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Covid-19 supply-side fiscal policies to escape the health-vs-economy dilemma

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Covid-19 supply-side fiscal policies to escape the health-vs-economy dilemma

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We develop a model that allows for online retail trade and for endogenous Covid-related health expenditures. The market equilibrium at best imperfectly internalises the infection risk from contact-intensive retail trade, and the anticipation of health costs has large contractionary effects. The Ramsey planner exploits a subsidy to online trade to limit lockdown policies. Relative to the market equilibrium, the optimal policy stimulates consumption and contains the surge in health expenditures, mitigating both the recession and the persistence of the Covid-19 shock.

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1 Introduction

We propose a simple macroeconomic model where an unconventional supply shock allows to mimick the adjustment to a pandemic shock. In our model firms have the option of switching between contact-intensive and online retail trade, where the former contributes to the persistence of the shock and the latter does not. All this paves the way for the analysis of optimal supply-side fiscal policies that must strike a balance between shock mitigation and the conventional macroeconomic stabilisation objective.

The outbreak of the Covid-19 pandemic shed light on the presence of a trade-off between the need of saving lives through health policies and the avoidance of the economic collapse, as a consequence of these policies. In this sense, Atkeson (2020) and Loayza (2020) warn how, when designing any possible public intervention, governments should always take into account the existence and the evolution of such a trade-off.

A number of contributions investigate the effects of the pandemic shock within a business cycle framework. Corrado et al. (2021) interpret pandemic-induced recession as the consequence of standard demand and supply shocks, exacerbated by adverse sector-specific disturbances in contact-intensive industries. Eichenbaum et al. (2022) highlight how a key feature of the Covid shock is that it acts like a negative shock to the demand for consumption and the supply of labor.
Guerrieri et al. (2022) show that a supply-side shock (i.e. a sectoral shutdown shock) can trigger a negative demand effect in other sectors, due to the complementarity that potentially arises in a multi-sector environment. In a similar vein, Baqaee and Farhi (2022) show that complementarities in production amplify Keynesian spillovers from supply shocks but mitigate them for demand shocks, and argue that for this reason demand stabilization policies in response to Covid-19 were relatively less effective. Buera et al. (2021) model the lockdown as an exogenous shutdown to a subset of entrepreneurs that operate in the economy, and impose an exogenous productivity increase for online trading firms to match the observed sectoral reallocation away from contact-intensive activities. Bayer et al. (2020), Elenev et al. (2020), and Faria-e Castro (2021) investigate the effectiveness of several fiscal tools, for example a decrease in income taxation, or an expansion of unemployment insurance. All these studies maintain the focus on demand-side policies and a concern for the stabilisation objectives that characterise macroeconomic these policies.
By contrast, Loayza and Pennings (2020) and Dupor (2020) point out that a macroeconomic stimulus aimed at propelling aggregate demand may not necessarily be the best choice in the middle a pandemic, i.e. when the policy maker's preeminent goal is avoiding the spread of the disease.

We design a model that incorporates the trade-off between stabilising consumption and mitigating the shock through a contraction of economic activity. First, we follow Corrado et al. (2021) in modelling the pandemic shock as a systemic labor supply shock, but we also allow for the endogenous mitigation of the shock conditionally to a reduction of contact-intensive activities in total economic activity. Second, we allow

for the possibility that profit-maximizing firms reallocate retail trading from contact-intensive to online activities. Third, our model accounts for the sharp increase in health expenditures after the shock. To the best of our knowledge, this is a new amplification channel of the macroeconomic adjustment to the shock.
Fourth, we investigate the design of Ramsey-optimal fiscal policies, where the planner relies on two tools, a sectoral production subsidy and an income tax rate. Our focus here is on the identification of policies that should mitigate the effects of the shock and favor consumption stabilization through a reallocation of retail trade towards online activities. The scope for fiscal intervention arises because retail trade through contact-intensive technologies generates a negative externality on the persistence of our proxy for the pandemic shock. Note that the income tax tool might be interpreted as a proxy for lock-down policies.

Our results in a nutshell. In the private sector equilibrium the pandemic shock generates a persistent contraction, and the reallocation away from contact-intensive trade is almost nil because both trades contract in a similar way. The increase in health expenditure triggers a strong contraction of private consumption through the standard crowding-out effect. Even if there is no sectoral reallocation, the fall in contact-intensive retail trade mitigates the shock. Relative to the market equilibrium, the Ramsey-optimal policy substantially mitigates the shock without exacerbating output losses. This is obtained combining a persistent stimulus to online trading with a contractionary increase in taxation.

We contribute to a rapidly growing literature that investigates the normative implications of the Covid-19 pandemic. A strand of literature focuses on the role of age-specific socioeconomic interactions to examine the effect of different containment measures on the spread of the pandemic. For example, Favero et al. (2020) and Rampini (2020) propose models which take heterogeneity in the population (in terms of different risk levels related to age and sectors) into account. The results claim that prudent policies of gradual return to work may save many lives with limited economic costs, as long as they differentiate by age group and risk sector. In a similar vein, Giagheddu and Papetti (2020) and Acemoglu et al. (2020) highlight how uniform social distancing measures are less effective compared with age-targeted measures. These papers focus on the effectiveness of age related containment measures, while our work is mainly interested in reallocation policies which can mitigate the pandemic shock.

Dealing with supply-side policies, Hubbard and Strain (2020a), Hubbard and Strain (2020b) and Hanson et al. (2020) argue that, in order to avoid firms bankruptcies, governments should provide financial aid in the form of grants to small firms (more likely to face a permanent revenue loss due to Covid-19), while should prefer loans to big firms, whose liquidity problems can be attenuated by greater internal resources and access to financial markets. While this literature mainly focuses on temporary financial measures, our work offers an alternative scope for supply-side interventions and highlights the advantages, both in terms of shock mitigation and of economic recovery, of providing an incentive to online trade.

