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An Agent-based Model

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Abstract

We study the distributional consequences of COVID-19 by using a stock-flow consistent agent-based model that captures some of the aspects of pandemic-related lockdowns. In particular, the model distinguishes between ‘essential’ and ‘non-essential’ industries, between jobs that can be done from home and jobs that must be carried out on site, and takes into account that firms need to hire a certain amount of overhead labour. Allowing for government-financed short-time working schemes and loan guarantees, we find that these policies significantly reduce the rise in firm liquidations and income inequality (the ‘Keynesian’ result). However, we also find that the absence of government policies leads to higher levels of productivity and GDP in the aftermath of the crisis, as it means that more of the less productive firms face liquidation during lockdowns (the ‘Schumpeterian’ result). The last finding must be taken with adequate caution as our model is designed to describe the short run, while statements about the long run would require the inclusion of additional features such as technological progress and the entry of new firms.

Keywords: stock-flow consistent agent-based models, COVID-19, creative destruction, income inequality, short-time work, public loan guarantees

JEL classification: E24, E25, E65

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1. Introduction

COVID-19 has had an enormous impact on societies worldwide. As has been pointed out by numerous empirical studies (see, for example, Blundell et al., 2022; Carta and De Philippis, 2021), the burden of the economic measures aimed at hampering the spread of the disease was not spread equally among members of society. The crisis affected different branches of economic activity – especially because of lockdown regulations – and also employees in these branches in different ways. In particular, some jobs could be undertaken from home relatively easily, while other jobs continued to be performed on site. Furthermore, there were distinct phases in the way in which the Covid crisis proceeded, owing to the various phases of lockdowns, which also impacted on spending patterns of the population. The labour market effects were significant in the short term and could also have longer-run consequences, such as lengthier spells of unemployment that could adversely affect prospects of regaining employment, and also the productivity of such workers once they were re-employed. During the crisis, governments also tried to intervene in a number of ways to alleviate its impact: through short-term work schemes to keep people in employment, financial assistance to firms to stay in business during lockdowns, various forms of income support and loan schemes to firms, and fiscal measures (delays in tax payments, discretionary fiscal spending etc.); monetary policy also played a role (affecting credit conditions on financial markets).

We have tried to capture some of these aspects in the model we employed in this paper. It captures 'structural aspects', such as some differentiation into economic branches (we distinguish between 'essential' and 'non-essential' sectors of the economy). In addition, it recognises the differentiation of the labour force between workers who have jobs that could be done from home ('home workers') and others with jobs that must be executed on site ('production workers'). It is also an 'agent-based' model, distinguishing large numbers of households and firms, so that we can track what happens to the various segments of the household and firm distributions during the various phases of the Covid crisis. We shall also attempt to capture the 'hysteretic' effects of the crisis, which result from spells of unemployment affecting the productivity of workers, and we analyse the impact of a number of government interventions, notably in short-term employment schemes and loan schemes for companies, as well as overall fiscal support. In this 'structural cum agent-based model', we shall focus on the structural and distributional aspects of the crisis (impacts on different segments of the labour force and on households' income and wealth positions) and on the effectiveness of different government measures. The model will capture Schumpeterian ('creative destruction') and Keynesian features (effectiveness of government policies) and emphasise market structure and distributional dynamics in the course of different phases of the Covid crisis.

We present a short literature review in Section 2, continuing with a description of the model in Section 3. Section 4 outlines the simulation scenarios, the results of which are presented in Section 5. Finally, Section 6 provides some robustness checks and Section 7 presents our conclusions.

2. Literature

Delli Gatti and Reissl (2020) build on the CATS framework (Assenza et al., 2015) and include an epidemiologic sub-model. They distinguish between three categories of firms: producers of capital goods, essential consumption goods and non-essential consumption goods. The household sector is made up of two types: workers and firm owners. Owners receive dividends from their firms, as well as a share of bank profits. The model assumes a single bank which supplies loans to firms, depending on a firm's net worth as well as its leverage. The possibility of household credit is not accounted for. Wages are assumed equal across firms and workers are homogenous. Allocation of consumption demand is a function of the relative prices of essential and non-essential goods. Agents that practise social distancing are assumed to shift consumption demand away from non-essential to essential goods. They assume that a part of the non-essential goods producers must stop production. Those that continue producing do so at reduced productivity. Within this framework, they analyse the impact of a short-time working scheme with full worker compensation, one-off government transfers to firms, credit guarantees by the government, government provision of equity to bankrupt firms and transfer payments to workers.

Basurto et al. (2020) build on the EURACE model (Deissenberg et al., 2008) and include an epidemiologic sub-model. They assume three kinds of sectors: manufacturing, services and food. These sectors differ with respect to labour productivity. Wages are sector-specific and depend on the average productivity in that sector. Household skills are assumed to be sector-specific, which means that each household is confined to one sector. Firm profits are distributed among households. Households allocate demand between the three types of products according to exogenous quotas, but it is assumed that in the case of income losses, food consumption is reduced by less than is proportional. They assume that a certain proportion of workers can work from home (drawing on a study by Fadinger and Schymik, 2020); this proportion is assumed to be equal to zero in the food sector. Concerning policy, they distinguish between a lockdown and an opening-up stage, where in the latter individual prevention measures and home office are kept. During these lockdowns, the shopping probability of households is reduced. The supportive government measures considered are short-term work and firm bailouts.

Mellacher (2020) accounts for eight types of agents (differing according to age, economic role and types of interactions), three private-sector branches (offices, factories and commercial leisure activities) and three types of government activity (schools, hospitals and other government activity). He subsequently looks at the implication of school closures on parental caring responsibilities. Thereby, he focuses on analysing the different types of interactions that take place and their epidemiological implications: Agents have different preferences for leisure activities, which vary in the amount of interaction with others. Occupations also differ in the level of interaction with others. Production in the factory branch is conducted using only blue-collar workers, whereas production in the office branch takes place with white-collar workers as the only input. The productivity of white-collar workers depends on their caring responsibilities. Agents allocate their budget according to fixed shares.

In contrast to the previous authors, Sharma et al. (2021) do not include an epidemiological sub-model. They model the household and the banking sector only at the aggregate level. Therefore, the model is

not able to discuss issues of household inequality. The model assumes that firms' adjustment of production to demand depends on the real interest rate and the indebtedness of firms. Wage negotiations at firm level also depend on these factors, as well as the unemployment rate. They model the pandemic as a shock to firm productivity and the household sector's propensity to consume. Government policies include providing easy access to credit and one-off government transfers to households; they find both measures to be highly effective.

Poledna et al. (2020) propose an agent-based model of the Austrian economy, exposing it to simultaneous shocks to domestic supply, export demand and imports, as well as accounting for short-time working, but also without including an epidemiologic sub-model. They find the largest losses in those sectors that cater to final demand (retail, construction, services, transportation).

In contrast to Delli Gatti and Reissl (2020), Basurto et al. (2020) and Mellacher (2020) – but in line with Sharma et al. (2021) and Poledna et al. (2020) – we do not include an epidemiological sub-model. We make this simplification because we want to concentrate on the distributional consequences of political measures rather than their epidemiological effects.[1] Contrary to Delli Gatti and Reissl (2020), our analysis accounts for different types of workers as well as the possibility that households take up loans. Unlike Sharma et al. (2021), we do not rely on aggregate representations of the household and banking sector. Although in Basurto et al. (2020) workers are bound to a certain sector, our agents can switch sectors. Mellacher (2020) focuses on the epidemiological consequences of agents performing different kinds of actions (several leisure- and work-related activities) which involve different degrees of interactions with other people and hence contribute differently to the spread of the disease. In contrast, we focus on the economic and distributional consequences. Finally, Poledna et al. (2020) employ a model that is designed to make economic forecasts, which means that its calibration considers a lot of very detailed data. The purpose of our model is not to make economic forecasts, but to choose a level of abstraction that allows us to identify basic channels through which structural change and inequality impacts emerge in different scenarios.

[1] Although of course they are not completely independent from each other.

3. Model

Our model contains two types of firms: one producing/supplying an 'essential' good or service, and the other a 'non-essential' good or service. Furthermore, we introduce two types of workers, production workers and home workers. We assume that tasks performed by the latter can be performed remotely, while those of the former cannot.

All agents in our simulation are placed in a specific location. We model the location of agents as placed on a circle. The location plays a role in job search decisions and consumption decisions by households.

3.1. ORDER OF EVENTS

In every period, the following events take place:

1. Banks and the central bank pay interest on deposits and collect debt payments (the issuing of loans follows later in the sequence). Government makes debt payments on its bonds.
2. Firms make their decisions:
    1. Update sales expectations.
    2. Calculate their labour demand.
    3. Set wages.
    4. Fire workers or send out job offers to households.
3. Unemployed households apply for jobs.
4. Firms hire households/workers who have replied to their job offers.
5. Government adjusts and distributes social security and unemployment benefits and decides how much to spend on goods (in part, based on a ‘fiscal rule’).
6. Firms produce their output, pay wages, set the prices for outputs, and deliver these to the market.
7. Households calculate their consumption demand (for every type of product, based on a consumer expenditure system) and go to the market to buy goods. Unsold goods are returned to firms and kept as inventories.
8. Firms pay taxes to the government.
9. Bank accounts are consolidated, i.e. households and firms with negative positions apply for credit to avoid bankruptcy. Bankrupt firms are liquidated, while the consumption level of bankrupt households is set to a subsistence level (until their loans are repaid) – this is discussed in more detail later.

3.2. HOUSEHOLDS

Households differ in the type of work they can perform. There are two types of work: 'home work' (work that can be carried out remotely or from home) and 'production work' (work that must be performed on site).

Households that are unemployed at the start of a period look for work: firms post vacancies to a job board, where households select a fixed number of job offers and rank the job offers by attractiveness. Attractiveness of a job offer depends on the posted wage offer as well as on the 'closeness' of the firm, i.e., households prefer jobs at firms that are located close to them. Firms will then review the applications and take on the most productive applicants. All households have the same initial individual level of 'worker productivity'. However, when households become unemployed, their productivity level starts to erode.[2] The longer a household stays unemployed, the more its productivity level suffers and the more difficult it becomes to get employed again. Worker productivity rises again when the household becomes re-employed.

Each household owns a deposit account at a bank. All income is transferred to that deposit. Households that remain unemployed will receive unemployment benefits from the government.

Employed households earn a wage (the wage setting is discussed in the section on firms, below), they go to the market and spend their consumption budget.

Households decide on their consumption budget and how to allocate it on the available products as follows. The total real consumption demand is calculated as:

$$C_{h,t}^{real} = \max\left\{c_0 + c_1 \cdot \left(\frac{Y_{h,t} + R_{h,t-1} - debtpay_{h,t}}{P_t} - C_a\right) + c_2 \cdot \frac{W_{h,t}}{P_t}, C_a\right\}$$

where c_0 is autonomous consumption (a subsistence level of consumption that every household must consume), Y_t is wage and interest income, R_t are received profits, $debtpay_t$ are debt repayments that a household may have to undertake, P_t is the aggregate price level, W_t is net wealth of the household and c_1 and c_2 are consumption propensity parameters. Specifically, c_1 is the propensity to consume out of current income and c_2 is the propensity to consume out of wealth.

Household net wealth is the difference between household deposits ($D_{h,t}$) and household loans ($L_{h,t}$):

$$W_{h,t} = D_{h,t} - L_{h,t}$$

The total nominal consumption spending is then simply the real consumption demand multiplied by the price level P_t.

As we allow for multiple products, the nominal consumption budget must be split among the products of the different producers. We rely on the Almost Ideal Demand System (AIDS) (Deaton and Muellbauer,

[2] We assume that individual productivity declines at rate γ during each period spent in unemployment. When re-employed, individual productivity rises at rate γ until the initial level is reached again. In practice, this means that each hired worker enters the production function as 1 unit of labour input, which e.g. reduces to $1 \cdot (1 - \rho)$ after one period of unemployment. If re-employed in the next period, that level would increase to $1 \cdot (1 - \rho) \cdot (1 + \rho)$ until eventually reaching a maximum of 1.

