic variables. The contribution of each fiscal measure to these developments is shown by the colored bars as indicated.

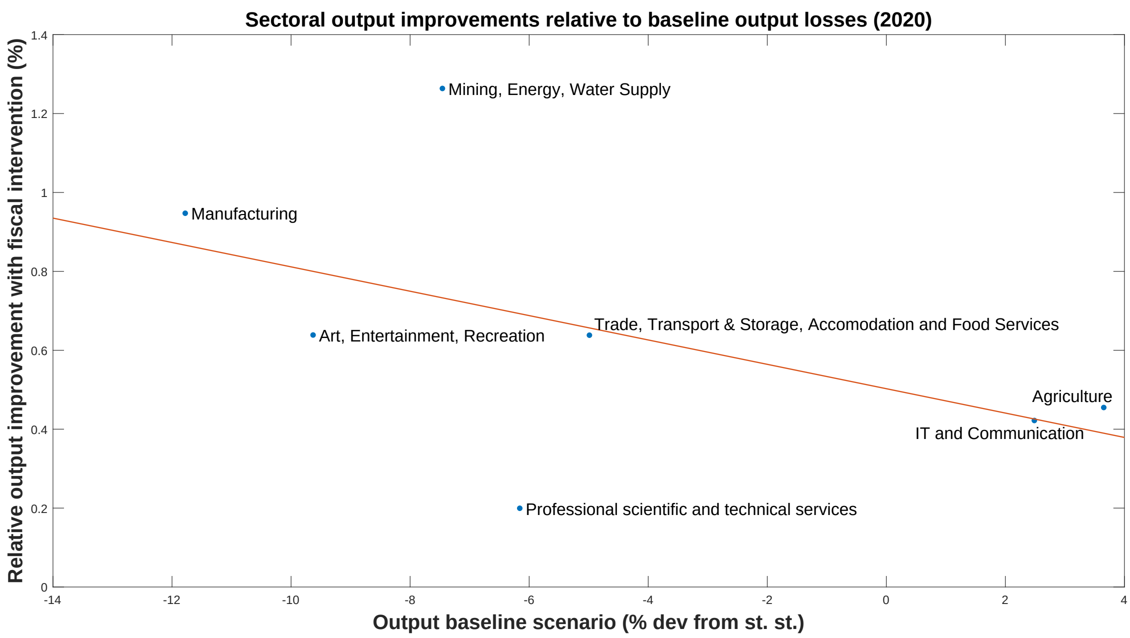
In terms of a cost-benefit analysis, and given the parametrization of the impact of public capital on productivity, public investment is a very efficient tool. Its impact on the primary deficit is rather small (see Figure 2), while the impact on output, investment and consumption is quite large (see Figure 7). However, it takes some time that these effects materializes which makes public investment perhaps less efficient in terms of short-term demand stabilization. Transfers, relief in terms of labor income taxation and social security contributions also seem to be quite cost-efficient. The reduction in consumption taxation, is quite costly, but also affects output positively through its success in stabilizing consumption of liquidity-constrained households. While subsidies for firms are costly, they do not show a large stabilizing effect on output. They stabilize consumption of both household types to a small extent, but crowd out investment at the beginning. In terms of subsidizing firms, it is however also worthwhile to have a closer look at the evolution of the sectoral default probabilities in Figure 5. As we can see, the probabilities of default fall below their steady-state levels in the agricultural (sector 1) and the IT (sector 5) sector. A probability of default below the steady-state level indicates that, because of the fiscal package, firms that would have left the market in normal times now survive (for longer) even though a severe negative shock is hitting the economy. This indicates that subsidies granted to firms, which are the main driver for the reduction in the probability of default; see also equation (19)- do indeed seem to create some "zombie" firms. On the one hand, together with the fact that subsidies make up a fairly large part of the fiscal costs (see Figure 2) while having only a modest effect on output, this might be an indicator that too many subsidies were provided (according to our model).[18] On the other hand, this "zombification" only seems to last for a limited period of time (given that default probabilities converge again quickly), and an appropriate distribution of subsidies is difficult to assess in practice given the currently uncertain situation.

We can also take a more sectoral look at the pandemic shocks and fiscal packages (the corresponding Figures A.1 to A.6 have been relegated to the Appendix to save space). We note that consumption has been stabilized most by up to 5 PP and 3.2 in the agricultural and the manufacturing sectors, respectively. The latter also shows th largest increase in capital investment through the fiscal intervention by 1.6 PP at the peak. Labor costs can be reduced by about 4 PP across all sectors (except for agriculture, which is not hit hard by the crisis). The sectoral output effects of the fiscal package are rather heterogenous. We use Figure 8 to assess which sectors benefit most from the fiscal intervention in 2020. In the figure, we plot the sectoral output improvements relative to their sectoral output losses without fiscal intervention over the baseline output losses. The linear regression trend line is given in orange. Sectors above the trend line benefit disproportionately from the fiscal intervention, while those below the trend line improve to a lesser extent. We see that the mining, energy and water supply sector and the manufacturing sector experience the largest output improvement relative to the baseline scenario. However, the latter also suffers the largest baseline output contraction in 2020, while the former has relatively moderate output losses without fiscal intervention. It therefore benefits disproportionately compared with the professional, scientific and technical services and the cultural sector, which shows the second-largest baseline output losses but a significantly smaller relative improvement. Hence, relative to the other sectors, this sectors comes off worst. This

[18]Note that these results depend to a very great degree on the simulated amounts of subsidies as well as on the specific distribution across sectors, that we do not know.

might be due to the fact that the latter is rarely used as an intermediate input and hence positive effects in other sectors do not spill over to this sector. For 2021 (see Figure 9), the cultural sector lies slightly above the trend line, but also experiences huge output losses in the baseline scenario. The professional, scientific and technical services have no benefits from the fiscal intervention, while suffering the second largest baseline output losses. All remaining sectors have positive improvements, but are not or only to a small extent affected by the crisis anymore. Especially, the mining, energy, water supply and the manufacturing sectors benefit disproportionately well in 2021. Still, these sectoral effects should be taken with some care. As already mentioned, they are sensitive to our assumptions about the distribution of transfers and subsidies for firms.