Another strand of literature integrates macroeconomic and epidemiological mod-

els. Farboodi et al. (2021) and Eichenbaum et al. (2021) investigate how the pandemic shock affects households' economic incentives. Krueger et al. (2020) argue that the composition of the households' consumption bundle endogenously tilts towards less contact intensive sectors. In a similar vein, Alvarez et al. (2021) study the optimal lockdown policy to control the fatalities of a pandemic while minimizing the output costs of the lockdown; while their findings prescribe a tight initial lockdown, our model shows that the exploitation of online trade translates into less severe lockdowns policies.
We share with these works the importance of considering the existence of the health-economy trade-off when implementing lockdowns or other public health policies. Moreover, another commonality is that individual responses to the shock do not fully internalise their effects on the persistence of the pandemic shock.

The remainder of the paper is organized as follows: section 2 describes the model, section 3 provides information on calibration and presents the results; section 4 concludes.

2 The model

The main actors in our model economy are: households, intermediate firms, final firms and the public sector. The model embeds frictions, both nominal and real: there are price stickiness and some level of rigidity in the reallocation of labor.
Households consume, save through government bonds and supply differentiated labor services. Perfectly competitive intermediate firms sell their goods to final firms, who are monopolistically competitive and face price rigidities; to produce their output, final firms can exploit two different technologies, a physical (contact-intensive) and an online one.
The public sector provides two different types of subsidies: the first is aimed at offsetting the distortion involved by the presence of imperfect competition in the final market, while the second is destined to boost the online production. Following the occurrence of the pandemic shock, the online subsidy is deployed as a tool for the containment of Covid-19, as it creates an incentive for a stronger utilisation of the less contagious channel (online). Moreover, the government levies labor income taxation and issues public debt.
Aside the online subsidy, the model also allows for public health services expenditure (financed through debt and labor income taxation), whose demand is an increasing function of the severity of the pandemic shock. Intermediate firms, in this context, produce health services in order to satisfy the public demand.
Finally, the economy is hit by a pandemic shock, whose persistence is endogenous to the share of contact-intensive productive activities.
The model economy is summarised in the flow diagram of Figure 1.

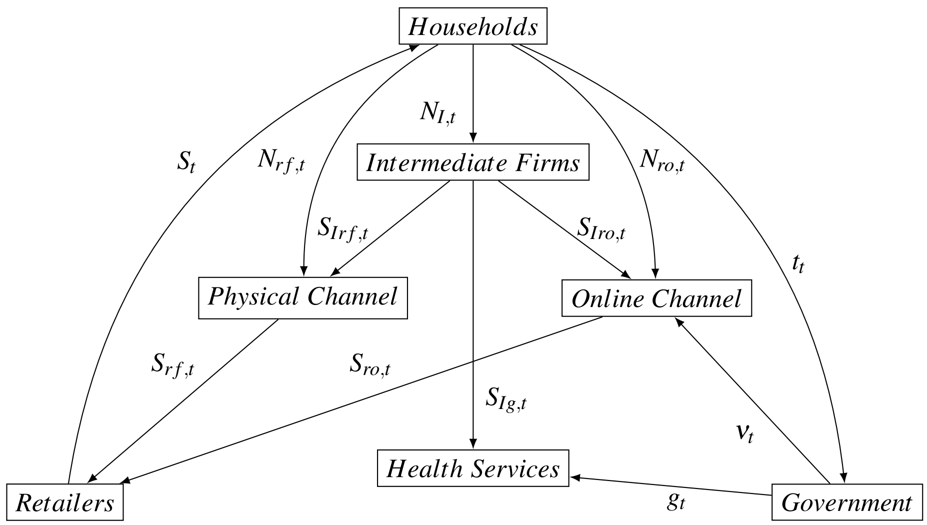

Figure 1: Flow diagram of the stylised economy

2.1 Intermediate Firms

The intermediate sector is characterised by the presence of fully competitive firms producing intermediate goods which will be used both as production inputs by the final sector and to produce public health services.
Firms have access to the following production function:

$$S_{I,t} = AN_{I,t}^{\alpha} \tag{1}$$

where $S_{I,t}$ is the intermediate output , $N_{I,t}$ is the labor used as productive factor in the intermediate production and A defines the level of productivity. Intermediate firms are subject to decreasing returns to scale, as $\alpha < 1$.
In each period, firms maximise their profits:

$$\Pi_{I,t} = p_{I,t}S_{I,t} - w_{I,t}N_{I,t} \tag{2}$$

where $p_{I,t}$ is the relative price of the intermediate good and $w_{I,t}$ is the real wage paid to workers in the intermediate sector.
The solution of the problem provides the optimal demand for intermediate labor:

$$w_{I,t} = p_{I,t}\alpha AN_{I,t}^{\alpha-1} \tag{3}$$

2.2 Final Firms

The final good sector is composed by a number j of producers, who operate in a monopolistically competitive market and face price adjustment costs à la Rotemberg (1982). In our model households treat the goods sold through the two alternative channels as perfect substitutes; therefore, the choice of the optimal bundle of physical and online quantities is completely made by the firm. We make this assumption because we are specifically interested in the analysis of supply-side policies and in understanding the response of the firms to the pandemic shock.
Our approach is therefore different from Krueger et al. (2020), who posit that an exogenous fraction of goods in the consumption bundle is associated to a lower probability of infection than the rest of the bundle.

In order to produce their output, final firms have access to two different production functions:

$$S_{i,t}^{j} = \left[\left(\frac{N_{i,t}^{j}}{\tau_i} \right)^{\alpha_r} \left(S_{Ii,t}^{j} \right)^{1-\alpha_r} \right]^{\theta} \tag{4}$$

where $i \in \{rf, ro\}$ denotes the physical/contact-intensive and the online technologies, $S_{i,t}^{j}$ is final sectoral production, $N_{i,t}^{j}$ are the quantities of contact-intensive and online worked hours needed by the firms, while τ_i are the related production costs.
The parameter $\theta < 1$ characterises decreasing returns to scale in both technologies.
Finally, firm j total output S_t^j is equal to the sum of the physical and the online outputs:

$$S_t^j = S_{rf,t}^{j} + S_{ro,t}^{j} \tag{5}$$

2.2.1 Price rigidities

In each period firms maximise their profits Π_t^j subject to a price adjustment cost, $\Phi_t = \frac{\gamma}{2} \left(\frac{P_t^j}{P_{t-1}^j} - 1 \right)^2 S_t$, and to the demand function:

$$S_t^j = S_t \left(\frac{P_t^j}{P_t} \right)^{-\psi} \tag{6}$$

where the parameter ψ is the price elasticity of demand.