1980) to compute the budget shares of products for a given overall consumption budget and current product prices:

$$w_i = \alpha_i + \sum_{j=1}^{n} \gamma_{ij} \cdot \log(p_j) + \beta_i \log\left(\frac{C_t^{nom}}{Q}\right)$$

where w_i is the (nominal) expenditure share on product i , p_j is the average price for product j, C_t^{nom} is the total nominal consumer spending (i.e. $C_t^{nom} = C_t^{real} \cdot P_t$). Furthermore, the aggregate price index Q is defined as:

$$\log Q = \alpha_0 + \sum_{j=1}^{n} \alpha_j \log(p_j) + \frac{1}{2}\sum_{j=1}^{n}\sum_{k=1}^{n} \gamma_{jk} \cdot \log(p_j)\log(p_k)$$

α_0, α_i, β_i and γ_{ij} are parameters that govern the reaction of the household to changing prices and income (in particular, γ_{ij} refers to substitution elasticities and β_i to the income elasticity for good i. We set the parameters so that they fulfil the requirements for *adding up* (budget shares sum to 1), *homogeneity* (if all prices and expenditure change proportionally, there is no change in the budget shares) and *symmetry* (the effect of a price change of good i on demand for good j is the same as the inverse of a price change of good j on demand for good i). The formula for the aggregate price index Q is somewhat complex as it takes account of the fact that the weights by which the different products enter the index are themselves endogenous and a function of the budget share decisions of households.

For each of the individual products, households observe the offers of all the firms that supply this product and rate these by their attractiveness: attractiveness (a_f) is influenced by the price charged by the firm (p_f) and its geographical proximity ($distance_{i,f}$) relative to the total geographical size of the economy ($size_e$):[3]

$$a_f = \mu \cdot \frac{distance_{i,f}}{size_e} + (1 - \mu) \cdot p_f$$

The household will then spend the largest share of purchases of a particular good on the most attractive firm offer and less on less attractive offers (the shares of the firms are based on the relative attractiveness).[4] If the offered quantity that can be supplied by a particular firm is exhausted, households will have to allocate the rest of their spending on that product to supplies from other firms.

The change in the amount on a household's deposit ($D_{h,t}$) is equal to the difference between its total income ($Y_t + R_t$), its total expenditures, consisting of consumption expenditure and debt payments ($debtpay_{h,t}$), which includes interest and repayment of the principal) and the amount of new loans $\Delta L_{h,t}$:

$$\Delta D_{h,t} = Y_{h,t} + R_{h,t} - C_{h,t} - debtpay_{h,t} + L_{h,t}^{new}$$

[3] For applications of similar mechanisms, see Caiani et al. (2018), Gräbner-Radkowitsch et al. (2022a) and Schütz (2022).

[4] As the attractiveness score is a number between 0 and 1, where lower attractiveness score is better, we compute the share of a firm in the consumption budget of the household as 1 / (attractiveness * adjustment_factor) where adjustment factor is set to 2. The resulting shares are then normalised so that they sum to 1.

Households apply for loans at the end of the income-expenditure cycle when they find themselves with a negative deposit. The attractiveness of a loan offer is determined by the bank's geographical proximity and the charged interest rate (see also Schütz, 2022), but as we assume for simplicity that interest rates are constant and uniform across banks, households accept the offer of the bank that is located closest to them. Household loans evolve according to:

$$L_{h,t} = L_{h,t-1} - repay_{h,t} + L_{h,t}^{new}$$

where $repay_{h,t}$ denotes the repayment of the principal and $L_{h,t}^{new}$ new loans taken by households. We shall return to the issue of household-bank relationships below, and also to wealth accumulation and bankruptcy of households.

3.3. FIRMS

Each firm owns a deposit account at a bank, which is used for settling its transactions. Firms are located in two distinct sectors of the economy (those that produce 'essentials' and those that produce 'non-essentials') and they differ in their productivity and in the composition of production and home workers that they employ. Firms also differ in terms of a 'total factor productivity' term, and these productivities – owing to the absence of technological change – stay constant throughout the simulation. In the current set-up, these are set to follow a log-normal distribution across firms. These productivities determine the quantity of a good that can be produced with one unit of (aggregated) labour input; thus, the most productive firms will have the lowest unit costs (as wage rates do not differ across firms).

At the beginning of every period, firms adaptively update their sales expectations, based on the observed previous gap between actual sales and sales expectations. Sales expectations are adjusted downwards when sales fall short of expectations owing to a lack of demand, but not when sales fall short because the firm was running out of goods to sell.

$$y_{t-1}^{d} > y_{t-1} \text{ and } inv_{t-1} = 0\text{: } s_t^e = s_{t-1}^e + \lambda \cdot \max(s_{t-1} - s_{t-1}^e, 0)$$

$$\text{else: } s_t^e = s_{t-1}^e + \lambda \cdot (s_{t-1} - s_{t-1}^e)$$

where y_{t-1}^{d} and y_{t-1} denote desired and actual production in the previous period, inv_{t-1} stands for inventories left from the previous period, s_{t-t} is the firm's sales in the previous period and s_t^e indicates the sales expectation for period *t* (see Caiani et al., 2016); λ governs the strength with which firms adjust their expectations and it holds that $0 \leq \lambda \leq 1$.

Based on the updated sales expectations, firms then make decisions about their desired labour force: if the current staff is too large, the most recently hired employees will be fired; if the staff is too small for the projected sales target, firms will hire additional workers. If the firms need to take on additional employees, they send out job offers (for each type of worker – production, home – separately) to a job board. There, unemployed households sort job offers according to attractiveness and apply for the most attractive ones. Firms then review the applicants and choose those with the highest productivity.[5]

[5] This means that, contrary to other agent-based models, neither the unemployed worker nor the firm automatically accepts a job offer/application. In Caiani et al. (2016), workers apply to a random subset of firms, with firms accepting

To translate the projected and planned output into labour demand, the firm calculates an average productivity per worker (as productivity levels of individual workers differentiate as a result of histories of unemployment and employment spells). As the productivity of newly hired employees can differ from this calculated average, the firm may or may not be able to produce as much as it originally planned.

The wage that is offered is the same for all employees of the same type, with home workers earning a higher wage than production workers.[6] Every 12 periods, it is adjusted for inflation, except during lockdowns.[7] All firms pay the same wages.

Firms produce according to a Leontief production function, where the input coefficients differ by the type of firm. One type of firm produces an 'essential' good (*e*) with a 'production worker-intensive' production technology, while the other type of firm employs a 'home worker-intensive' production technology to produce a 'non-essential' good (*ne*). Furthermore, in each sector firms differ in their basic levels of productivity (θ_f), leading to different input coefficients across firms. These basic levels of productivity are drawn from a log-normal distribution.[8] Specifically, the production function in sector *s* looks like:

$$y_s = \min\{\alpha_{pw,s} L_{pw}, \alpha_{hw,s} L_{hw}\}$$

where α_x is the input coefficient and L_x is the input quantity of input x. The subscripts pw and hw stand for production worker and home worker, respectively.

As an additional innovation, we assume that firms always require a certain number of home workers to operate, which we call 'overhead labour'. These home workers do not increase the possible production output, but they are required to oversee production, and perform accounting and management functions etc. Overhead labour will play an important part in the simulations, as it means that firms cannot scale down labour costs to the same extent as they reduce production.[9] The required number of this overhead labour is positively dependent on total output as $L_{oh} = c_{oh} + \text{ceiling}\left\{\frac{y}{\beta_{oh}}\right\}$, c_{oh} is a constant and β_{oh} is a parameter that governs the output threshold at which a new overhead worker is needed, i.e. hiring of these 'overhead' workers expands in discrete intervals in line with desired output levels. This also allows consideration of excess capacities of overhead labour.

Firms adjust prices (p_f) gradually:

$$p_{f,t} = p_{f,t-1} + \nu \cdot \left(p_f^d - p_{f,t-1}\right)$$

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the applicant with the lowest wage demands. Other models assume that workers accept the first job offer, with workers receiving job offers on a random basis (see Delli Gatti and Reissl, 2020; Basurto et al., 2020; Mellacher, 2020; Poledna et al., 2023).

6 The relationship between wages of home (w_{hw}) and production workers (w_{pw}) is $w_{hw} = w_{pw} \cdot (1 + \zeta)$.

7 As prices are very volatile during lockdowns, adjusting wages to the observed inflation rates would have a highly destabilising impact on the model. Therefore, wages are only adjusted outside lockdown periods.

8 Input coefficients for the production worker-intensive technology are calculated as $\alpha_{hw,e} = \theta_f/(\tau_h - \psi)$ and $\alpha_{pw,e} = \theta_f/[1 - (\tau_h - \psi)]$, while in the case of the home worker intensive technology they are calculated as $\alpha_{hw,ne} = \theta_f/(\tau_h + \psi)$ and $\alpha_{pw,ne} = \theta_f/[1 - (\tau_h - \psi)]$. Here τ_h denotes the exogenously chosen average ratio of home workers involved directly in the production process, whereas ψ provides the differentiation in terms of home worker intensity between sectors.

9 For a discussion of overhead labour, see, for example, Kalecki (1943, 1971), Lavoie (1992) and Dutt (2012).

where their desired price (p_f^d) is based on a mark-up (m) on unit labour costs (ULC): [10]

$$p_f^d = (1 + m) \cdot ULC \cdot (1 + t_{VAT})$$

where t_{VAT} denotes the value-added tax rate. Unit labour costs take into account variable labour costs (workers employed directly in the production process) as well as the utilised part of overhead staff.[11] The mark-up is adjusted in every period: if the firms' inventory (the amount of goods that could not be sold) is higher than a certain desired 'buffer' inventory stock (i.e. the firm has sold less than it expected), it will decrease its mark-up. However, if inventories are below the desired buffer inventory (i.e. the sales have exceeded the expectation of the firm), it will increase the mark-up. In situations when inventory is exactly equal to the desired level, the mark-up remains unchanged:

$$inv > inv^d\colon\ m_t = m_{t-1} \cdot (1 - \chi)$$
$$inv < inv^d\colon\ m_t = m_{t-1} \cdot (1 + \chi)$$
$$inv = inv^d\colon\ m_t = m_{t-1}$$

whereby desired inventory represents a share of sales expectations adjusted for any overproduction in the current period (i.e. any output exceeding desired output): [12]

$$inv^d = \iota \cdot s^e + y^o$$

Final output is then delivered to the market and offered at the calculated price. Households go, sequentially, to the market and buy their consumption goods. Goods that remain unsold are returned to the firms to be sold in the next period.

Finally, firms pay value-added taxes (calculated as a percentage of total sales) to the government and can then calculate their profits. Gross profits $R_{f,t}^{gross}$ are subject to a corporate income tax rate t_c. The rest will be distributed as income to the household owning the firm. When firms pay wages and distribute profits, they automatically withhold income taxes on wages $t_w \cdot W_{f,t}$ and profit income taxes $t_r \cdot \left(R_{f,t}^{gross} - t_c R_{f,t}^{gross}\right)$ and pay these to the government. Thus, net profit that can be paid to the owner household is equal to:

$$R_{f,t} = (1 - t_r)\left(R_{f,t}^{gross} - t_c R_{f,t}^{gross}\right)$$

The change in a firm's deposit $D_{f,t}$ thus becomes:

$$\Delta D_{f,t} = R_{f,t}^{gross} - t_c\, R_{f,t}^{gross} - R_{f,t} - t_r\left(R_{f,t}^{gross} - t_c\, R_{f,t}^{gross}\right) + L_{f,t}^{new}$$

[10] When short-time working schemes are in place, those wages borne by the government are excluded from unit labour costs.

[11] Overhead staff is hired in larger discrete units than the expansion of output proceeds; the rate of utilisation is then calculated as the ratio of actual output to the level of output that could be produced with hired overhead labour.

[12] See Caiani et al. (2016). The difference to Caiani et al. (2016) is that in their model, the mark-up is also raised when inventories are exactly equal to desired inventories and that desired inventories are calculated by looking at past sales instead of expected sales (see also Schütz, 2022).

where $L_{f,t}^{new}$ denotes new loans incurred in period t. Firms apply for loans if they otherwise ended up with a negative balance on the deposit account at the end of the period. The stock of firm loans evolves according to:

$$L_{f,t} = L_{f,t-1} - repay_{f,t} + L_{f,t}^{new} - cancel_{f,t}$$

where $cancel_{f,t}$ denotes the cancellation of loans in case of the liquidation of a firm. The details regarding firm-bank relationships, possible insolvency and liquidation of firms are discussed in the next section.

3.4. BANKS

Our modelling of the banking sector builds on Schütz (2022). Households and firms have deposits at the bank that is located closest to them. Banks and the government hold reserve deposits at the central bank. Banks pay interest i_D on these deposits. The same can be true for reserve deposits at the central bank; we assume that the interest rate on central bank deposits is zero.