Figure 8: Sectoral output improvements relative to baseline output losses (2020)

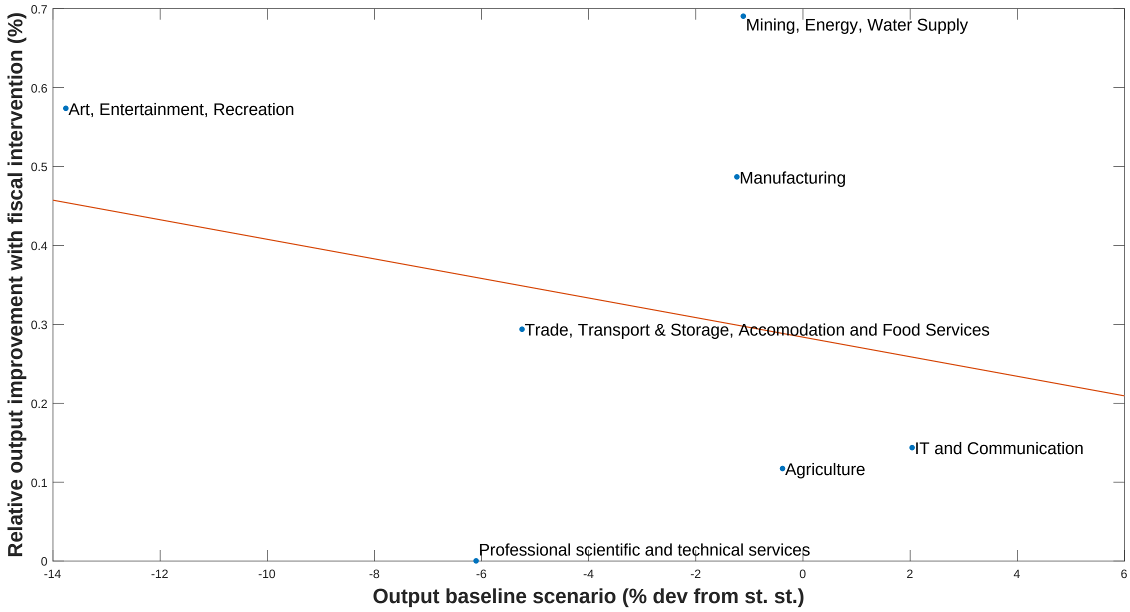


Notes: Figure plots sectoral relative output improvements with fiscal package 2 over sectoral output losses in the baseline pandemic scenario. The yearly result for 2020 was computed by averaging over the respective four quarters. The orange line denotes the linear regression trend line.

5.2 Fiscal multipliers

One way to measure the success of a fiscal stimulus program is to calculate a fiscal multiplier (Coenen et al., 2013). In our model, present value fiscal multipliers during the COVID-19 pandemic are calculated using a modified version of the multiplier presented by, for example, Leeper et al. (2010) and Bouakez et al. (2020). To be more precise, the present value multiplier for aggregate output, Y_t, to, for example, government transfers, TR_t, is given by the discounted sum of deviations of output with the fiscal change relative to a situation without the fiscal change, $\left(Y_{t+i}^{fiscal} - Y_{t+1}^{pandemic}\right)$. As the pandemic shocks are the same in both scenarios, this is close to calculating the fiscal stimulus package

Figure 9: Sectoral output improvements relative to baseline output losses (2021)



Notes: Figure plots sectoral relative output improvements with fiscal package 2 over sectoral output losses in the baseline pandemic scenario. The yearly result for 2021 was computed by averaging over the respective four quarters. The orange line denotes the linear regression trend line.

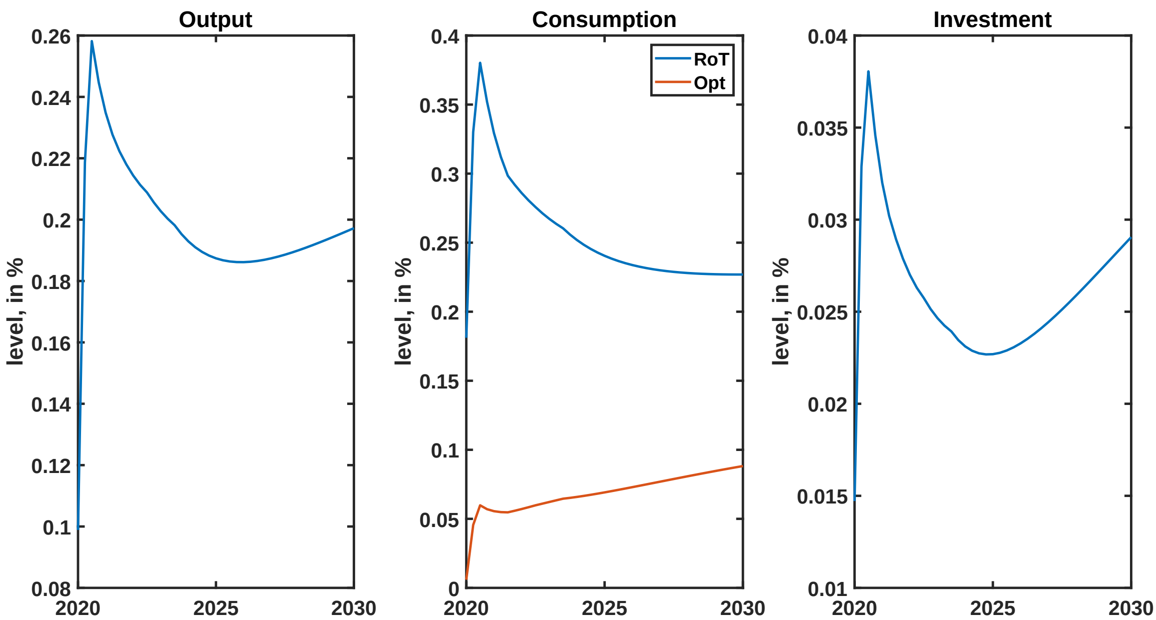
starting in the steady-state (see also Boysen-Hogrefe, Fiedler, Groll, Jannsen, Kooths, and Mösle, 2020, Box 2, for a discussion). Formally, the present value output multiplier of government transfers is given by

$$PV_t(k) = \frac{\sum_{i=0}^{k} \bar{R}^{-i} \cdot \left(Y_{t+i}^{fiscal} - Y_{t+i}^{pandemic}\right)}{\sum_{i=0}^{k} \bar{R}^{-i} \cdot \left(TR_{t+i} - \bar{TR}\right)}, \tag{35}$$

where k indicates the time span for which the multiplier is calculated ($k = 0$ is the impact multiplier, $k = 4$ the year-one multiplier, and so on). The multiplier holds analogously for other fiscal instruments and for sectoral output. To obtain the multiplier of the entire package, we have to sum the measures in the denominator (Figure 2) and take the corresponding transition path in the numerator (Figure 7 for the full stimulus program).