Firm j profit function is:

$$\Pi_t^j = \frac{P_t^j}{P_t} S_t^j - (1-\omega)\left[(1-\nu_t)\left(w_{ro,t} N_{ro,t}^j + p_{I,t} S_{Iro,t}^j\right) - \left(w_{rf,t} N_{rf,t}^j + p_{I,t} S_{Irf,t}^j\right)\right] - \Phi_t \tag{7}$$

Final producers receive from the public sector a subsidy ν_t, whose aim is providing an incentive to a larger utilisation of the online technology.
The Ramsey planner intervenes in the economy to correct every type of inefficiency implied by the model structure. Since we want to isolate the planner's intervention targeting uniquely the negative impact of the shock, we need to clean the model from any other possible distortion. This is why we introduce a fixed public subsidy ω to the marginal costs, whose goal is offsetting the inefficiency implied by monopolistic competition in steady state. [1]

2.2.2 Cost minimisation

Firms optimally choose $N_{rf,t}^j, N_{ro,t}^j, S_{Irf,t}^j, S_{Iro,t}^j$ so that the physical and online labor demands are:

$$N_{rf,t}^j = \frac{\theta \alpha_r MC_t^j S_{rf,t}^j}{(1-\omega) w_{rf,t}} \tag{8}$$

$$N_{ro,t}^j = \frac{\theta \alpha_r MC_t^j S_{ro,t}^j}{(1-\omega)(1-\nu_t) w_{ro,t}} \tag{9}$$

while, the physical and online demands for intermediate inputs are:

$$S_{Irf,t}^j = \frac{\theta (1-\alpha_r) MC_t^j S_{rf,t}^j}{(1-\omega) p_{I,t}} \tag{10}$$

$$S_{Iro,t}^j = \frac{\theta (1-\alpha_r) MC_t^j S_{ro,t}^j}{(1-\omega)(1-\nu_t) p_{I,t}} \tag{11}$$

[1] Firms produce until, at the zero inflation steady state, it holds that $MC = \left(\frac{\psi-1}{\psi}\right)\frac{1}{(1-\omega)}$. Hence, we set ω so that the effect of the markup is eliminated as if the market would be characterised by perfect competition.

The first order conditions (8), (9), (10) and (11) show that the demands for factors are directly correlated with the sectoral output produced, while inversely related to the price of the factors.

According to the cost minimisation problem, we derive the firm's marginal cost:

$$MC_{i,t} = (1-\omega)\frac{1}{\theta}(1-\nu_t)(\tau_i)^{\alpha_r}\left(\frac{w_{i,t}}{\alpha_r}\right)^{\alpha_r}\left(\frac{p_{I,t}}{(1-\alpha_r)}\right)^{1-\alpha_r}(S_{i,t})^{\frac{1-\theta}{\theta}} \tag{12}$$

The marginal cost is an increasing function of the factor prices (wages and intermediate good prices), of the production costs τ_i and of the sectoral production. In the same vein as the demands for productive factors, the marginal cost related to online production is affected by the subsidy ν_t.

Finally, cost minimisation implies that $MC_{rf,t} = MC_{ro,t}$. Moreover, using equation (5), the total marginal cost can be written as:

$$MC_t = (1-\omega)\frac{1}{\theta}(1-\nu_t)(\tau_{ro})^{\alpha_r}\left(\frac{w_{ro,t}}{\alpha_r}\right)^{\alpha_r}\left(\frac{p_{I,t}}{(1-\alpha_r)}\right)^{1-\alpha_r}\left(\frac{S_t}{1+\left[(1-\nu_t)\frac{(\tau_{ro})^{\alpha_r}}{(\tau_{rf})^{\alpha_r}}\left(\frac{w_{ro,t}}{w_{rf,t}}\right)^{\alpha_r}\right]^{\frac{\theta}{1-\theta}}}\right)^{\frac{1-\theta}{\theta}} \tag{13}$$

2.2.3 Optimal price setting

The solution to the optimal price setting problem yields the standard New Keynesian Phillips Curve:

$$(1-\psi)+\psi MC_t+\gamma\mathbb{E}_t\Lambda_t\left[(\pi_{t+1}-1)\pi_{t+1}\frac{S_{t+1}}{S_t}\right] = \gamma(\pi_t-1)\pi_t\frac{S_{t+1}}{S_t}{}^{2} \tag{14}$$

[2]The NKPC can be written also as:

$$(1-\psi)+\psi(1-\omega)MC_t^m+\gamma\mathbb{E}_t\Lambda_t\left[(\pi_{t+1}-1)\pi_{t+1}\frac{S_{t+1}}{S_t}\right] = \gamma(\pi_t-1)\pi_t\frac{S_{t+1}}{S_t}$$

where

2.3 Households

Households preferences are defined over consumption S_t and labor effort, which can be divided in three different types: intermediate $N_{I,t}$, contact-intensive $N_{rf,t}$ and online $N_{ro,t}$. The representative households' lifetime utility function $U_t(S_t, N_{rf,t}, N_{ro,t}, N_{I,t})$ is akin to Moura (2018) and defined as:[3]:

$$\sum_{t=0}^{\infty} E_t \beta^t \left\{ \frac{(S_t)^{1-\sigma}}{1-\sigma} - \frac{\alpha_t^N}{1+k} \left[\chi_1 \left(N_{rf,t}\right)^{1+\eta} + \frac{\chi_2}{\chi} \left(N_{ro,t}\right)^{1+\eta} + \chi_3 \left(N_{I,t}\right)^{1+\eta} \right]^{\frac{1+\kappa}{1+\eta}} \right\} \tag{15}$$

where β is the subjective discount factor, σ is the intertemporal elasticity of substitution, α^N is the pandemic shock, which will be discussed later in detail. The specification of the labor bundle implies reallocation rigidities, and hence imperfect labor mobility, when $\eta > 0$. This would introduce heterogeneity in wages and hours worked. The parameter κ measures the aggregate elasticity of labor supply and χ_1, χ_2 and χ_3 are weights attached respectively to the physical, online and intermediate labor.