Agents (which could be households or firms) use these deposits to settle their financial transactions. If, at the end of the period, an agent is left with a negative amount on its deposit account, it must apply for a bank loan to settle the difference. These loans run for a fixed number of 120 periods, and clients make fixed annuity payments – including interest and down payments – each period. As we assume that banks charge the same interest rate, agents apply for loans at the bank that is located closest to them. Banks decide how much credit they are willing to provide to the agent. Specifically, they take the agent's income from the previous period and subtract already existing debt payment obligations. This provides the maximum amount that could be paid to the bank each period, although without taking into account any other potential needs. Therefore, banks additionally subtract a certain margin of safety, leaving them with the maximum annuity payment ($annuity_{max}$) deemed affordable for the agent. This margin of safety (ms) is set with reference to the poverty line ($poverty_t$) in the case of households (where the poverty line is defined as 50% of the median household income in the economy), and with reference to current labour costs ($labour_t$) in the case of firms:

$$ms_{h,t} = \mu_h \cdot poverty_t$$

$$ms_{f,t} = \mu_f \cdot labour_t$$

The maximum amount of credit offered to a particular agent (L_{max}) can be calculated straightforwardly, as follows:

$$L_{max} = annuity_{max} \cdot \frac{(1+i_L)^{pm-1}}{(1+i_L)^{pm} \cdot i_L}$$

where i_L denotes the interest rate and pm the periods until maturity.

If households or firms are unable to secure sufficient credit to balance their negative deposit, the deposit remains negative and they have to pay interest i_L on that amount. If the agent fails to balance the account within 12 periods, the bank declares the agent insolvent. Once that happens, the remaining negative balance on the agent's account is turned into a loan and the agent's future income will be used to repay the

outstanding debt. In the case of households, their consumption becomes limited to the poverty line, and everything exceeding that level goes towards debt repayment. In the case of firms, all future profits will be used for repayment. Being insolvent also means that agents lose access to further credit. This is particularly difficult for firms, as it usually means that firms become unable to pay the wage bill of their workers and have to stop producing. Agents remain insolvent until they manage to repay all outstanding debts. In the case of insolvent firms, there is also the possibility of liquidation. As soon as a firm is declared insolvent, the bank checks each period whether earnings over the previous 12 periods exceeded labour costs during that time. If that is the case, the firm is allowed to continue operating. If not, it is liquidated, meaning that it has to stop production and sell all its remaining inventories at fire sale prices.[13]

Transactions between banks proceed through their reserve accounts at the central bank. Whenever a bank's client makes payments to another agent who holds a deposit at a different bank, this creates a reserve claim. In each period, all of these claims are recorded and are netted out at the end of the period, so that the flow of reserves corresponds to net claims. Furthermore, banks have to hold a certain level of minimum reserves, equal to 1% of total deposits.

At the end of the period, banks provide interbank loans to each other, which mature at the end of the next period. Interbank loans are settled on the interbank market. Banks that are left with excess reserves at the end of the period offer these on the interbank market. Banks with insufficient reserves can subsequently borrow these reserves by taking up one or more of these reserve offers. Similarly to the household decision process, we assume that geographical proximity has an influence. As all banks charge the same interest rate, this implies that banks take the reserve offer from the bank that is located closest to them. If banks do not obtain sufficient reserves on the interbank market, they can get the missing reserves from the central bank. The interest rate on interbank loans is identical to the interest rate charged by the central bank. Central bank loans also mature after one period. The evolution of interbank ($L^{IB}_{b,t}$) and central bank loans ($L^{CB}_{b,t}$) is hence given by:

$$L^{IB}_{b,t} = L^{IB}_{b,t-1} - repay^{IB}_{b,t} + L^{IB,new}_{b,t}$$

$$L^{CB}_{b,t} = L^{CB}_{b,t-1} - repay^{CB}_{b,t} + L^{CB,new}_{b,t}$$

Banks' gross profits $R^{gross}_{b,t}$ are defined as the difference between total interest revenue (consisting of interest on private loans, treasury bills and reserve deposits) and total interest expenditure (consisting of interest on central bank loans, interbank loans and private deposits). Gross profits are subject to the corporate tax rate t_c. A bank distributes all profits to the household that owns it (which is assumed to be one household per bank) as long as it fulfils the necessary equity requirements (see below). When distributing profits, the bank already withholds the tax on profit income, which is later transferred to the government:

$$R_{b,t} = (1 - t_r)\left(R^{gross}_{b,t} - t_c R^{gross}_{b,t}\right)$$

Whenever the bank does not fulfil the equity requirement, $R_{b,t} = 0$.

[13] Specifically, this means that each period the firm will lower its price by rate ξ until all inventories have been sold.

Banks have to hold a certain amount of capital ($E_{min,t}$) in their retained earnings account ($D_{b,t}^{re}$) to comply with banking regulations. In particular, we assume that the leverage ratio of banks is not allowed to fall below 3% (see also the Basel III accord). Should this criterion not be met, banks are not allowed to distribute any profits. In order to comply with these standards, banks have to hold a minimum amount of capital in their retained earnings deposit account:

$$E_{min,t} = l_{min} \cdot \sum L_{\text{provided}}$$

where l_{min} denotes the minimum leverage ratio and $\sum L_{\text{provided}}$ denotes the value of provided loans.

The change in their retained earnings account is equal to:

$$\Delta D_{b,t}^{re} = R_{b,t}^{gross} - t_c R_{b,t}^{gross} - R_{b,t} - t_r\left(R_{b,t}^{gross} - t_c R_{b,t}^{gross}\right)$$

3.5. GOVERNMENT

The government collects taxes, pays out unemployment and social security benefits, and spends on goods. When workers have been employed in at least one of the previous six periods and become unemployed, they receive unemployment benefits equal to a certain share (currently 70%) of their previous wage, but not less than current social security benefits. If unemployed households do not qualify for unemployment benefits, they receive social security benefits, which correspond to 50% of the current average wage rate. Social security payments are updated every 12 periods.

Government spending depends on an autonomous term as well as the output gap (OG_{t-1}):[14]

$$G_{D,t} = g_0 + g_1 \cdot OG_{t-1} \cdot Y_{t-1}$$

Although the distance to the producer plays a role in the consumption decision of households, this is not the case for the government (as we assume that the government is not restricted to a unique location). Contrary to the households, the government simply allocates its expenditure across the various products by using equal shares, i.e. it does not use an AIDS system. However, like households, the government ranks producers supplying these products by price and purchases the largest share from the cheapest supplier.

The output gap is calculated as follows:

$$OG_t = \frac{Y_{pot,t} - Y_t}{Y_{pot,t}}$$

where $Y_{pot,t}$ denotes potential output. The latter is the sum of GDP and the average ability of unemployed workers multiplied by the average labour input coefficient of firms (see the Leontief

[14] Researchers have suggested different ways of adding a cyclical component to government spending. Instead of using the output gap, others have used the following indicators: the rate of unemployment (Keen, 1995), inflation (Greenwood-Nimmo, 2014), private sector leverage ratios (Nikolaidi, 2014) or debt-to-income ratios (Dafermos, 2018), loan defaults (Kapeller et al., 2018) and firms' access to credit (Gräbner-Radkowitsch et al., 2022b).

production function) for each worker type, where coefficients are weighted according to firms' current market shares.

The government finances its activities by collecting a value-added tax, a corporate tax on firms' and banks' profits, a tax on distributed profits, and a tax on wage income.

All government transactions are settled through its central bank deposit. If the government is left with a negative deposit at the end of the period (i.e. a fiscal deficit), the residual amount is financed by issuing government bonds. Here we assume that each bank buys an equal amount of these bonds. The change in the government's central bank deposit $D_{g,t}$ corresponds to:

$$\Delta D_{g,t} = T_{g,t} - benpay_{g,t} - debtpay_{g,t} + B_{g,t}^{new}$$

where $T_{g,t}$, $benpay_{g,t}$, $debtpay_{g,t}$ and $B_{g,t}^{new}$ refer, respectively, to total tax revenues, benefit payments, debt payments (including interest and repayment of the principal) and the revenue from the sale of newly created treasury bills. Government bonds run for a fixed number of periods, where the government pays interest in each period and repays the principal at maturity. The evolution of government debt $B_{g,t}$ is given by:

$$B_{g,t} = B_{g,t-1} - repay_{g,t} + B_{g,t}^{new}$$

4. Scenarios

4.1. MODELLING THE PANDEMIC

Because we do not explicitly model the epidemiological basis of a pandemic, we must model the pandemic implicitly. That is, at a certain point in time, we introduce an exogenous shock to the model that mimics the effects of the pandemic on the economy. More precisely, the pandemic has the following effects in our simulation.

Supply shock: Firms in the 'non-essential' sector have a production limit imposed on them during the pandemic (mimicking the supply shock in the early stages of the pandemic, when some sectors could not work at full capacity, owing to contact restrictions imposed on their workforce), e.g. service industry firms such as hairdressers or masseurs. Firms in the 'essential' sector can continue to work as before the pandemic because they are deemed to be 'systemically relevant'.

Labour market shift: There is a shift away from 'production workers' (workers who must be present at the workplace) towards 'home workers' (those whose job content allows them to do the work remotely, from home). In the model, this is achieved by increasing the required share of home workers in production and decreasing the share of required production workers in the 'non-essential' sector. Adams-Prassl et al. (2020), Casarico and Lattanzio (2022) and Hurley et al. (2021) document such differential effects of the COVID-19 pandemic on the labour market, depending on working-from-home arrangements and industry sectors.

Demand shock: As a result of lockdown restrictions and fear of contracting COVID-19, households have a reduced consumption propensity out of current income during the pandemic. Households therefore postpone consumption decisions (even though from the household budget point of view it would have been possible to fulfil these).[15] In addition, households spend a higher share of their consumption budget on essential goods during the pandemic than the AIDS budgetary decision would indicate. After the end of the pandemic, the consumption propensity out of current income is reset to its pre-pandemic level and households return to using the same AIDS parameters as before the pandemic, i.e. they allocate their consumption shares in line with the AIDS system.

4.2. POLICY REACTIONS BY THE GOVERNMENT

We include two commonly used policy instruments that were employed by governments around the world.

Short-time work: The government pays for the workforce that is kept (and not fired) during the pandemic. Firms are not allowed to reduce their workforce during the pandemic below pre-pandemic levels: this means that, as long as their firm does not face liquidation, all workers hired pre-pandemic

[15] See, for example, Christelis et al. (2020), who document this for the largest six EU countries, as well as the references mentioned there.

keep their jobs. The government pays only for the fraction of workers that are not needed for production (i.e. only for those workers that would have been fired if the short-time working policy was not in place).

State guaranteed loans: Firms that need a loan during the pandemic but are not deemed profitable enough by banks will get a state guaranteed loan at the bank of their choice. When a firm goes bankrupt and is not able to repay its loan, the government will pay the outstanding amount.

5. Results

In the following, we distinguish the following model simulations:

› **Baseline:** Simulation without the occurrence of a pandemic.

› **Pandemic:** Lockdown from period 100 to 150 (see Section 3.1).

› **Pandemic + short-time work:** Lockdown is accommodated with short-time work scheme starting in period 100 and running further until period 200 in order to allow the short-time work scheme to phase out.

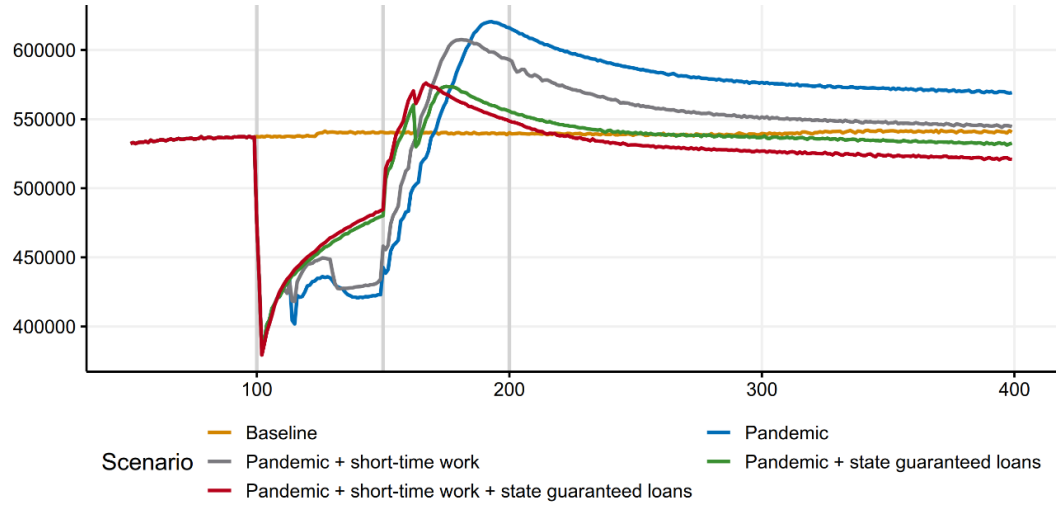
› **Pandemic + state guaranteed loans:** Lockdown is accommodated by state guaranteed loans to firms.