Figure 10 shows the present value fiscal multipliers for output, consumption (by household type) and investment over time, respectively. The output multiplier peaks in the second half of 2020 at a value of roughly 0.26, declines afterwards and converges to 0.2. The consumption multipliers confirm our finding that the fiscal stimulus measures are quite effective in stabilizing consumption of liquidity-constrained households. However, the investment multiplier is rather small driven by the fact that the share of public investment, which is usually associated with a multiplier larger than one, in the total package is also relatively small. Moreover, as shown in Figure 7, some measures lead to a crowding-out of private investment, reducing the investment multiplier. Overall, our model-implied output multiplier is perfectly in line with the corresponding estimates presented by the five leading German research institutes in their bi-annual forecast (with a special focus on the stimulus package; see GD, 2020, chapter 5). Their estimates for 2020 and 2024 range between (0.2, 0.7) and (0.2, 1.0), respectively. Our results rather lie at the lower bound, but the simulations also differ in several ways. First, we use a multi-sectoral DSGE model, while all research institutes do not allow for sectoral heterogeneity on the production side.[19] Second, we use updated fiscal data. Hence, the size and the composition of the fiscal package under investigation differs. Third, there exist different modeling approaches for single measures. For example, some do not directly include subsidies for firms that reduce production costs, but rather try to capture the effect by a reduced capital tax rate.

Figure 10: Present value fiscal multipliers



Notes: Figure plots present value fiscal multipliers for output, consumption by household types (Rule of thumbers and optimizers) and investment, respectively.

Besides that, there are two side remarks to be made here. As described above, we assume that lump-sum taxes levied on optimizers only do the job of consolidating the fiscal stimulus eventually in our simulations (as is done in, for example, Coenen et al., 2013, too). On the one hand, it is not clear whether or not such a non-distortionary consolidation instrument exists. If we were to use other fiscal instruments to bring the debt-to-GDP level back to the initial steady-state, the multiplier would decrease with the

[19]Note, that we would actually expect a higher multiplier in a model with inter-sectoral linkages due to the fact that any measure that alleviates the situation in one sector does the same in others as well, given that the sectors depend on each other. Hence, if all sectors benefit from the fiscal measures, the impact is increased relative to a one-sector economy that is usually assumed. The issue is discussed in more detail in Bouakez et al. (2020).

degree of distortions this instrument introduces in the economy. On the other hand, it is not entirely clear if the pandemic also affects the growth path in the long run (which is suggested by some commentators; see also Jordà, Òscar and Singh, Sanjay R and Taylor, Alan M, 2020). If it leads to a lower growth path, and if fiscal policy was able to prevent this (or at least to reduce the drop in long-run growth), multipliers could also be larger (see also Priesmeier and Stähler, 2011, for a more detailed discussion of such mechanisms). While these aspects of the pandemic are certainly of interest and highly important, we will leave them for future research for now.

5.3 Welfare

Another way to measure the success of a fiscal stimulus program is to calculate welfare with and without the fiscal policy intervention. To do so, we calculate the consumption-equivalent welfare gain, ce^i, for $i = o, r$, such that

$$\sum_{t=0}^{\infty} \beta^t \, U\left((1+ce^i)\bar{C}^i, \bar{N}^i\right) = \sum_{t=0}^{\infty} \beta^t \, U\left(C_t^i, N_t^i\right),$$

where the exact utility function $U(\cdot)$ is given by equation (1). Utility positively depends on the level of consumption, C_t^i, and negatively on N_t^i, the amount of labor provided (which measures forgone leisure). The bar indicates initial steady-state values. Hence, ce^i represents the amount of initial steady-state consumption a household of type i is willing to give up in order to live in a scenario without the shocks and the fiscal packages that we simulate. Results are summarized in Table 6. Note that aggregate economy-wide welfare is calculated as $ce = (1-\mu) \cdot ce^o + \mu \cdot ce^r$.

Table 6: Welfare assessment

	Optimizer	Rule-of-thumb	Total
Baseline pandemic scenario	-4.83	-0.94	-3.08
...with fiscal intervention	-4.72	-0.75	-2.94

Notes: Welfare presented as life time consumption equivalents for different household types. Aggregate economy-wide welfare is calculated as $ce = (1-\mu) \cdot ce^o + \mu \cdot ce^r$.

The pandemic is, as we can see, an extremely costly event. If they were able to avoid it, households would be willing to give up about 3% of their steady-state level of consumption each period. Costs are higher for optimizing households with a magnitude of almost 5 %. The reason is that the pandemic generates a huge loss in profits and capital gains, which is born entirely by optimizers. The fiscal stimulus package set up by the government is able to reduce welfare costs by about 5 %. In relative terms, rule-of-thumb households benefit more with a reduction in welfare costs of more than 20% versus a reduction of about 2% for optimizers. However, bearing in mind that the typical costs of business cycles amount to roughly 1% of steady-state consumption, as discussed in Gali et al. (2007) and Imrohoroglu (2008), among others, we see that the pandemic is a highly costly event and that the huge fiscal stimulus package set up by the government does indeed do a good job of alleviating these costs from an overall perspective.

6 Conclusion

The worldwide recession triggered by the COVID-19 pandemic required fiscal policy to step in to alleviate societal costs. The German government implemented various fiscal stabilization and stimulus measures. We assess this policy intervention by means of a dynamic New Keynesian multi-sector general equilibrium model in which different production sectors interact with each other.

Our results indicate that the fiscal package is indeed able to mitigate output and consumption notably in the short run. The present value fiscal output multiplier of the package amounts to around 0.2 in the long run, and the welfare costs of the pandemic can be reduced by around 5% on average and by 20% for liquidity-constrained households. The reduction of consumption taxation and direct transfers to households notably back consumption by liquidity-constrained consumers and stabilize output. Subsidies for firms are quite costly compared to their stabilizing effect, while public investment is the most cost-effective instrument. However, the positive effects of the latter materialize rather in the long run. Our paper sheds light on the question as to which fiscal policy measures help to mitigate the impact of the crisis and can provide guidance for possible further fiscal stimulus packages. Future research should also address the long-term consequences of the pandemic and tools for fiscal policy to improve the long-run outlook as well as appropriate ways to ensure the sustainability of public finances.