We consider two different specifications of the utility function: the parameter χ is set equal to 1 for a shock that is symmetric to every labor type; otherwise, we set $\chi = (\alpha_t^N)^{\frac{1+\kappa}{1+\eta}}$. This latter case allows to model a scenario where the private sector internalises the benefits from avoiding contact-intensive activities. This is akin to Krueger et al. (2020), where households internalise -even in the market economy equilibrium- the different likelihood of being infected as a consequence of their consumption choices. More precisely, they describe a scenario with different infection probabilities according to the different sector, i.e. one sector is more contact-intensive and infectious than the other. With the second specification of equation (15) we are able to replicate this dynamic, even if our reallocation mechanism operates through the labor supply and not through consumer choices.

Nevertheless, we decided to consider the second case as an alternative and to use as benchmark the specification with $\chi = 1$, where the Covid-19 shock affects every type of labor. This because we envisage the pandemic not uniquely as a sectoral phenomenon, but instead as a shock diffused to the entire economy. In this sense, also a less contact-intensive sector may be affected by negative spillovers coming from the interaction of its labor force with that of the other, more contagious, sectors, for example in a domestic environment. In order to sharpen our analysis and results, we also simulate the model considering the asymmetric shock (i.e., the second specification for χ) to check

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$$MC_t^m = \frac{1}{\theta}(1-\nu_t)(\tau_{ro})^{\alpha_r} \left(\frac{w_{ro,t}}{\alpha_r}\right)^{\alpha_r} \left(\frac{p_{I,t}}{(1-\alpha_r)}\right)^{1-\alpha_r} \left(\frac{S_t}{1+\left[(1-\nu_t)\frac{(\tau_{ro})^{\alpha_r}}{(\tau_{rf})^{\alpha_r}}\left(\frac{w_{ro,t}}{w_{rf,t}}\right)^{\alpha_r}\right]^{\frac{\theta}{1-\theta}}} \right)^{\frac{1-\theta}{\theta}}$$

is the standard monopolistic competition marginal cost without the subsidy ω.

[3]When the value of the parameter σ is equal to one, equation (15) is logarithmic in consumption S_t

whether the market equilibrium optimally reallocates part of the production, without the intervention of the planner.

The budget constraint is:

$$S_t + b_t = \frac{R_{t-1} b_{t-1}}{\pi_t} + (1 - t_t)(w_{rf,t} N_{rf,t} + w_{ro,t} N_{ro,t} + w_{I,t} N_{I,t}) + \Pi_t \tag{16}$$

Where b_{t-1} is the real stock of government bond the households hold, R_{t-1} is the interest rate, b_t is the purchase of real public bonds, $w_{rf,t}$, $w_{ro,t}$ and $w_{I,t}$ are real wages paid for, respectively, physical ($N_{rf,t}$), online ($N_{ro,t}$) and intermediate ($N_{ro,t}$) labors. Finally, π_t is the inflation rate, t_t are distortionary income taxes and Π_t are firm real profits.
The households optimally choose, through maximisation of (15) subject to (16), the sequence of the allocation of $\left\{S_t, b_t, N_{rf,t}, N_{ro,t}, N_{I,t}\right\}_{t=0}^{\infty}$.
This yields the Euler equation for consumption and the labor supplies for each sector:

$$\frac{1}{R_t} = \beta \left[\pi_{t+1}^{-1} \left(\frac{S_{t+1}}{S_t} \right)^{-\sigma} \right] \tag{17}$$

$$(1 - t_t) w_{rf,t} = \left(\alpha_t^N \right) \chi_1 (N_{rf,t})^{\eta} (S_t)^{\sigma} \tag{18}$$

$$(1 - t_t) w_{ro,t} = \left(\alpha_t^N \right) \chi_2 (N_{ro,t})^{\eta} (S_t)^{\sigma} \tag{19}$$

$$(1 - t_t) w_{I,t} = \left(\alpha_t^N \right) \chi_3 (N_{I,t})^{\eta} (S_t)^{\sigma} \tag{20}$$

The first order conditions (18), (19) and (20) highlight how the shock α^N directly affects the disutility of labor. Hence, as a consequence of the pandemic, households will be less willing to supply worked hours unless they receive an higher wage.

2.4 The Covid-19 shock

To mimick the effect and the endogenous persistence of the pandemic, we need to model a shock incorporating:

- an increase in the disutility of labor, i.e. households should be less willing to supply their labor in consequence of the pandemic, as in Corrado et al. (2021);

- an endogenous persistece mechanism, that should be related to the dynamics of contact-intensive activities. We therefore assume the following

$$\alpha_t^N = \left(\alpha_{t-1}^N\right)^{\rho} \left(\frac{S_{rf,t}}{S_{rf,t-1}}\right)^{\Delta(1-\rho)} \exp\varepsilon_t \tag{21}$$

where ρ is the exogenous persistence of the process, $\left(\frac{S_{rf,t}}{S_{rf,t-1}}\right)$ proxies the endogenous persistence channel, due to contactintensive activities, and Δ allows to characterize the strength of this latter mechanism.
The underlying intuition is that the growth of contact-intensive retail trade raises possibility of getting infected, and therefore adversely affects the supply of worked hours. In consequence of this shock modelisation, the Ramsey planner is confronted with a trade-off between stabilising consumption and mitigating the shock through a contraction of economic activity.