› **Pandemic + short-time work + state guaranteed loans:** Lockdown is accommodated by short-time work programme (period 100-200) and state guaranteed loans (period 100-150).

5.1. MACRO LEVEL

At the start of the lockdown (period 100), we observe a quite uniform initial fall in output that is followed by a gradual recovery (see Figure 1). However, in those scenarios without state loan guarantees, these initial signs of recovery are rather short-lived: as firm insolvencies – followed by liquidations – start to occur (see Figure 2), output falls again. In contrast, in those scenarios that include a state loan guarantee (lasting until period 150), recovery continues throughout the lockdown as liquidations do not occur until well after the end of lockdown measures. Once the lockdown is lifted (period 150) and savings propensities fall to pre-lockdown levels, output quickly recovers, leading to a self-propagating economic boom fuelled by firms' optimistic sales expectations. As this post-pandemic boom fades, output levels approach their new stable levels. In those simulations with short-time work schemes, these continue until period 200.

Figure 1 / Real GDP



Here we observe an interesting result. While during the pandemic, credit guarantees are more important for the recovery of output than short-time work (as they prevent the liquidation of firms), those scenarios that do not feature credit guarantees settle on higher long-term levels of output once the pandemic is over. The reason for this result is that in the absence of credit guarantees, it is the less productive firms that are hit by liquidation. Once the economy recovers, the more productive firms take over the liquidated firms' market shares, leading to higher aggregate productivity and hence potential output levels. This points to a Schumpeterian 'cleansing out' (creative destruction) effect in our model.

Figure 2 / Percentage of insolvent and liquidated firms

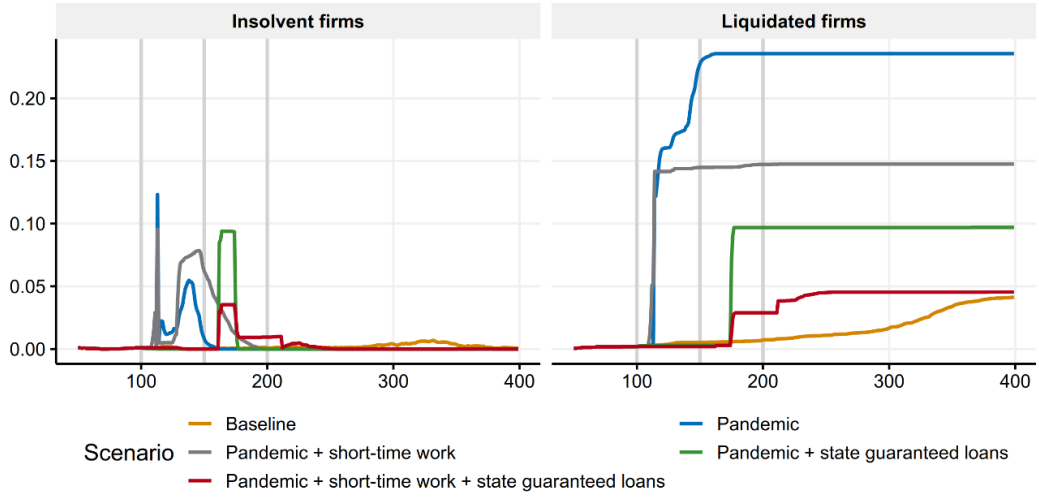
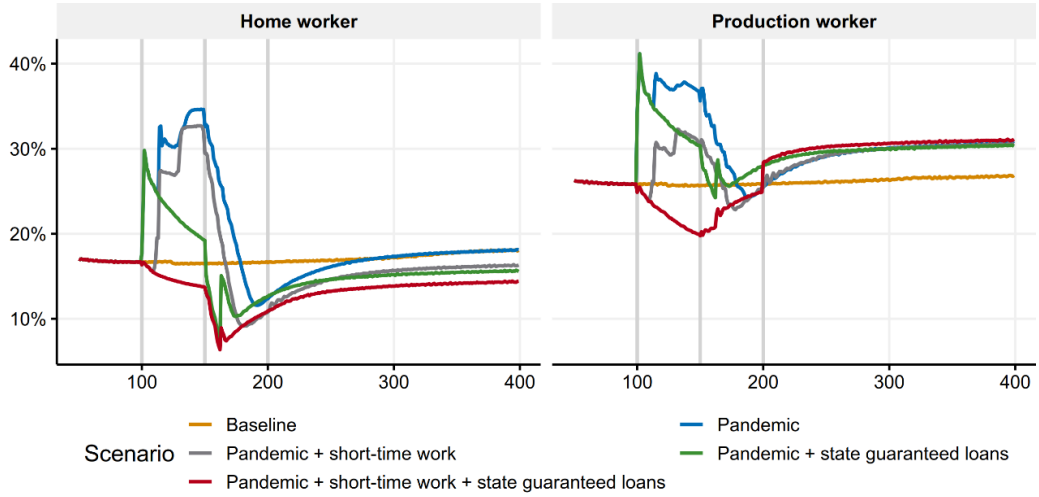


Figure 3 / Unemployment rate



Short-time work is initially successful in preventing a rise in unemployment: although unemployment immediately soars in the other scenarios, it declines in those scenarios involving short-time work. However, this trend of declining unemployment is only sustained in the scenario that also involves a state loan guarantee scheme. In the absence of that scheme, unemployment starts to increase rapidly after a while as some firms face liquidation and workers lose their jobs. In this phase, unemployment

under the short-time work support scheme is even higher than under the credit guarantee scenario without short-time work. Once the pandemic is over, unemployment falls immediately across all scenarios, initially reaching very low levels as a consequence of the post-pandemic boom, before settling at its new stable levels. As in the case of output, post-pandemic unemployment is lowest in the scenario without any government intervention, owing to the 'creative destruction' effect on output expansion of the 'no policy intervention' scenario. However, this comes at the cost of substantially higher unemployment during the entire duration of the Covid crisis and also during parts of the recovery.

5.2. STRUCTURAL EFFECTS ON CREDIT, FINANCE, LIQUIDATION, BANKRUPTCY

Interesting dynamics evolve in relation to insolvency and liquidation of firms under the different scenarios, the macroeconomic impact of which we have mentioned in the previous section (Figure 2). There are three phases in which insolvency jumps take place: 1) immediately, at the start of the lockdown; 2) towards the end of the lockdown, but before it is lifted; and 3) once the loan scheme is lifted together with the lockdown. Accordingly, we see different developments in the different scenarios. The immediate lockdown effect is the same across all scenarios, but under the loan guarantee scheme it does not lead to the liquidation of firms until well after the lockdown is lifted and the loan scheme expires. Under the short-time work policy, firms are immediately liquidated once the 12-period liquidation deferral given to them by the banks to balance their accounts has lapsed. This leads to a wave of liquidations in the first phase of the lockdown. However, the number of liquidated firms does not rise in the second phase, despite a rising number of insolvencies (that is, firms unable to meet debt payments), because the above-mentioned deferral period suffices to allow firms to survive until the lockdown closures are lifted. Thus, despite a second wave of insolvencies, this does not show up in another wave of liquidations. In the aggregate, the number of firm liquidations is, as could be expected, highest in the scenario where government policies are absent, followed by the scenarios involving short-time work, then by the one involving only credit guarantees and, finally, by the scenario involving both credit guarantees and short-time work.

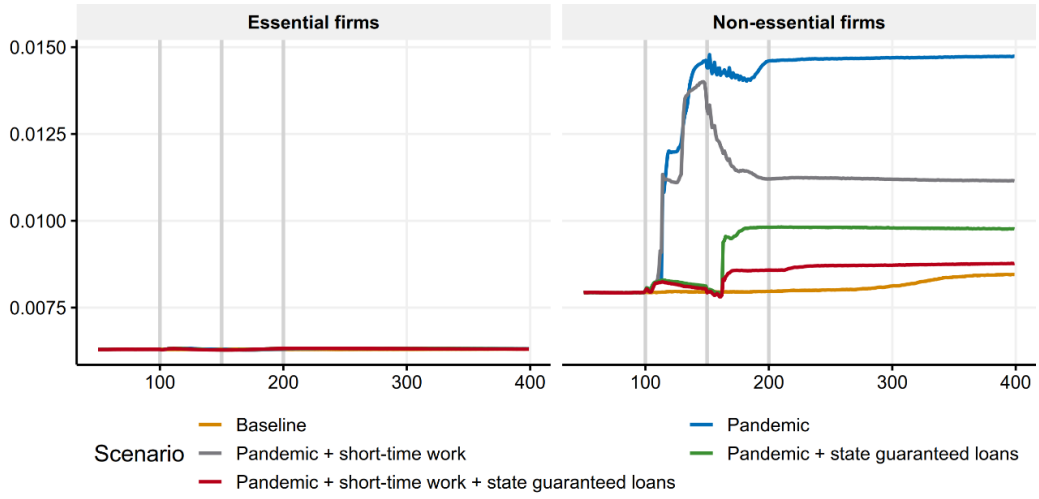
Once the loan guarantee programme has been phased out, but the short-time work scheme continues until period 200, we see a difference in liquidation between the loan guarantee scenario and the loan guarantee + short term work support scenario in that the second shows fewer insolvencies and fewer liquidations. That is because of the more favourable aggregate demand conditions created under short-time work, as unemployment is lower under short-time work in this phase (see Figure 3).

It looks as if under the loan scheme, labour demand (in the non-essential sector) and profits are higher than in the combined loan guarantee + short-time work scheme scenario once lockdown is lifted. Also output development is higher in that scenario.

5.3. STRUCTURAL PRODUCTION EFFECTS

Lockdown conditions have different impacts on the essential and the non-essential goods sectors. Although we observe no change in firm concentration in the essential goods sector, concentration immediately increases in the non-essential sector after the lockdown measures have been put in place. The latter is due to the imposed production restrictions and declining demand and the consequential firm bankruptcies, as less productive firms increasingly face liquidation. This has a significant long-term impact on the non-essential sector, leaving the non-essential sector far more concentrated in the scenario without government policies, followed by the scenario that involves only short-time work. If credit guarantees are combined with short-time work, concentration ends up slightly lower than at the beginning, while the scenario with credit guarantees but without short-time work ends up with concentration slightly higher. This is because of government action (and here in particular credit guarantees) that keeps less competitive firms in business during the lockdown.

Figure 4 / Herfindahl-Hirschman index of market concentration in the essential and non-essential goods sectors



Relative concentration effects also show up in mark-up dynamics, with the highest mark-ups observable in the absence of government policies followed by the short-time work scenario (see Figure 5). As large numbers of firms go out of business in these scenarios, more and more demand gets attracted to the remaining firms, which react to the increasing demand for their products with higher mark-ups/prices. However, under the state guarantee scheme a higher number of companies survive, with greater competition leading to lower mark-ups.

We also see that while mark-ups initially increase in the post-pandemic boom across all scenarios, they start to decline again once this boom is over. This is because we move from an excess demand situation during the lockdown towards an excess supply situation in the aftermath of the crisis, as revealed by the ratio of actual inventory to desired inventory in Figure 6.