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A.1 Appendix

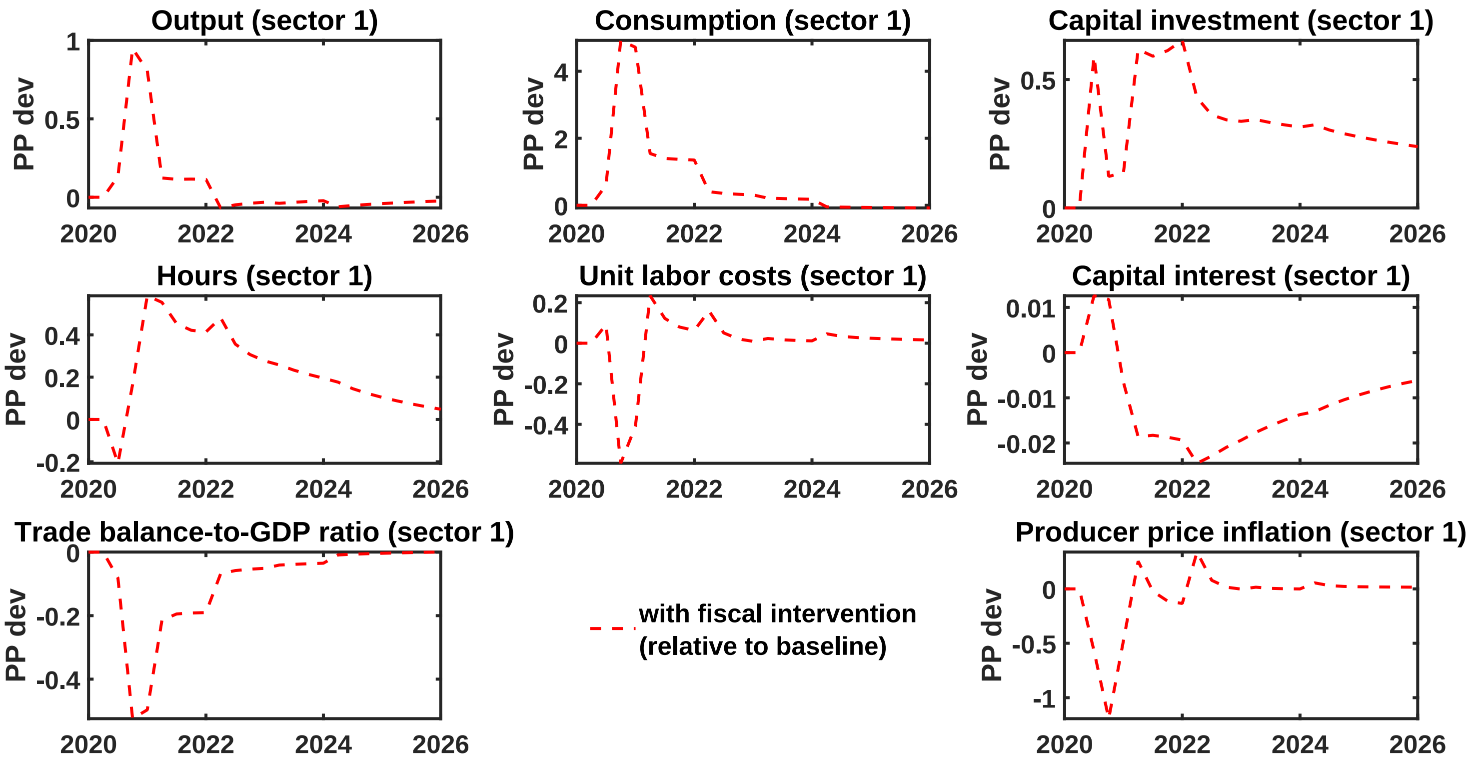
In this appendix, we provide more information on the sectoral assignments and show additional figures (some of which have already been touched upon in the main text).

Table A.1: Sector Assignments

Model Sector	NACE Sector
1. Agriculture, forestry and fishing	A
2. Mining and quarrying,	B
Electricity, gas, steam and air conditioning supply,	D
Water supply; sewerage; waste management and remediation activities	E
3. Manufacturing	C
4. Wholesale and retail trade; repair of motor vehicles and motorcycles,	G
Transporting and storage,	H
Accommodation and food service activities	I
5. Information and communication	J
6. Professional, scientific and technical activities,	M
Administrative and support service activities	N
7. Arts, entertainment and recreation,	R
Other services activities	S

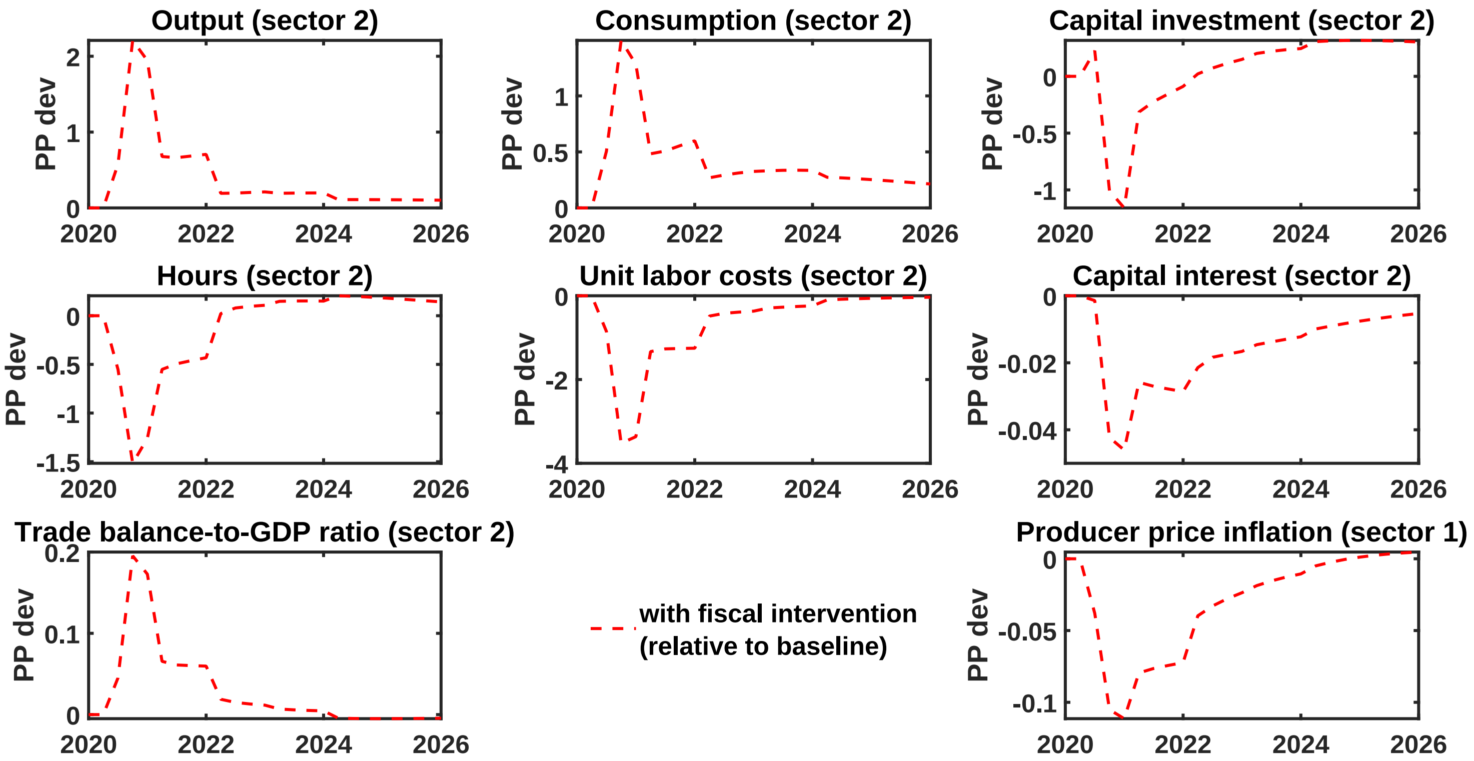
Note: This table summarizes the model sector assignments based on the NACE classification.