2.5 Public sector

The government's budget constraint is:

$$\nu_t S_{ro,t} + \frac{R_{t-1} b_{t-1}}{\pi_t} + g_t = t_t(w_{rf,t}N_{rf,t} + w_{ro,t}N_{ro,t} + w_{I,t}N_{I,t}) + b_t \tag{22}$$

The public sector needs to levy taxes on the labor income and to issue new debt in order to repay interest on past debt, to finance the provision of the online subsidy and the supply of health services, g_t.
[4]

2.5.1 Public expenditure

In order to face the outbreak of Covid-19, the public sector needs to increase its expenditure on health and sanitary goods and services as documented in Mendoza et al. (2020). The demand for public expenditure is:

$$g_t = \bar{g} + \left[1 - \left(\frac{\bar{\alpha}^N}{\alpha_{t-1}^N}\right)^{\phi_g}\right] \tag{23}$$

[4] We posit that the government finances ω by means of lump-sum taxes. For the sake of simplicity, we remove from (16) both these subsidies and the revenues from lump-sum taxes that finance them.

where $\bar{g}$ is the steady state (or non-pandemic) level of public expenditure, $\bar{\alpha}^N$ is the steady state value of the shock and ϕ_g represents the elasticity to the shock α^N.
The supply of g_t is:

$$g_t = (S_{Ig,t})^{\alpha_g} \tag{24}$$

where $S_{Ig,t}$ is the fraction of intermediate input devoted to the production of the public good. The parameter α_g defines decreasing returns to scale, as it is lower than 1; moreover, we assume that this type of production presents returns that decrease faster with respect to those in the final good sector.
Assuming such a productive structure for g_t has an impact on the aggregation of the intermediate good $S_{I,t}$, as:

$$S_{I,t} = S_{Irf,t} + S_{Iro,t} + S_{Ig,t} \tag{25}$$

Following the shock, the increase in g_t will trigger an endogenous reallocation effect, because the relative price of intermediate goods will increase.Thus the the presence of Covid-related public expenditures will generate an additional supply-side effect.

2.6 Market clearing

An aggregate resource constraint closes the model, as aggregate production S_t has to cover not only the level of consumption C_t, but also needs to take into account the presence of public expenditure; hence:

$$S_t = C_t + g_t \tag{26}$$

2.7 Monetary and fiscal policies

2.7.1 The Ramsey planner

Provided the two available instruments to fight the pandemic, we evaluate the optimal level of these tools through a standard Ramsey problem. Hence, the Ramsey planner maximises households' expected utility of equation (15), subject to: the firms equilibrium conditions (1), (3), (4), (8) - (11), (13), (14), to the households equilibrium conditions, equations (17) - (20), to the public sector equilibrium conditions (22) - (24), (27), (28); to the market clearing condition (25) and to the aggregate resource constraint (26).

In our experiments, the planner always controls the online subsidy v_t as an instrument, and the planner can also optimally set labor taxation. In this sense, taxes are a proxy for administrative lockdown policies. We take here inspiration from Eichenbaum et al.

(2022), who defines the lockdown by means of a tax on consumption.

To better illustrate the distinct contributions of the two policy tools in the Ramsey-optimal plan, we also consider the possibility that the tax rate follows a simple rule aiming at control of public debt, as advocated in Schmitt-Grohé and Uribe (2004):

$$\frac{t_t}{\bar{t}} = \left(\frac{b_{t-1}}{\bar{b}}\right)^{\xi} \tag{27}$$

where $\bar{t}$ and $\bar{b}$ are respectively the steady state levels of income taxation and public debt. ξ defines the intensity of the reaction of taxation to debt accumulation.

2.7.2 Monetary policy

The monetary authority is assumed to follow a standard Taylor rule:

$$\frac{R}{\bar{R}} = (\pi_t)^{\theta_\pi} \left(\frac{S_t}{\bar{S}}\right)^{\theta_S} \tag{28}$$

where $\bar{S}$ is the steady-state level of output.

3 Results

3.1 Model calibration

Households preferences are quite standard, the discount factors β is 0.99 and the elasticity of intertemporal substitution σ is equal to 1; both parameters that characterize labor market frictions, κ and η, are assumed to be equal to 2, following Moura (2018). We set the steady state ratio between physical and online production, $\frac{\bar{S}rf}{\bar{S}ro}$, equal to six; this indicates that the contact-intensive output accounts for the majority of total output and is in line with what observed from US Census Bureau (2022).
We opted for a conservative choice concerning the level of debt, which is equal to 80% of GDP, on annual basis. This pin downs a tax rate of 4%. The aggregate labor supply $N_{rf} + N_{ro} + N_I$ is assumed to be equal to 1 in steady state. We calibrate the three weights χ_1, χ_2, χ_3 attached to each labor type consequently.
The level of the intermediate productivity A is assumed to be equal to 1, and this yields a steady state value of the intermediate production S_I equal to one fifth of total production S.

Concerning the shock, ε is chosen in order to simulate an initial 10% drop in the aggregate production in the market equilibrium. The parameter $\Delta = 8$ defines the sensitivity of the shock to the share contact-intensive output. This implies that the higher is Δ, the stronger will be the planner's incentive to intervene in the economy.
With respect to production and labor markets, the share of labor in the final production function is assumed to be $\alpha_r = 0.66$.
Intermediate and final productions are subject to decreasing returns to scale, as $\alpha = \theta = 0.87$; this follows Basu and Fernald (1997).
With respect to public expenditures, we set $\alpha_g = 0.7$ in order to obtain a persistent reaction of health services to the shock. We opted for this suggestive calibration to underline the importance of accounting for long-term Covid-19 expenses in the model (National Institute Health Care Excellence (2022)).
Monetary policy parameters are $\theta_\pi = 1.5$ and $\theta_S = 0.2$, in line with the priors form Christiano et al. (2014).
Finally, the steady state value of the online subsidy ν is zero.
Table 1 summarises the calibration.

(i) Parameter	Value	Definition
β	0.99	Households discount factor
σ	1	Elasticity of intertemporal substitution
κ	2	Aggregate elasticity of labor supply
η	2	Reallocation cost for labor
α	0.87	Returns to scale intermediate production
A	1	Productivity
α_r	0.66	Share of labor in final production
θ	0.87	Returns to scale final production
γ	18.5	Rotemberg menu cost
ψ	6	Price elasticity of demand
ξ	1.2	Intensity of tax reaction to debt accumulation
θ_π	1.5	Taylor rule: inflation
θ_S	0.2	Taylor rule: output
α_g	0.7	Persistence of health expenditures
ρ	0.9	Shock persistence
Δ	8	Sensitivity of the shock to variation in $S_{rf,t}$

(ii) Steady State	Value	Definition
$\frac{Srf}{Sro}$	6	Ratio physical to online output
$\frac{B}{S}$	80%	Debt to GDP ratio
t	4%	Labor income tax rate
ν	0	Online production subsidy

Table 1: *(i) Main parameters (ii) Steady state values*

3.2 Model dynamics

Our benchmark for policy analysis is the market equilibrium where there is no public intervention and taxes follow the simple heuristic rule of equation (27). We also consider the possibility that households internalise the benefits from supplying labor to the online sector (asymmetric pandemic shock). Finally, we consider the presence of health goods expenditure in the model.