Figure 5 / Mark-ups of firms in the essential and non-essential goods sectors

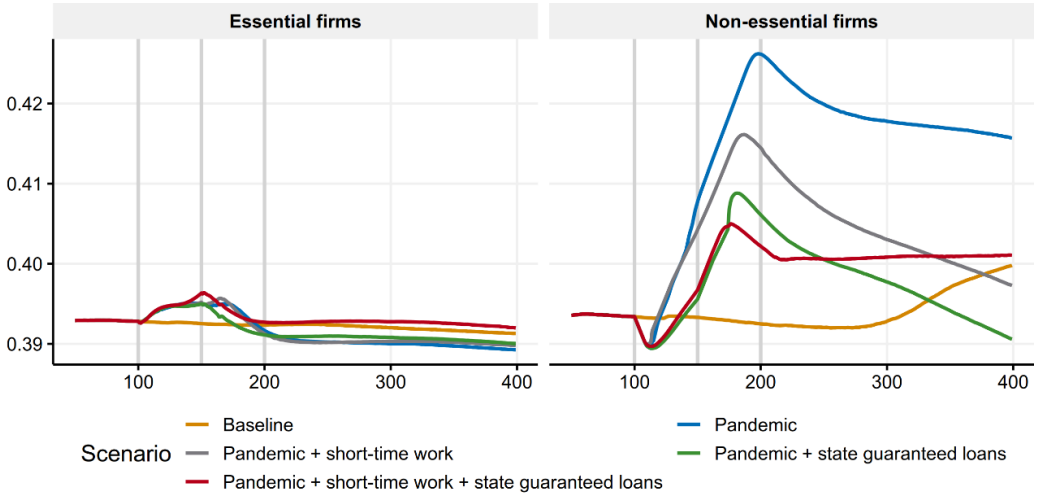
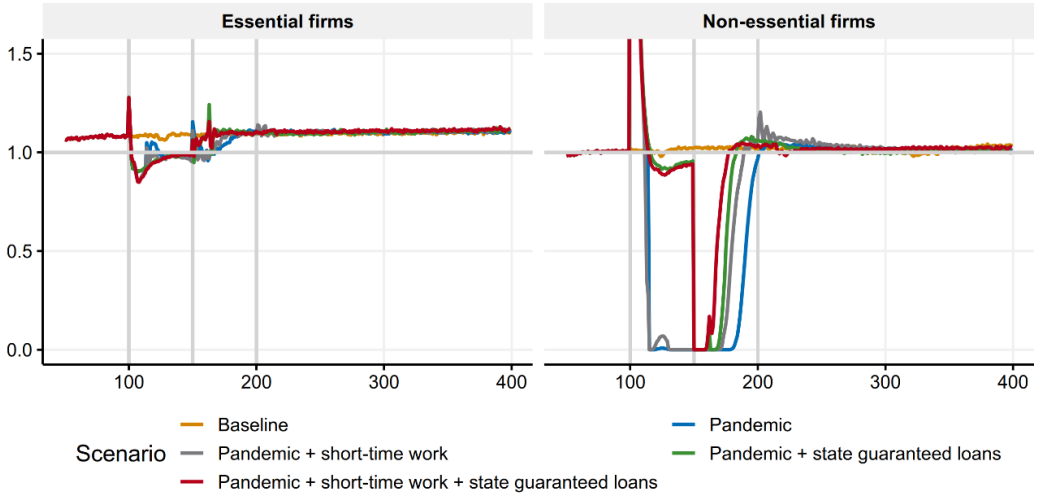


Figure 6 / Ratio of actual inventory to desired inventory in the essential and non-essential goods sectors



5.4. LABOUR MARKET DYNAMICS AND HYSTERESIS

Figure 7 gives a summary of the evolution of the number of individuals belonging to certain groups over the course of the simulation: we separate the household agents into employed home or production workers, unemployed households and households relying on social security. As mentioned earlier, households drop down to lower social security benefits (i.e. below the level of unemployment benefits) after they have been unemployed for six consecutive periods. What these figures show is that the number of households that receive social security is highest in the pandemic scenario without government interventions.

Figure 8 compares the actual level of output to the level of output that would prevail if none of the employed workers had suffered productivity losses due to unemployment (i.e. in the absence of this

hysteresis effect). Hence the figure gives us an indication of the hysteretic effects that arise from the productivity loss impact of being unemployed under the different scenarios. We see that in a number of scenarios, the production loss attributable to the hysteretic effect amounts to 2-2.5% of GDP per period.

Figure 7 / Shares of economic groups in population

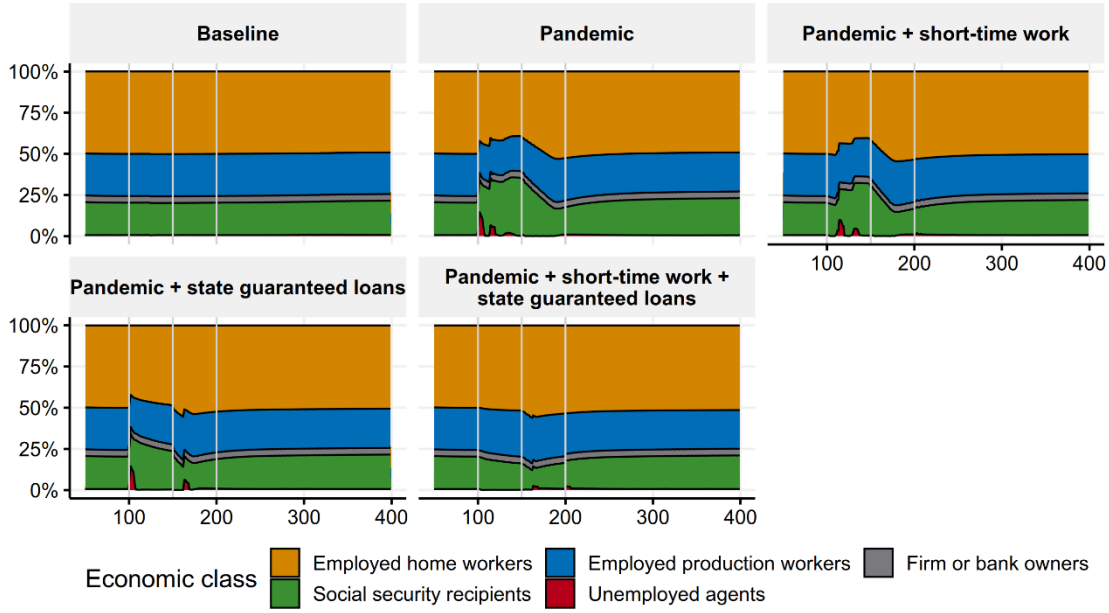


Figure 8 / Ratio of actual output to output without hysteresis

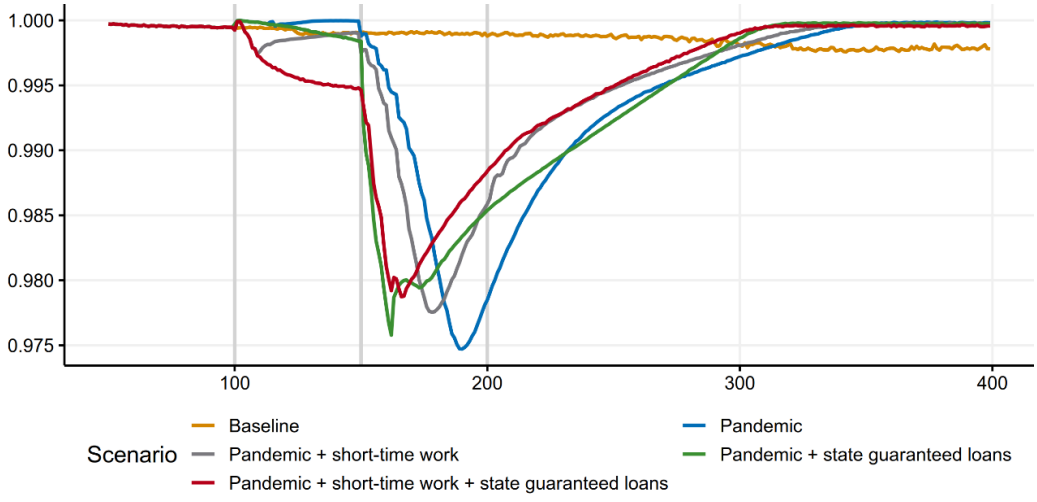
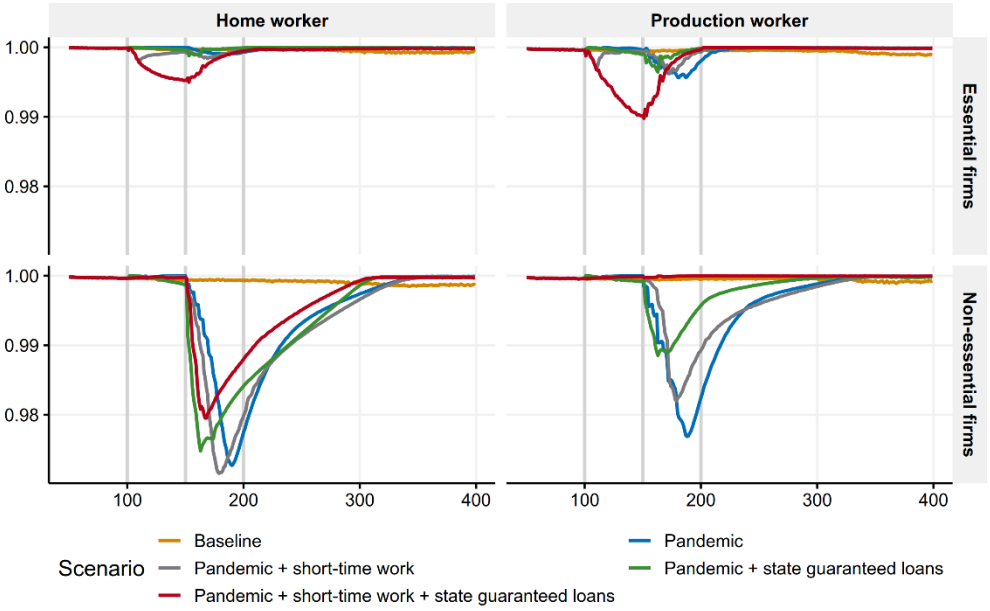


Figure 9 displays the average worker productivity of the employed workforce. This declines when unemployed households (with a lowered productivity) become employed again and thus decrease the average of the whole employed labour force.

For example, in the combined scenario of short-time work and state guarantees, average worker productivity decreases in the essential firms. This is because, owing to the shift of consumption to this

sector during the pandemic, more demand is directed towards it, meaning that firms are expanding production and hiring new workers (and because these workers were previously unemployed, average worker productivity falls).

Figure 9 / Average worker productivity by type of worker

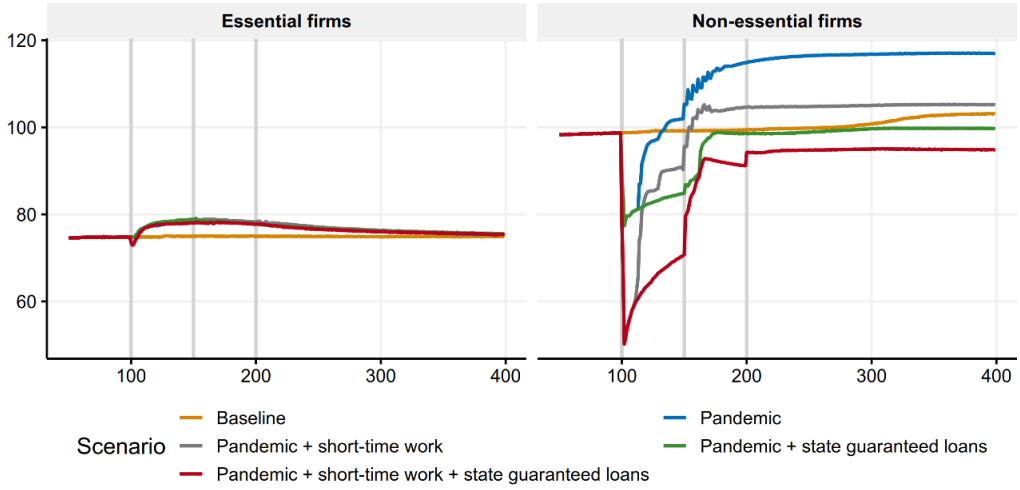


For the non-essential sector, a very large drop in average worker productivity happens after the end of the pandemic, when consumption shifts back to non-essential goods and these firms are expanding their production again. The largest drop occurs in the scenario with state guaranteed loans: in this scenario firms did not go bankrupt during the pandemic, so the re-employment effect is the strongest. Thus, we see here also the largest fall in average worker productivity.

By contrast, in the scenarios with short-time work or the scenario without government interventions, the drops in average worker productivity are lower. In these scenarios, low-productivity firms go out of business and only the high-productivity firms remain. When consumption rises again after the pandemic, the high-productivity firms can meet this surge in demand by hiring workers – but fewer workers than in the scenario with state guaranteed loans. Thus, the fall in average worker productivity is lower here.

Firm labour productivity is calculated as output per employee. In the non-essential sector, we see large drops in firm labour productivity, owing to output restrictions as well as the shift of consumption away from non-essential goods (Figure 10). The drop is largest for the short-time work and the combined intervention scenario: because of the short-time work policy, more workers than necessary remain employed without producing extra output, resulting in a loss of firm labour productivity. By contrast, in scenarios where no employment guarantees exist (those coloured blue and green in the figure), firms fire all excess workers and can thus keep the fall in firm labour productivity smaller. Then, low-productivity firms are liquidated during the pandemic in these scenarios, which induces firm labour productivity to rise above the pre-pandemic level.

Figure 10 / Firm labour productivity by industry



5.5. STRUCTURAL DISTRIBUTION EFFECTS

Mark-up dynamics, underlying concentration processes and excess demand/supply dynamics also explain the differential (income and wealth) distribution dynamic in the different scenarios. Across all scenarios, the pandemic leads to more unequal distributions, no matter whether we look at the capitalist share of income (Figure 11) or the Gini coefficients of net wealth (Figure 12), income (Figure 13) and profit income (Figure 14). Generally, distribution ends up most unequal in the scenario that does not involve any policy intervention. Interestingly, this scenario is followed by the scenario in which only short-time work support is provided. This means that loan guarantees dampen the rise in inequality more effectively than short-time work programmes, while the combination of both ends up with the lowest rise in inequality. Thus, keeping companies alive during the crisis seems to be very important to avoid a deterioration of income and wealth distribution, even more important than short-time work support schemes alone.