Figure A.1: Implications of COVID-19 pandemic and fiscal stimulus package for key macro variables (Sector 1)



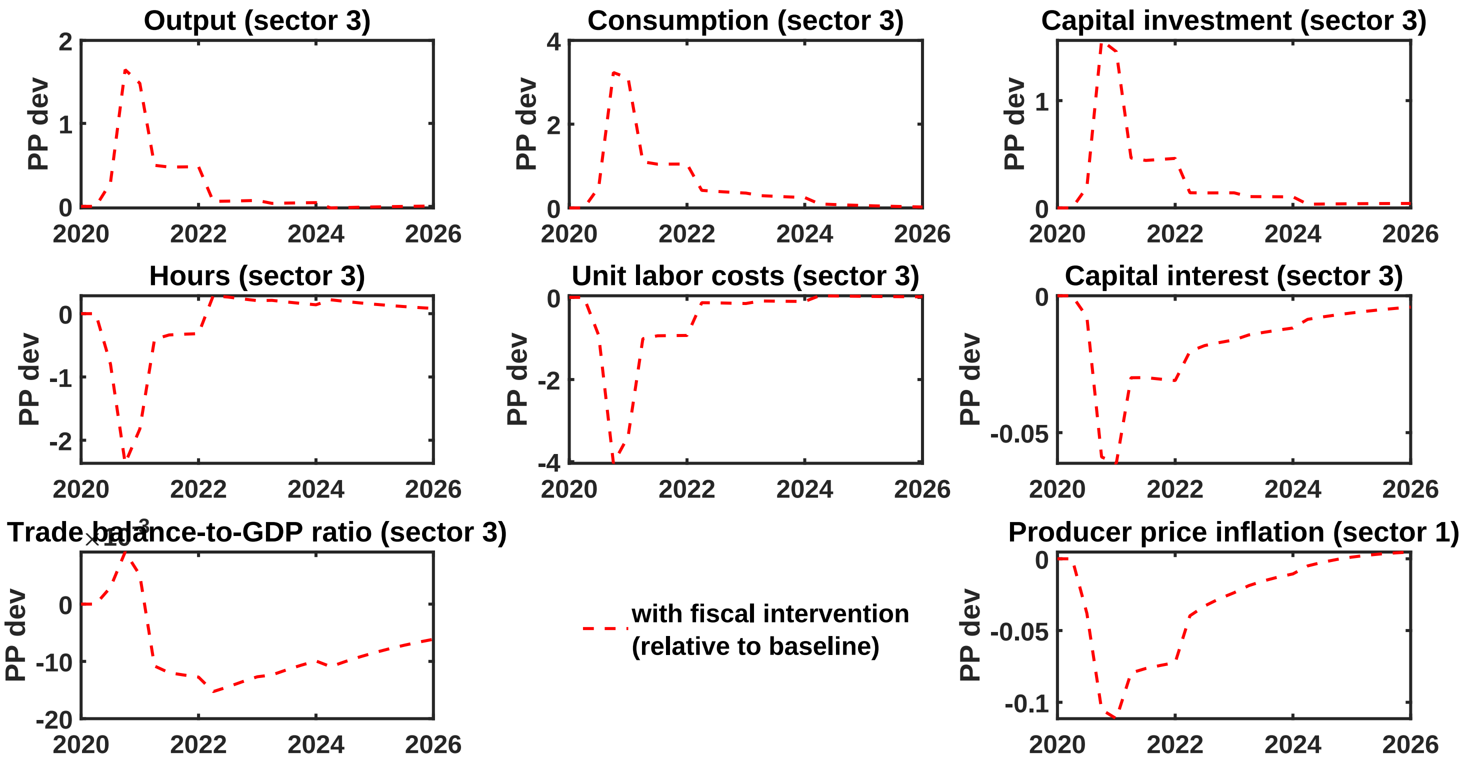
Notes: Figure plots (projected) path of selected variables of sector 1 after COVID-19 pandemic shocks without fiscal intervention (blue solid line) and with the fiscal package (red dashed line).

Figure A.2: Implications of COVID-19 pandemic and fiscal stimulus package for key macro variables (sector 2)