We adopt a Ramsey-optimal approach [5], as described in section 2.7.1, in order to investigate how the planner would intervene in response to the pandemic. Thus, we simulate the Covid-19 shock affecting the economy and, in addition, we consider two different specifications of the set of instruments of the Ramsey planner (i.e., online subsidy alone and a combination of subsidy and labor taxation), in order to analyse the optimal supply-side fiscal policies.
We start presenting the results (Figures 2 and 3) for the simulation for a shock calibrated to reproduce a 10% drop in aggregate output, without health expenditure. We opt for this choice because we first want to focus on the impact of the two fiscal tools controlled by the planner. After that, we add public expenditure to investigate how the economy behaves with this additional fiscal instrument, which is not directly under the control of the planner.

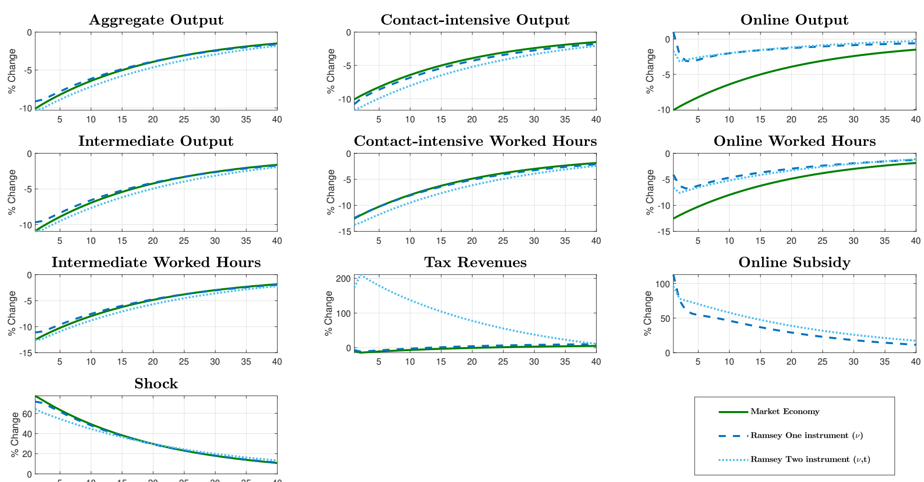

Figure 2: *IRFs to a pandemic shock, percentage deviations from steady state*

Consider first the market equilibrium. According to condition (15), the shock affects

[5] The Ramsey optimal policy is computed using a first-order approximation using Dynare 4.6.4

every type of labor, making the households less willing to supply their labor. We observe a generalized contraction. Firms do not internalize the effect of contact-intensive retail trade on the shock persistence, so there is no incentive to reallocate towards online trade.
The Ramsey planner faces two different objectives: mitigating the economic recession, in order to stabilise consumption, while trying to contain the spread of the disease. When the planner only relies on the subsidy, she will try to induce labor and production reallocation towards the online industry.
The provision of a positive online subsidy is successful in achieving a reallocation of worked hours towards the online sector, while the contact-intensive and intermediate productions still decline. This shift dampens the fall in aggregate output and implies a reduction in the persistence of the shock, i.e. achieve a more effective containment of the pandemic.

Adding the labor income tax to the set of planner's policy tools allows to strengthen the shock mitigation effect. This is achieved by means of a relatively large and persistent increase in the tax rate. With the reallocation effect still valid, the economy experiences a contraction in aggregate output, due to a tighter fiscal regime: the increase in the level of taxation reduces the households purchasing power and consequently generates a reduction in consumption. This scenario confirms that, when an economy is in the middle of a pandemic, a contraction of output, necessary to obtain a more powerful mitigation effect, raises welfare.

3.2.1 Asymmetric shock

In order to corroborate the previous analysis, here we discuss the results obtained assuming that Covid-19 hits asymmetrically the households' labor supply functions. It is the case (described in section 2.3) where the utility function (15) assumes a values for χ equal to $(\alpha_t^N)^{\frac{1+\kappa}{1+\eta}}$. Such a design implies that the shock affects only two labor supplies, the contact-intensive and the intermediate. Figure 3 presents the results.

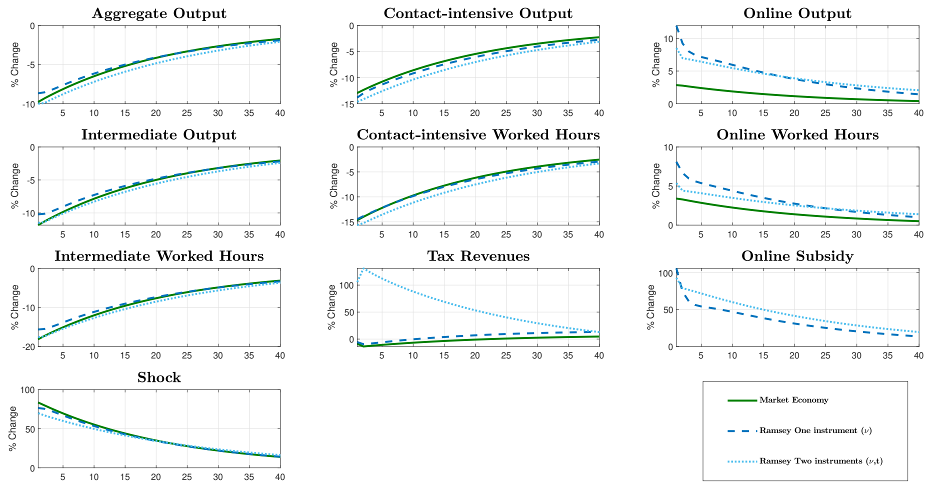

Figure 3: *IRFs to an asymmetric pandemic shock, percentage deviations from steady state*

The private sector now shifts the labor supply towards the online channel. Hence, the decentralised equilibrium now generates a relative expansion in the the online sector and a reduction in the intensity of the shock, since the economy is less dependent from contact-intensive activities.
The planner's intervention is coherent with the response to the symmetrical shock. This happens because the private sector does not internalise the impact on the persistence of shock implied by the contact-intensive trade.