Figure 11 / Capitalist share of income

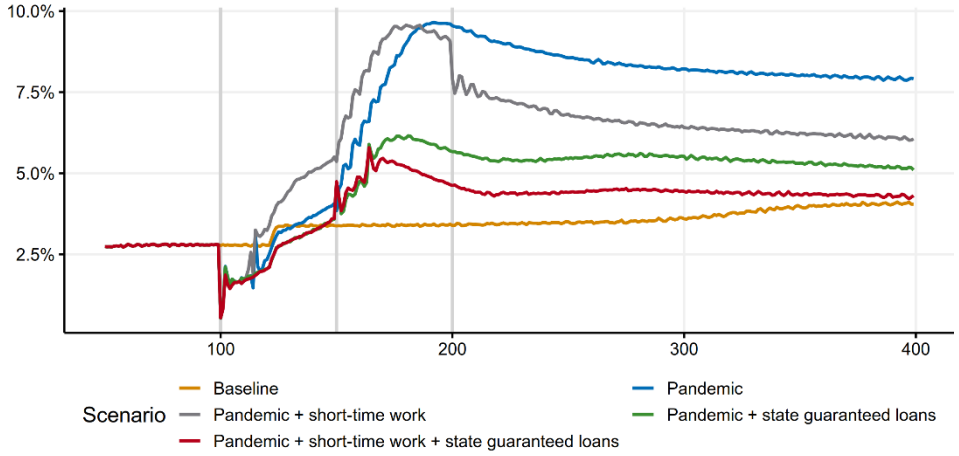


Figure 12 / Gini coefficient, net wealth

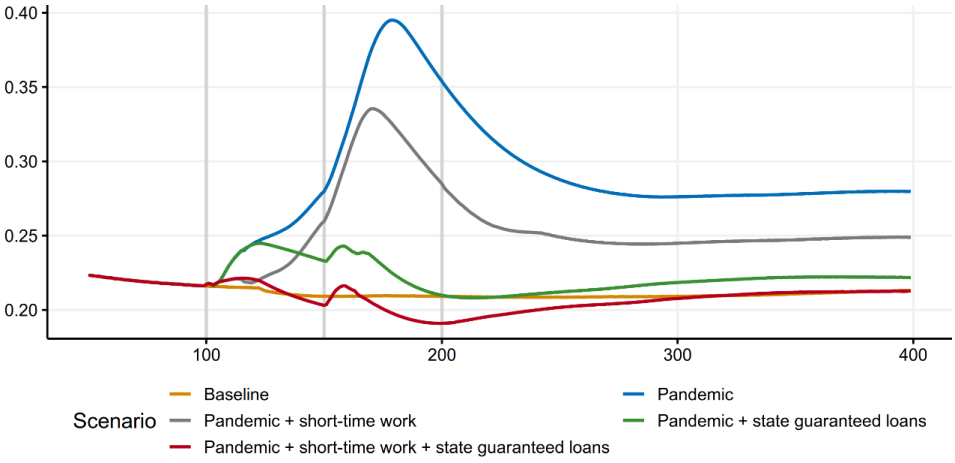


Figure 13 / Gini coefficient, income

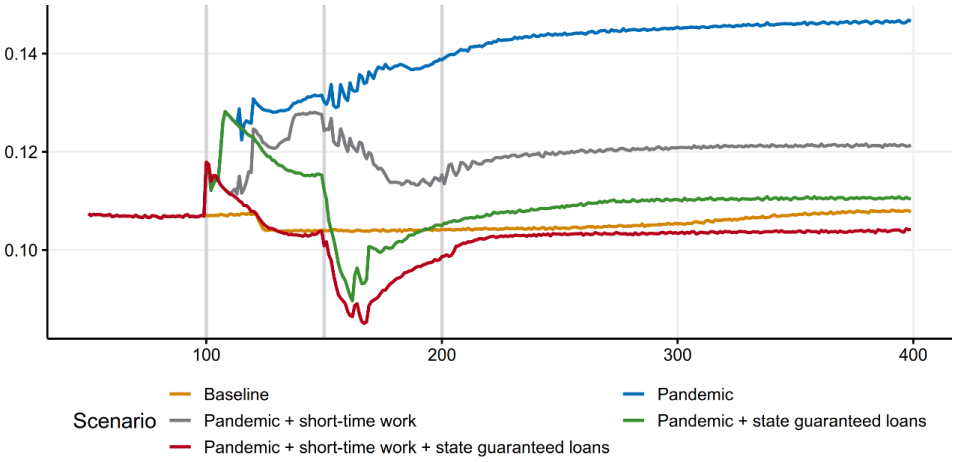
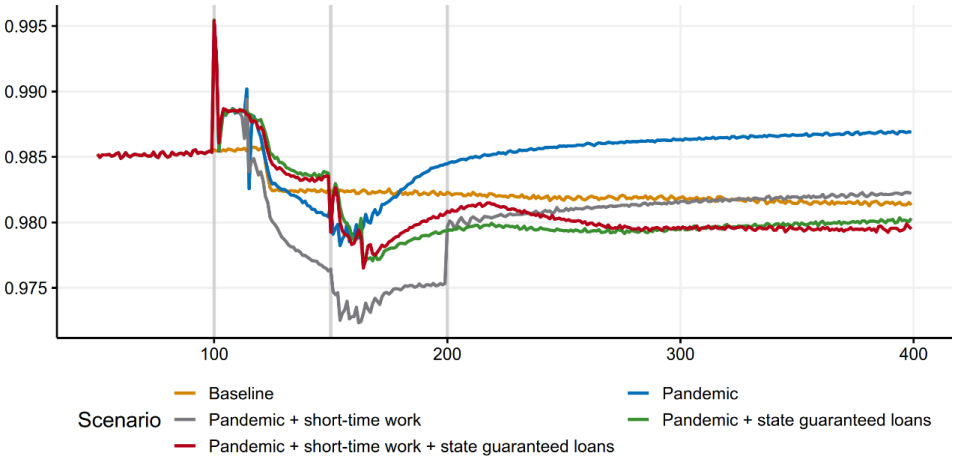
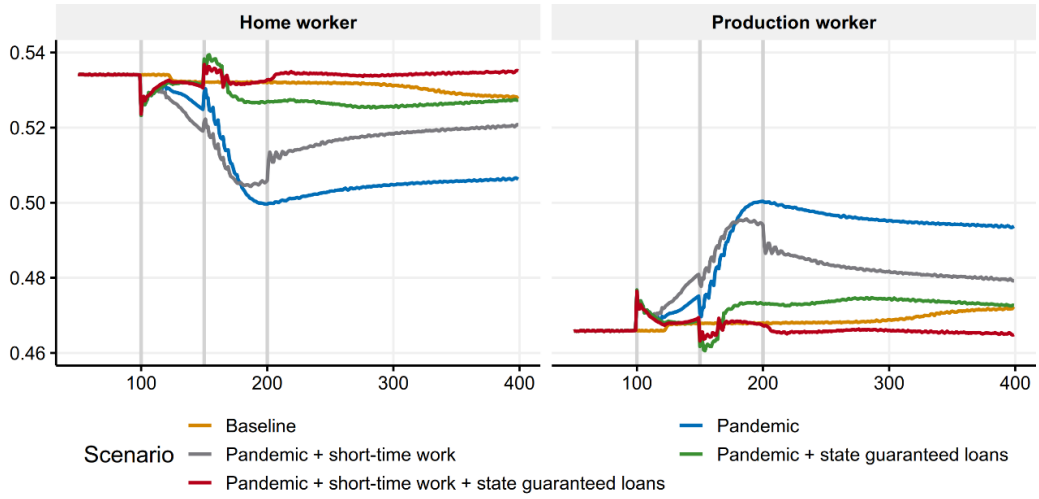


Figure 14 / Gini coefficient, profit income



Moreover, when looking at the distributional outcome, one also needs to consider the composition of the labour force, particularly home workers vs production workers and short-time workers vs unemployed workers. Because they all receive different incomes, changes in the composition among these four groups will affect distribution measures. We can see this by looking at the rising share of production workers in real consumption demand (Figure 15), which is attributable to different employment patterns: the sector with more home workers (non-essential sector) directly suffers under output restrictions, whereas the sector with more production workers (essential sector) suffers only indirectly through the general downswing of the cycle. However, they suffer less under the loan guarantee programme, because firms are kept alive, and they keep their employment.

Figure 15 / Share of home and production workers in real consumption demand



5.6. FISCAL BUDGET EFFECTS

Finally, we can look at the corresponding costs of these policies for the government. Figure 16 shows that firms make intense use of short-time work. When combined with a credit guarantee scheme, government outlays for short-time work support are even higher as more of the firms that rely on this continue to operate. This changes when we look at the post-pandemic phase, during which the short-time work programme is allowed to continue for a while: in this phase, short-time work outlays are higher without the credit guarantee scheme, indicating that surviving firms are in slightly better shape under this scheme.

It is a general feature that short-time work and credit guarantees positively reinforce each other's impact. Another example of this is also provided in Figure 16, showing the losses that the government incurs as banks call on some of those credit guarantees: with short-time work support additionally in place, losses from given credit guarantees amount to only half as much. In general, we see a steep rise in the demand for credit guarantees once the pandemic starts, which continues until the end of the lockdown. Outstanding guarantees subsequently decline, which is partly because of debtors becoming unable to pay and banks calling in those guarantees (as is particularly the case shortly after the end of the lockdown), and firms normally repaying these loans.

Figure 16 / Government spending arising from the pandemic (short-time work outlays, outstanding credit guarantees, losses due to given credit guarantees)

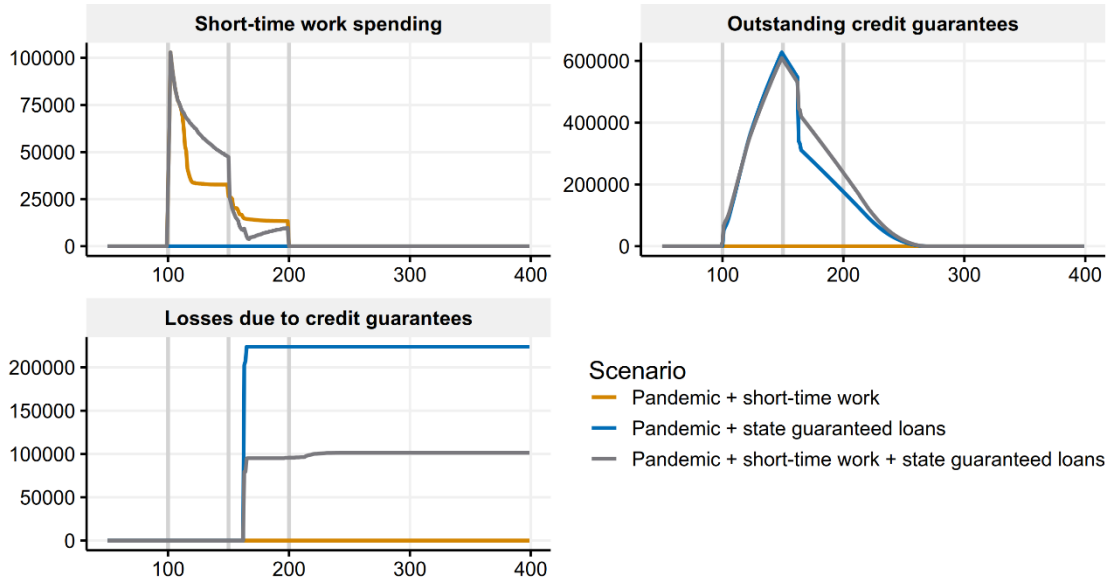
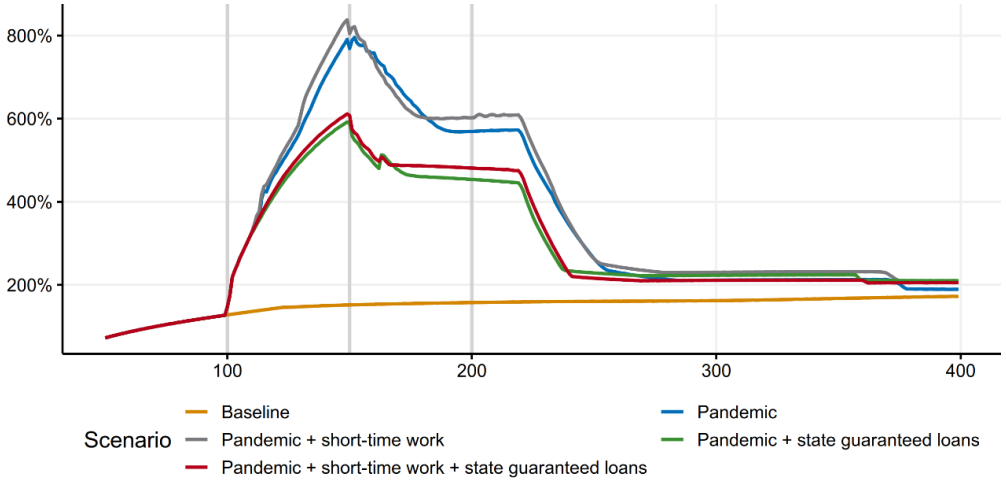


Figure 17 / Government debt to GDP ratio



Finally, when looking at government debt to GDP ratios across scenarios (Figure 17), we see that the government faces the highest increases in its debt burden in the short-time work scenario and in the scenario without any policy intervention. On the one hand, this shows that the short-time working scheme does constitute a significant cost for the government. On the other hand, it also shows that the costs of remaining passive in terms of the debt burden are roughly equal to introducing only short-time work and significantly higher than providing credit guarantees as well as short-time work combined with credit guarantees. Once government measures end, debt to GDP ratios gradually converge towards broadly comparable levels.