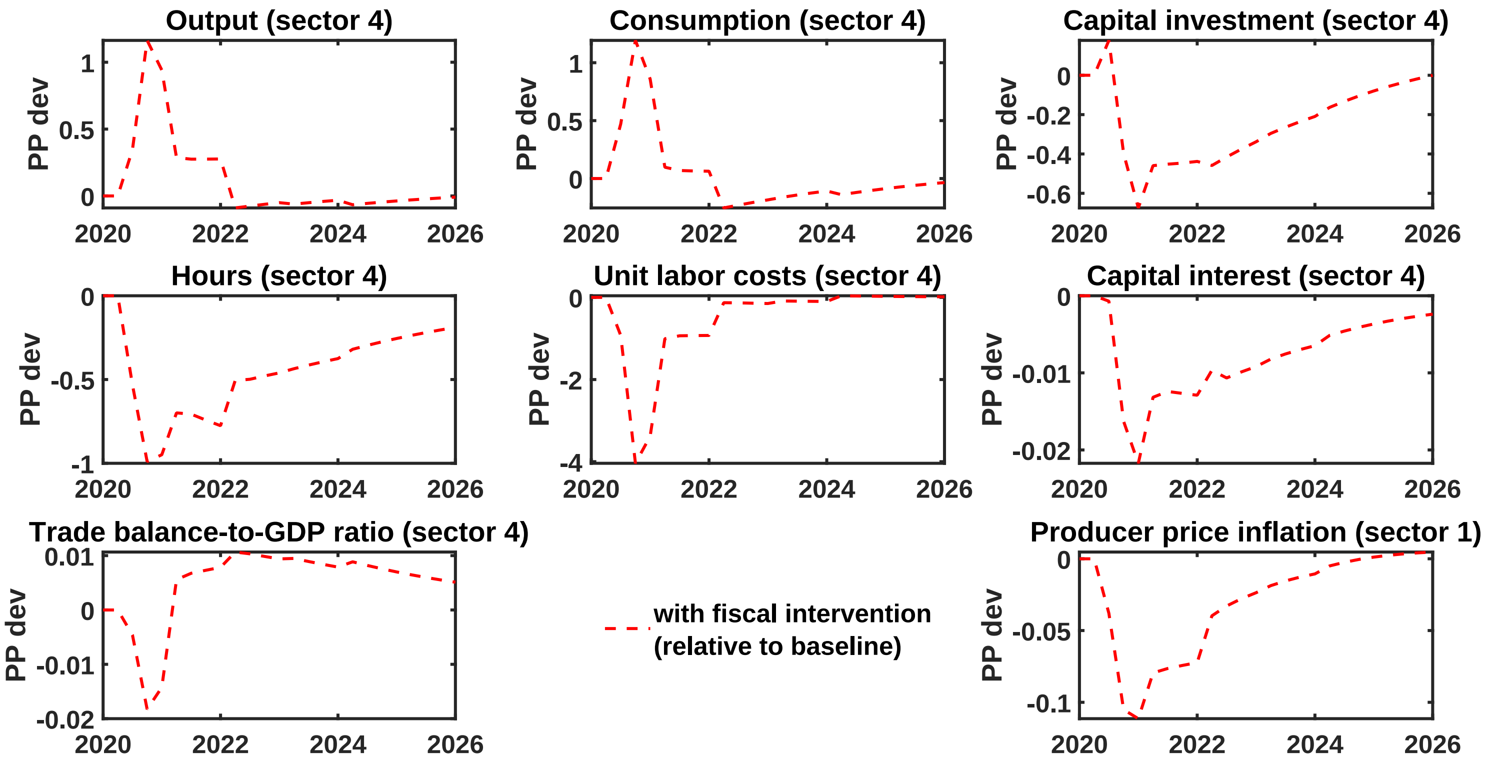
Notes: Figure plots (projected) path of selected variables of sector 2 after COVID-19 pandemic shocks without fiscal intervention (blue solid line) and with the fiscal package (red dashed line).

Figure A.3: Implications of COVID-19 pandemic and fiscal stimulus package for key macro variables (sector 3)



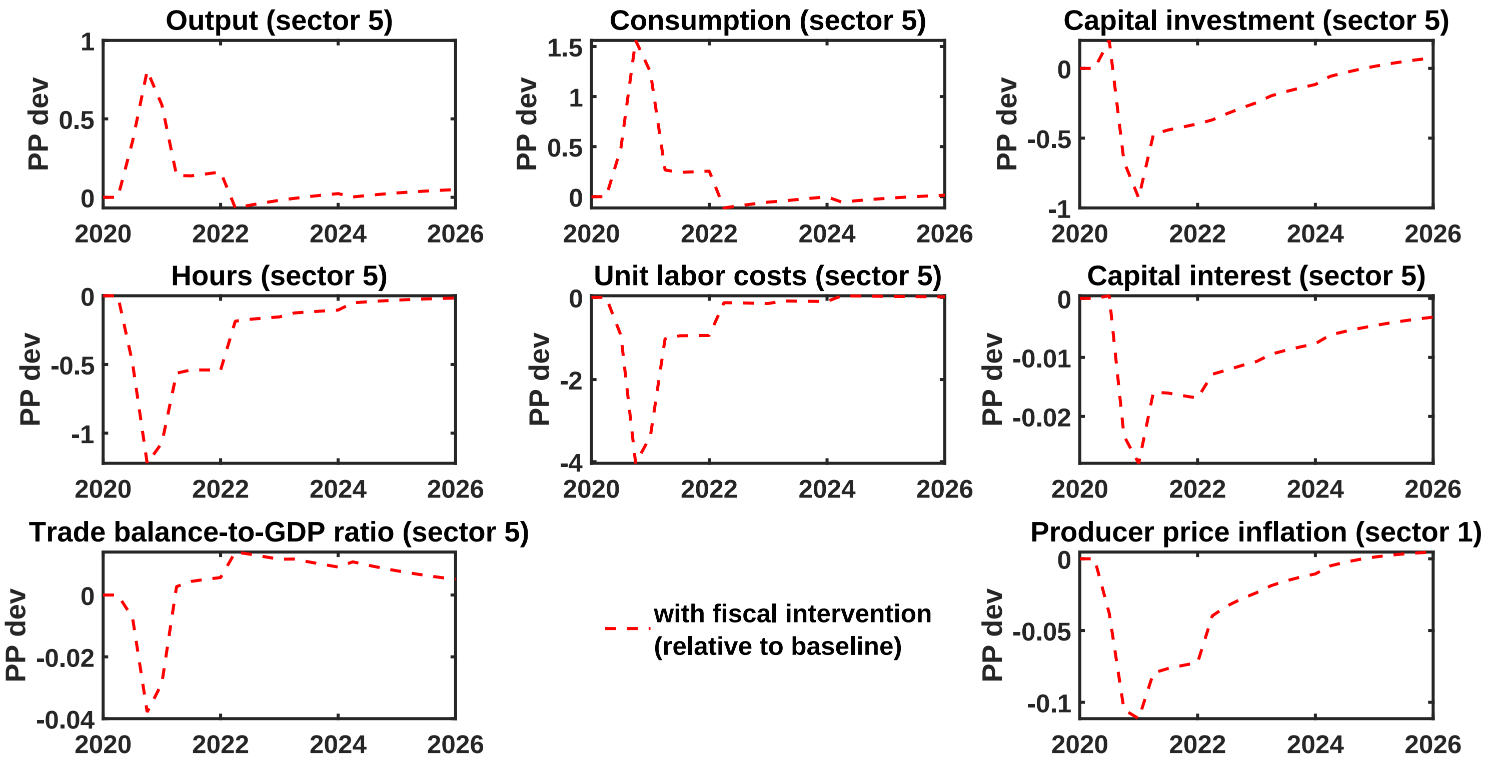
Notes: Figure plots (projected) path of selected variables of sector 3 after COVID-19 pandemic shocks without fiscal intervention (blue solid line) and with the fiscal package (red dashed line).