3.3 Public expenditure for health services

We now presents the full version of the model, which features the presence of health expenditures. Figures 4 and 5 show the results.

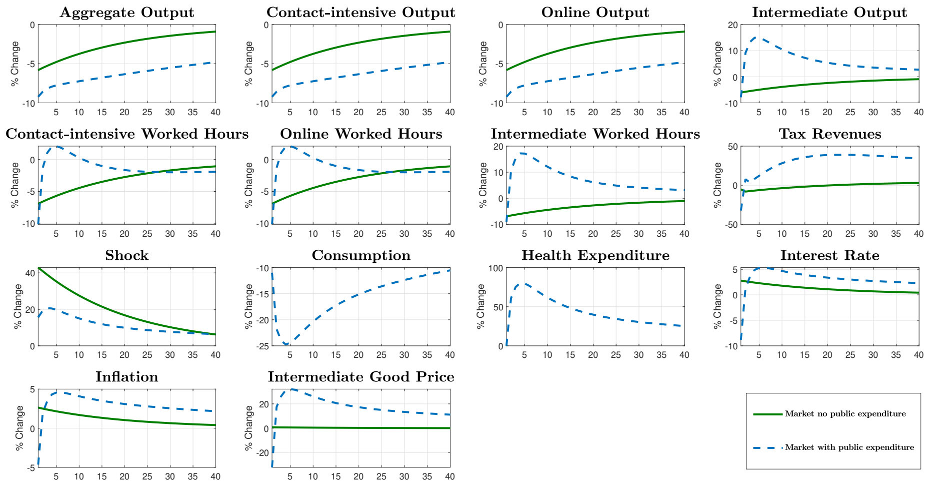

Figure 4: *IRFs to a pandemic shock, market economy with endogenous public health expenditures, percentage deviations from steady state*

The comparison between the two different market outcomes (Figure 4) clearly shows that the main mechanism driving this version of the model is based on the fact that, as a reaction to the pandemic outbreak, the public sector increases health expenditures (panel 12). As a consequence, the anticipation of higher future taxes induces households to reduce their private consumption (panel 11).

This additional reduction in consumption makes the economic recession to be more pronounced in the model embedding public expenditure. The crucial consequence is a more effective containment of the pandemic, due to a stronger contraction of productive activities.

There are other channels through which the increase in public expenditure affects the dynamics of the economy; first, if g_t raises, so does taxation that target public debt, causing an additional labor supply distortion which further depresses output.

Furthermore, fewer worked hours are allocated on contact-intensive and online productions, in favour of the intermediate sector, creating a contractionary effect on final production. This creates a strong difference with respect to the case without g_t.

Finally, we also observe a monetary channel; as a matter of fact, in the simulation including public expenditure, both inflation and the interest rate grow more than in the other scenario. The increase in g_t boosts intermediate production, raising the relative price of the intermediate good (Panel 15).

The monetary contraction leads to a further demand fall, strengthening the economic recession, but also contributing to a more powerful mitigation of the pandemic.

Summing up, in the market equilibrium the endogeneity of public health expenditures triggers a deeper contraction because households anticipate higher future taxes. One unintended consequence is that this dampens the shock.

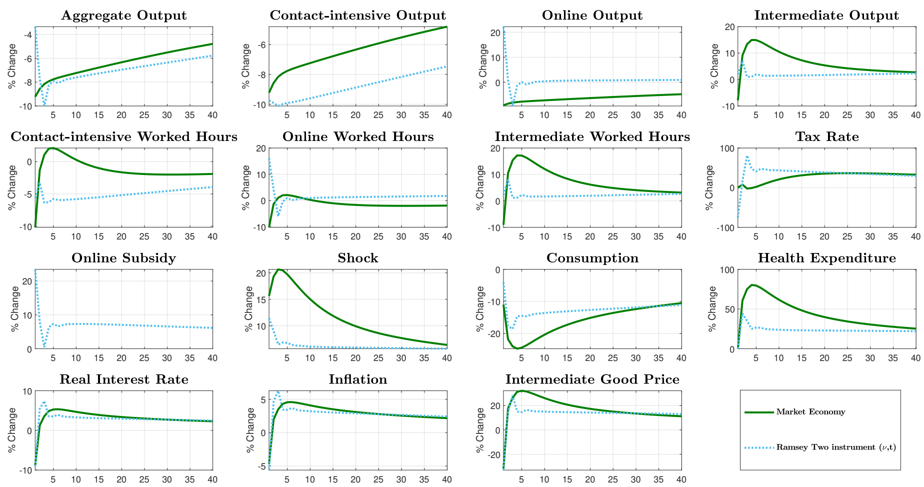

Figure 5: *IRFs to a pandemic shock, Ramsey two instruments with public expenditures, percentage deviations from steady state*

Figure 5 compares the Ramsey planner's equilibrium (with two instruments) with the market equilibrium with endogenous public expenditure. Considering the presence of g_t does not change the fact that the private sector does not internalise the endogenous infection risk; this means that the Ramsey planner still has an incentive in intervening in the economy. Hence, the planner provides the online subsidy in order to reallocate the production and increase labor taxation to achieve the necessary drop in aggregate output.

The planner's intervention mitigates the shock, and reduces health expenditures. This consequently implies a lower drop of private consumption. In spite of the sharp acceleration in the containment of the shock, due to the penalisation of contact-intensive activities, the persistence of health expenditures slows down the overall adjustment process. When the reduction of contact-intensive activities has drastically reduced the shock, the planner generates tax revenues that match health expenditures dynamics. This is obtained by keeping the tax rate above steady state. The persistently high online subsidy reduces marginal costs in the retail sector, compensating for the inflationary effect of the higher tax rate.