6. Sensitivity analysis

In order to check the robustness of these results, we provide two sensitivity checks here. First, we re-run our simulations under the assumption that there is an even larger technological shift in the labour market away from production workers towards home workers.[16] As a second sensitivity check, we increase the wage premium for home workers, i.e. start with an even larger inequality between the two types of workers.[17] Generally, the results are qualitatively similar to those previously obtained.

6.1. STRONGER LABOUR MARKET SHIFT TOWARDS HOME WORKERS

As a result of intensifying the shift towards home workers, unemployment of home workers is, unsurprisingly, lower across all scenarios. This set-up results in fewer liquidations (in all scenarios except the pandemic + short-time work scenario), as higher employment of better-earning home workers creates more favourable aggregate demand conditions. Fewer liquidations (and hence less concentration of market share around more productive firms) are also part of the reason why levels of GDP tend to be lower in the aftermath of lockdowns. There are more liquidations in the pandemic + short-time work scenario because the (more intense) shift towards home workers increases unit costs by more than in the default scenario. These increased unit costs drive a few more firms into liquidation. This leaves the most productive firms in this scenario with even more market share, resulting in only a small drop in firm output (see Figure 18).

Although a stronger shift towards home workers causes lower unemployment for home workers and slightly higher unemployment numbers for production workers, in the aggregate we see lower unemployment numbers in all scenarios except the pandemic + short-time work scenario.

We find that a stronger shift towards home workers also results in lower inequality, a cause of the lower unemployment (in the aggregate) in this setting. In the pandemic + short-time work scenario, where the aggregate unemployment rate is higher than in the default settings, we see higher inequality.

[16] This means decreasing the labour productivity reaction parameter from 0.8 to 0.7.

[17] This means raising the wage premium of the home workers from 10% to 30%.

Figure 18 / Labour market shift, real GDP

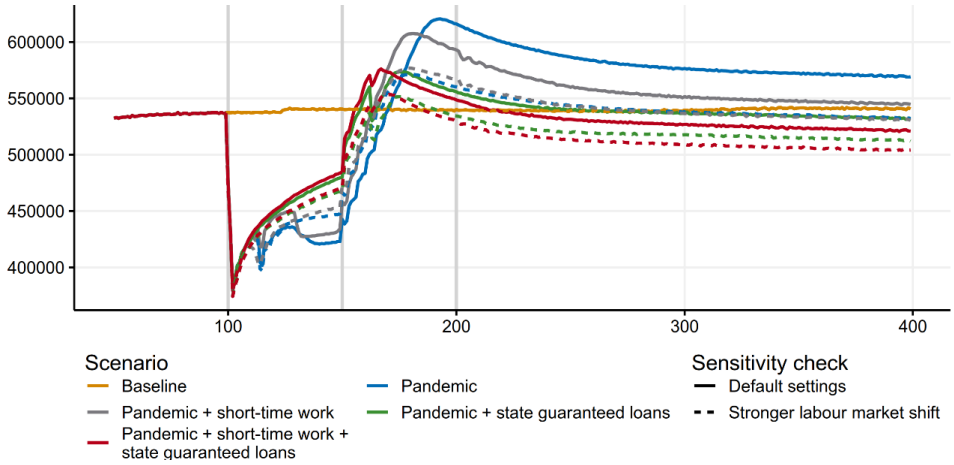


Figure 19 / Labour market shift, average real firm output by industry

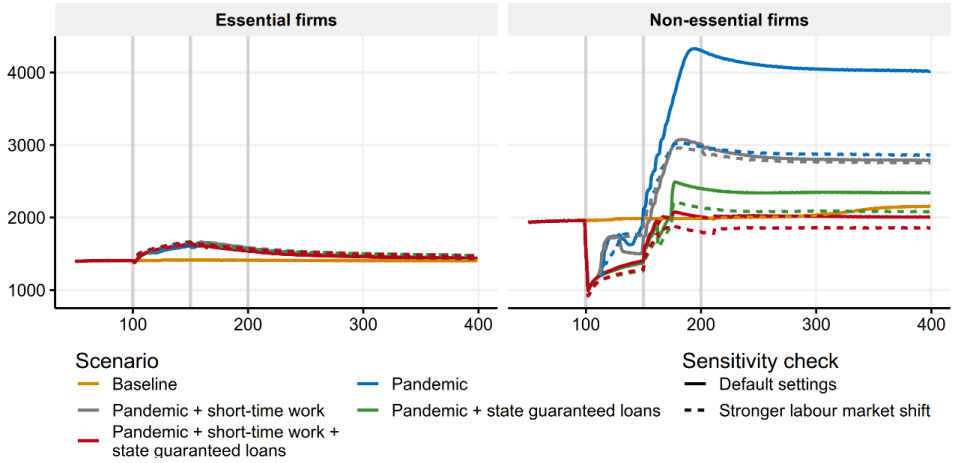


Figure 20 / Labour market shift, insolvent and liquidated firms

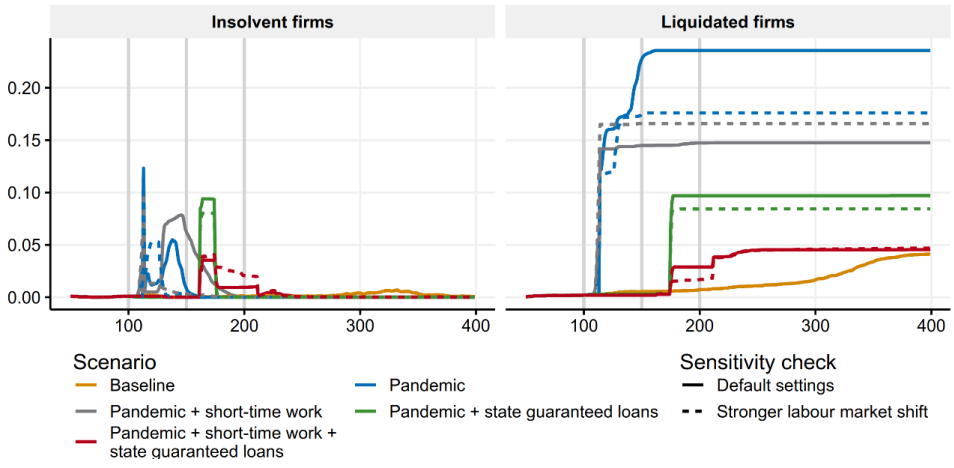


Figure 21 / Labour market shift, unemployment rate

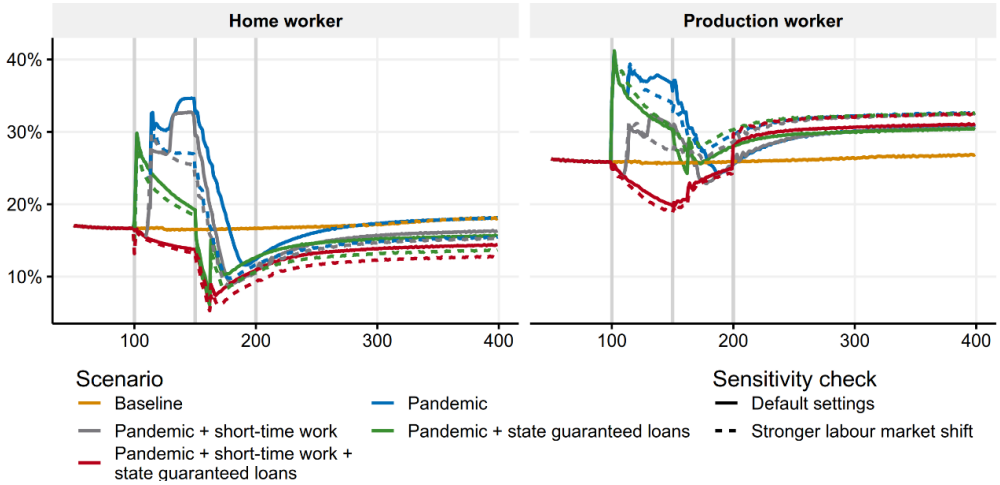
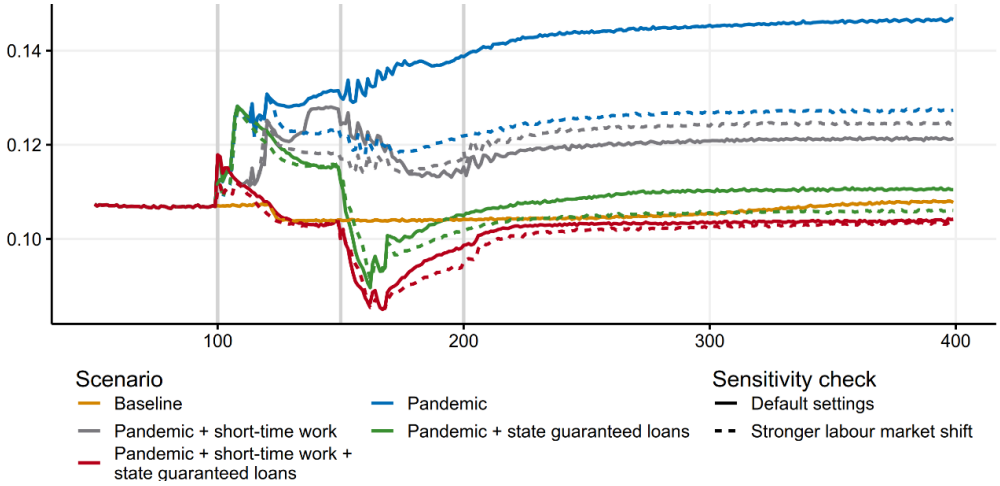


Figure 22 / Labour market shift, Gini index: income



6.2. HIGHER WAGE PREMIUM FOR HOME WORKERS

A higher wage premium for home workers raises GDP levels in all scenarios, because higher wages – even if only for part of the population – leads to higher aggregate demand. However, higher wages not only raise aggregate demand, but also unit costs and the amount of loans that firms need in order to be able to operate. This pushes more firms with low productivity into bankruptcy, which results in the higher liquidation rates that we see in Figure 25. Unemployment rates are not significantly affected. The Gini coefficient for income is higher, owing to higher wage inequality (home workers vs production workers).