Figure A.4: Implications of COVID-19 pandemic and fiscal stimulus package for key macro variables (sector 4)



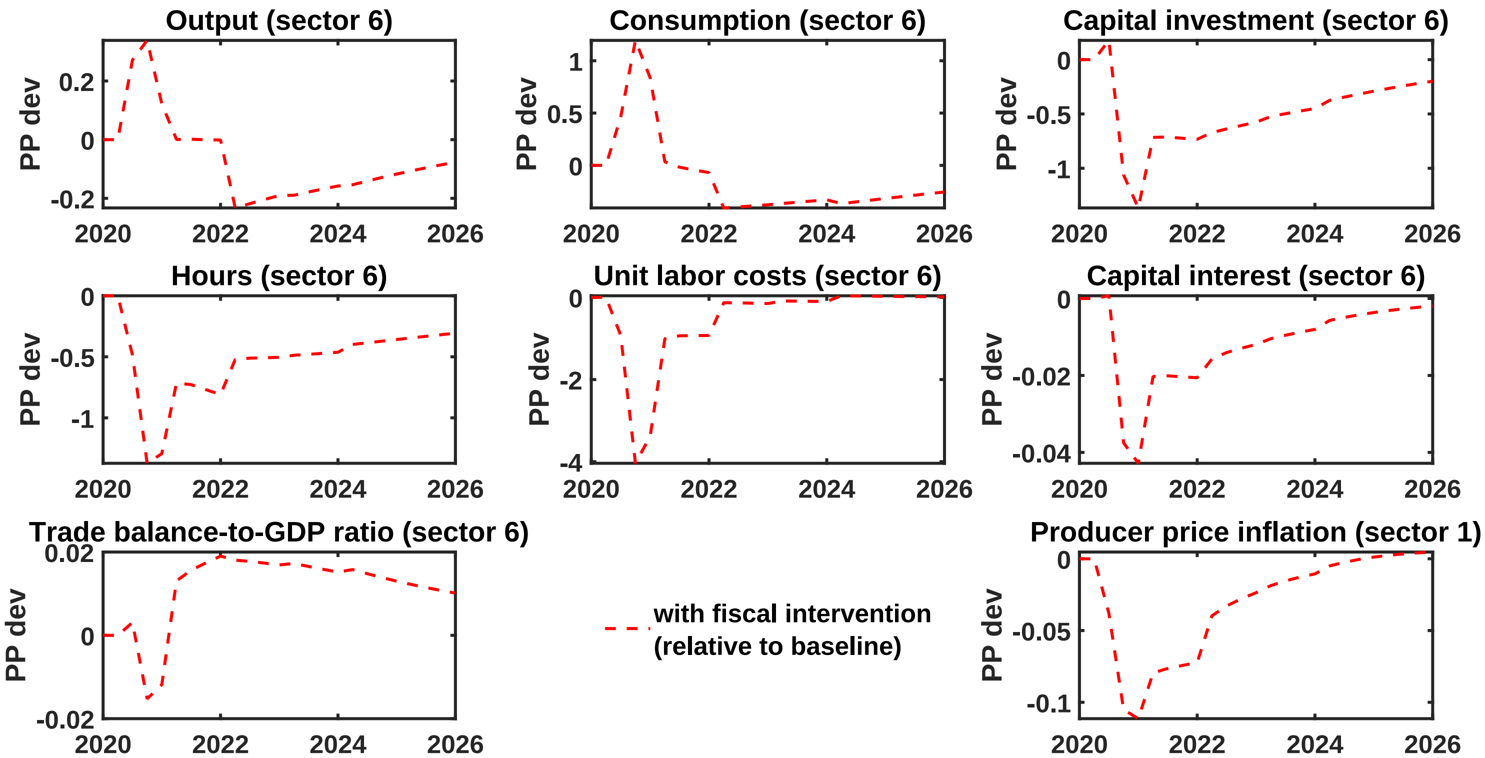
Notes: Figure plots (projected) path of selected variables of sector 4 after COVID-19 pandemic shocks without fiscal intervention (blue solid line) and with the fiscal package (red dashed line).

Figure A.5: Implications of COVID-19 pandemic and fiscal stimulus package for key macro variables (sector 5)



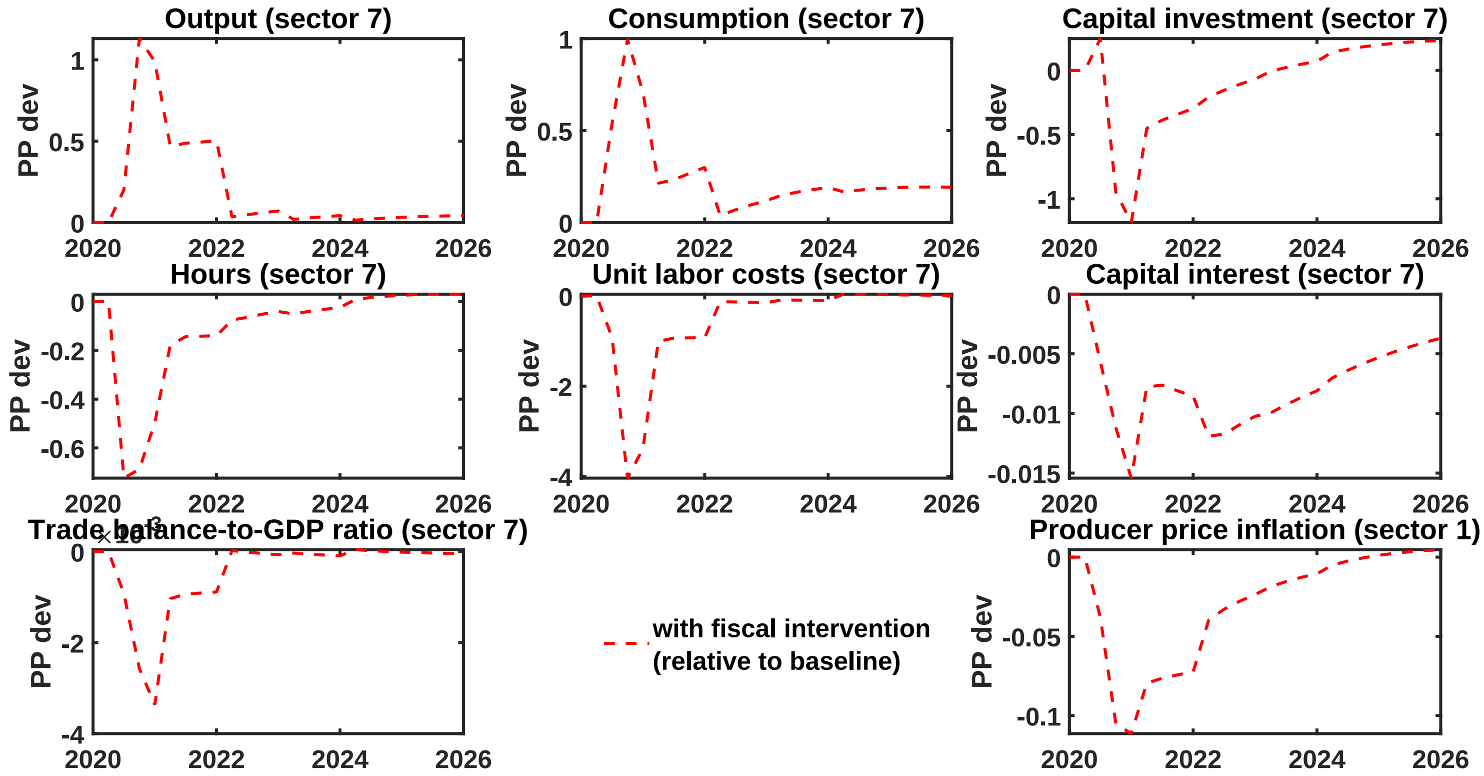
Notes: Figure plots (projected) path of selected variables of sector 5 after COVID-19 pandemic shocks without fiscal intervention (blue solid line) and with the fiscal package (red dashed line).