Figure 23 / Wage premium, real GDP

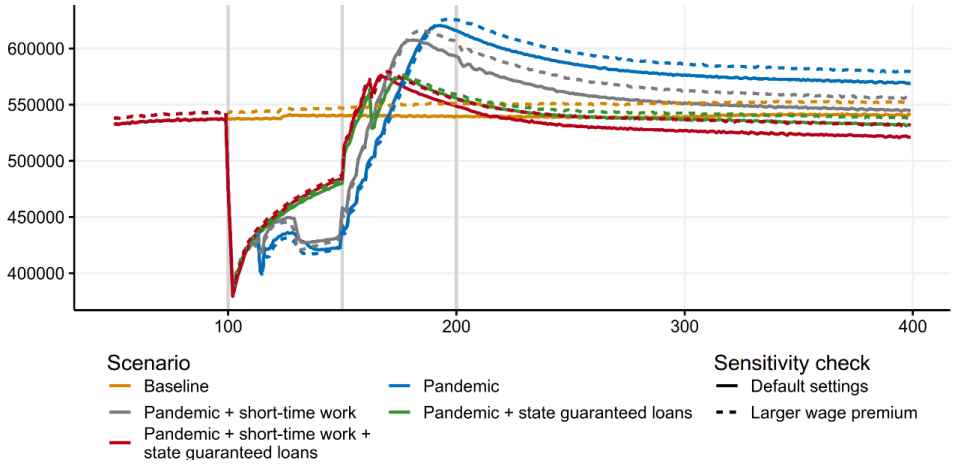


Figure 24 / Wage premium, loans by type of firm

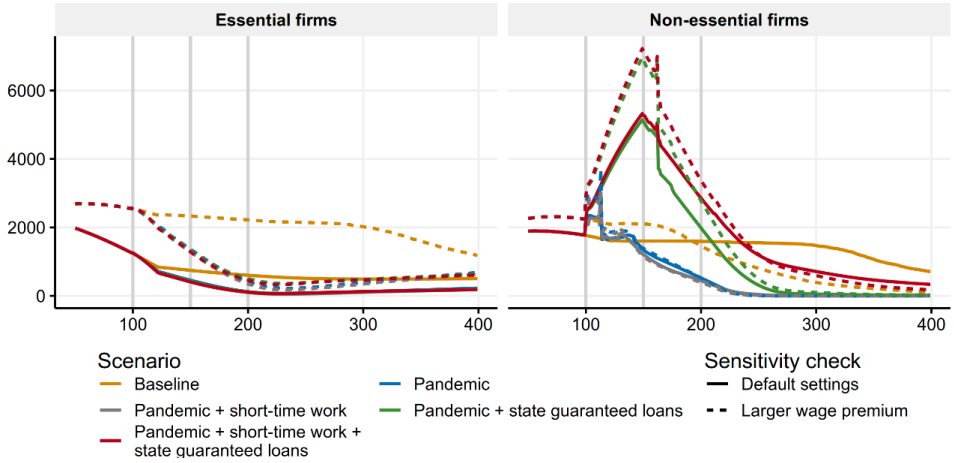


Figure 25 / Wage premium, insolvent and liquidated firms

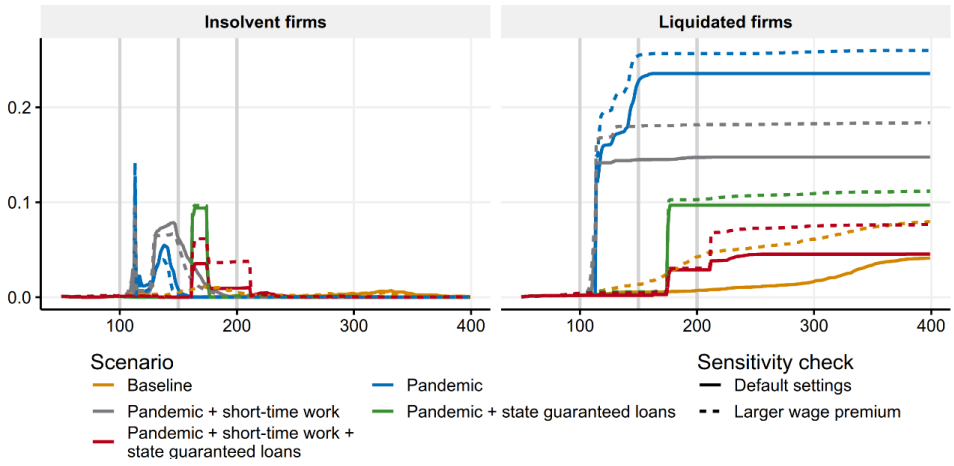


Figure 26 / Wage premium, unemployment rate

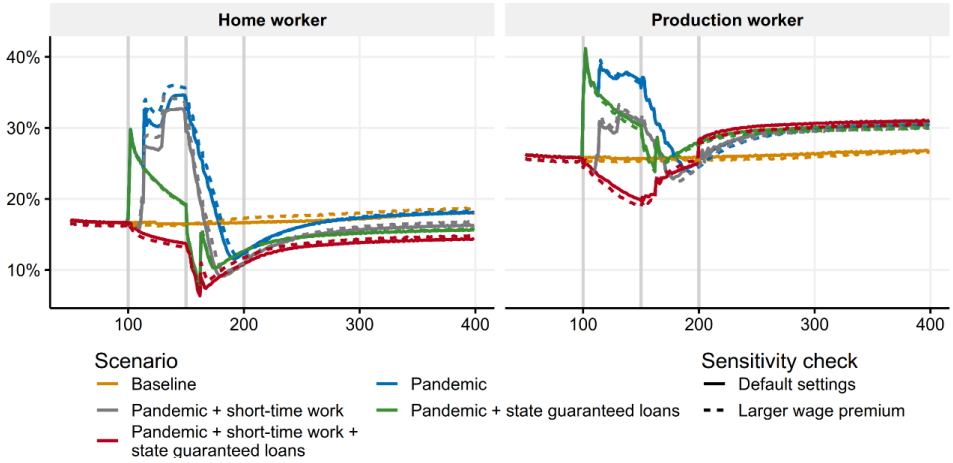
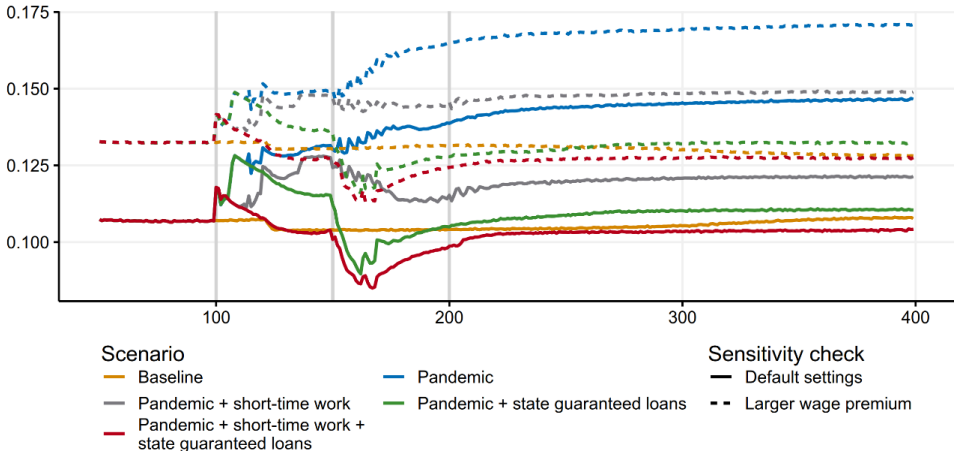


Figure 27 / Wage premium, Gini index: income



7. Conclusions

In this paper, we used a stock-flow consistent agent-based model to gain a better understanding of the structural change and distributional implications of COVID-19. For this purpose, we constructed a model that distinguished between 'essential' and 'non-essential' economic activities (or 'industries'), allowed for a range of firms (differentiated by productivity levels) operating in these industries, distinguished between jobs that could be performed 'from home' ('home workers') and those that had to be executed 'on site' ('production workers'), and accounted for the fact that firms need to employ a certain amount of overhead labour. As the Covid crisis proceeded, we looked at the impact of initial 'lockdowns', which affected 'non-essential' activities more strongly, and at recovery phases. We attempted to capture the impact of government policies (short-time work schemes and loan guarantees to firms that required support) and analysed the impact they had on firm populations in the different sectors, on sectoral productivity developments (an attempt to capture the dynamics of 'creative destruction', although without dealing yet with technological change) and on distributional dynamics.

What we found is that, in the absence of accommodating government policies, lockdowns lead to a marked increase in inequality. Although the capitalist share of income falls at the start of the pandemic, it quickly rises significantly above initial values. The same is true for the Gini coefficients for net wealth and income. However, we found that short-time work schemes and state loan guarantees are very effective in countering these surges.

The following channels explain these results. 1) Lockdowns lead to unemployment, inflicting income losses on the affected households. The only scenario in which such a rise in unemployment could be avoided involves a combination of short-time work and loan guarantees. Short-time work on its own is unable to prevent rising unemployment over a longer time horizon, as without loan guarantees, forced liquidations of firms eventually set in. 2) Less productive firms frequently face liquidation as a result of declining sales, leaving their owners without incomes. State loan guarantees are very effective – and even more so when combined with short-time work – in reducing the number of liquidations. 3) On the one hand, structural shifts in the production process raise the demand for better-paid workers whose tasks can be performed from home, while reducing the demand for workers whose jobs must be performed on site. On the other hand, essential economic activities (which are not subject to lockdowns) involve a larger share of workers whose jobs cannot be performed from home, favouring a shift in demand towards on-site workers, who are more strongly represented in these activities. 4) Liquidations of less productive firms during the pandemic mean that, once the lockdown is over, sales become concentrated with the remaining (more productive) firms. This leads to higher market concentration and higher mark-ups, raising the share of profit income in total income, at the expense of wage income. 5) Low labour demand during lockdowns means that more workers become ineligible for unemployment benefits and instead end up receiving (lower) social security benefits.

It showed throughout our analysis that government action leads to smaller economic contraction during the pandemic and hence works very effectively against rising inequality. We refer to this as the 'Keynesian' result. By creating more favourable macroeconomic conditions, it also reduces the number

of liquidations, which leads to an additional result: in the absence of government action, GDP in the post-pandemic phase is higher compared with those scenarios in which the government does act. The reason behind this is that less support during the pandemic effectively leads to more liquidations of less productive firms. As post-pandemic production ends up concentrated in the hands of the most productive firms, overall GDP is higher (what we call the 'Schumpeterian' result), although this higher production level comes at the cost of higher mark-ups (more market concentration) and higher overall inequality. However, the last result must be regarded with some caution, as although our model is well equipped to describe short-run events, it is not designed to deal with long-run developments. Important missing elements in this respect are the entry of new firms, as well as technological progress. We regard the inclusion of these elements as an important avenue for future research.

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Appendix

Table 1 / Starting values and parameters

Parameter	Value	Description
n_h	8000	Number of households
n_f	320	Number of firms
n_b	4	Number of banks
α_{hw}	0.5	Production coefficient home workers
α_{pw}	0.5	Production coefficient production workers
λ_{hw}	0.6	Share of home workers in workforce
μ	0.5	Weight of geographical distance in household decision making
$size_e$	100	Geographical size of the economy
ρ	0.001	Worker productivity adjustment factor
τ_h	0.5	Average ratio of home workers in the direct production process
ψ	0.1	Home worker intensity variation factor
χ	0.001	Mark-up adjustment factor
m_0	0.4	Initial mark-up
ι	0.05	Desired inventory ratio
ν	0.5	Price adjustment factor
c_{oh}	4	Constant overhead
β_{oh}	0.001	Overhead parameter
s_0^e	4000	Firm's initial sales expectations
θ	100	Parameter log-normal distribution of firm productivity
ζ	0.1	Wage premium home workers
ξ	0.1	Liquidation price discount
c_0	40	Autonomous consumption
c_1	0.8	Marginal propensity to consume out of income
c_2	0.03	Marginal propensity to consume out of wealth
σ	5	Number of job offers considered by unemployed household
α_e	0.5	AIDS parameter essential goods
α_{ne}	0.5	AIDS parameter non-essential goods
β_e	-0.1	AIDS parameter essential goods
β_{ne}	0.1	AIDS parameter non-essential goods
α_0	100	AIDS parameter
$\gamma_{e,e}$	-0.1	AIDS parameter
$\gamma_{e,ne}$	0.1	AIDS parameter
$\gamma_{ne,e}$	0.1	AIDS parameter
$\gamma_{ne,ne}$	-0.1	AIDS parameter
μ_h	2	Margin of safety parameter households
μ_f	1	Margin of safety parameter firms
i_L	0.02/12	Interest rate on loans
i_D	0.001/12	Interest rate on deposits
i_{LCB}	0.005/12	Interest rate on central bank loans
l_{min}	0.03	Minimum leverage ratio
i_B	0.01/12	Interest rate on government bonds
E_0	100	Initial bank equity
r_{min}	0.01	Minimum reserve ratio
ben_u	0.7	Unemployment benefit ratio
ben_s	0.5	Benefit ratio social security
t_{VAT}	0.05	Value-added tax rate
t_c	0.25	Corporate tax rate
t_r	0.25	Capital income tax rate
t_w	0.2	Wage income tax rate
g_0	10000	Government expenditure parameter
g_1	0.25	Government expenditure parameter

Table 2 / Pandemic scenario parameters

Parameter	Value	Description
c_1	0.3	Propensity to consume out of income
α_e	0.6	AIDS parameter essential goods
α_{ne}	0.4	AIDS parameter non-essential goods
limit	0.75	Production limit factor
str	0.85	Short-time work replacement rate

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