Figure A.6: Implications of COVID-19 pandemic and fiscal stimulus package for key macro variables (sector 6)



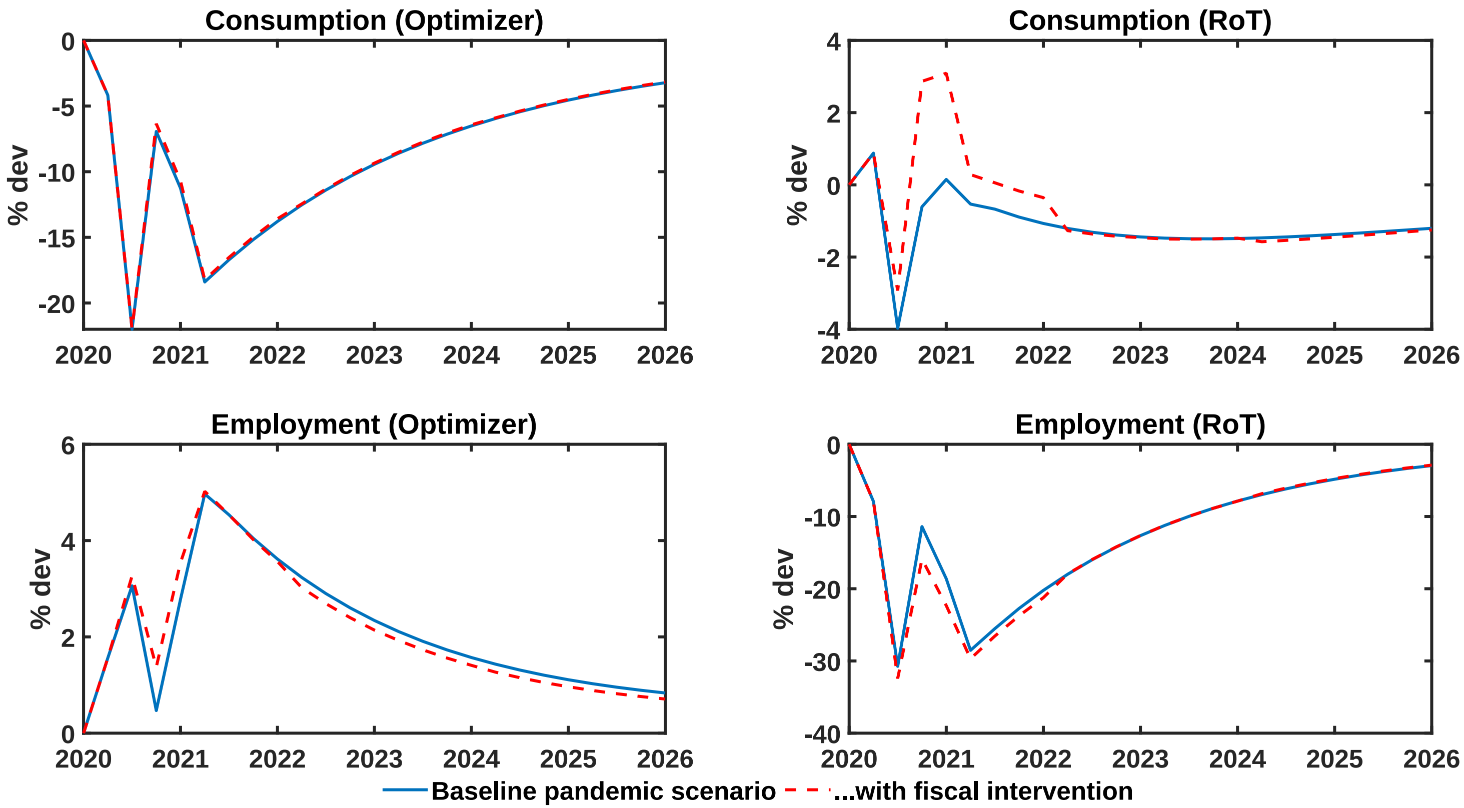
Notes: Figure plots (projected) path of selected variables of sector 6 after COVID-19 pandemic shocks without fiscal intervention (blue solid line) and with the fiscal package (red dashed line).

Figure A.7: Implications of COVID-19 pandemic and fiscal stimulus package for key macro variables (sector 7)



Notes: Figure plots (projected) path of selected variables of sector 7 after COVID-19 pandemic shocks without fiscal intervention (blue solid line) and with the fiscal package (red dashed line).

Figure A.8: Implications of COVID-19 pandemic and fiscal stimulus package for household-specific variables



Notes: Figure plots (projected) path of selected household-type variables after COVID-19 pandemic shocks without fiscal intervention (blue solid line), with the first fiscal package (green dashed line) and the full fiscal stimulus package (including the first emergency assistance package; red dotted line).