4 Conclusions

In our model economy, the market equilibrium is inefficient because agents do not internalize the endogenous persistence of the shock, i.e. the market does not reallocate retail trade towards the online sector and away from contact-intensive activities. By including endogenous health expenditures, we highlight a hitherto unexplored channel that magnifies the contraction in economic activity. The model allows investigating how supply-side fiscal policies can affect the health-vs-economy trade-off that has characterized the debate about the optimal policy responses to the Covid-19 pandemic. The Ramsey planner improves the trade-off between macroeconomic stabilisation and infection mitigation, engineering a reallocation away from contact-intensive. In this regard, a production subsidy for online trade turns out to be very effective. To sharpen the analysis, we have followed a heuristic approach and opted for a highly stylized model. Our proposed set of policy interventions should be verified in models that integrate a richer macroeconomic structure with a more realistic characterization of the epidemiological aspects of the Covid-19 shock. We leave this for future research.

The Ramsey planner improves the trade-off between macroeconomic stabilisation and shock mitigation, engineering a reallocation away from contact-intensive activities, obtained with a subsidy provided to the online technology. Moreover, adding labor income taxation (a proxy for administrative lockdowns) to the planner's tools allows to achieve a stronger mitigation of the Covid-19 shock. The results show that a contraction in overall economic activities is necessary when the system is in the middle of a pandemic and hence a strong macroeconomic stimulus focused on boosting aggregate demand may not represent the best policy to fight the spread of Covid-19. In this spirit, the work sheds light on the importance of investigating supply-side policies oriented to a potential reallocation towards less contagious sectors. Considering public expenditure in the form of health services as a weapon to react to the pandemic generates a more effective virus containment; this happens mainly thanks to the reduction in private consumption. This implies a drop in the level of production, especially the contact-intensive one and, consequently, reduces the severity of the pandemic. In addition, combining the planner's intervention with the provision of health services leads to a stronger and more effective containment of the spread of Covid-19, without the exacerbation of output losses.

Finally, our paper provides a methodological contribution to the design of the Covid-19 shock in macroeconomic non-SIR models. As a matter of fact, in a Ramsey-optimal framework, our proposal successfully creates a trade-off for the planner, who has to decide the optimal policy to fight both the health effect of the spread of the disease and the economic recession. In this framework, thinking of Covid-19 as an sectoral adverse productivity shock (in line with Guerrieri et al. (2022)) fails in generating the sanitary/economic trade-off, leading to a non-intervention of the planner in the economy. We think that our proposal could be well-suited to investigate public policies with a Ramsey-optimal approach.

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Appendix

A The role of labor reallocation frictions

In this section we simulate the model for different values of the parameter η, which controls the reallocation cost for labor. Figure 6 and 7 respectively present the results for the market equilibrium and for the Ramsey optimal policy (two instruments case).

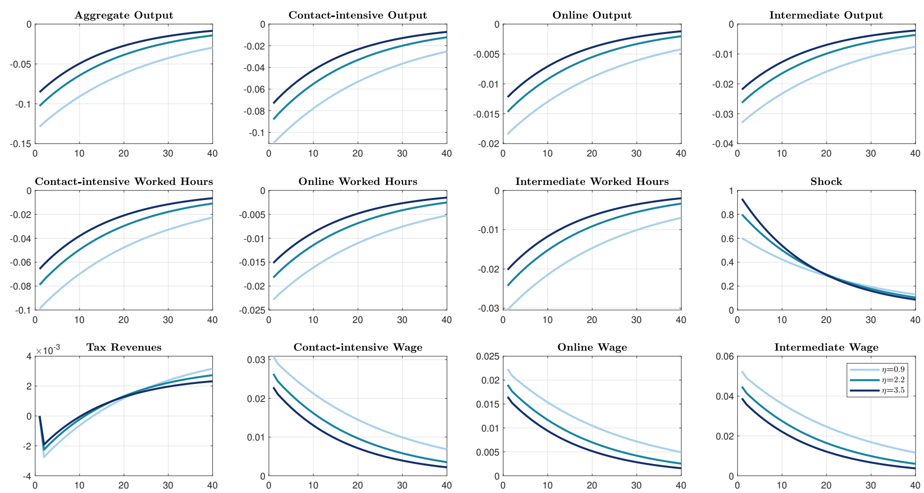

Figure 6: *IRFs to a pandemic shock for different levels of* η*, market economy*

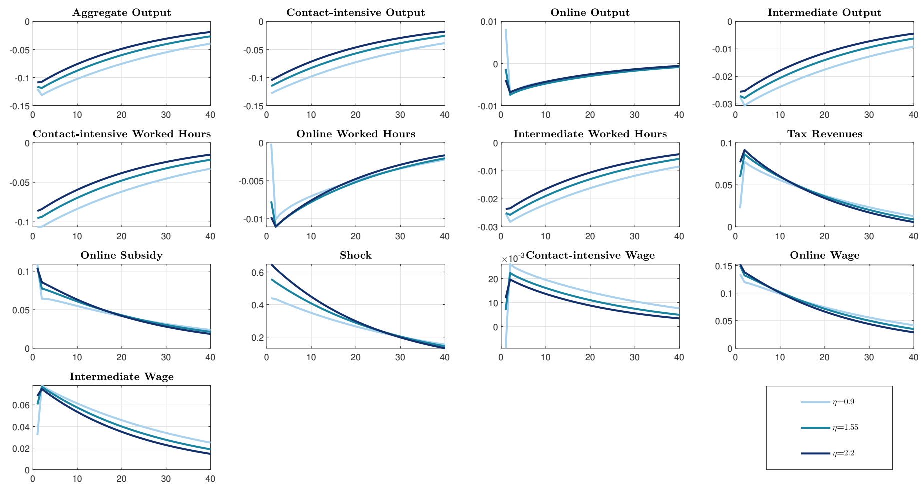

Figure 7: *IRFs to a pandemic shock for different levels of* η*, Ramsey two instruments*

The shock to the disutility of labor triggers a rise in the level of wages, for every type of labor, in order to compensate the households' lower propensity to supply worked hours. Firms demand less labor. Overall, this effect leads to a reduction in the number of worked hours. To understand how labor reallocation frictions affect the mechanism at play, recall the labor supplies of equations 18, 19 and 20. We can write them as[6]:

$$N_{rf,t} = \left(\frac{(1-t_t)w_{rf,t}}{\left(1+\alpha_t^N\right)\chi_1\left(S_t\right)^{\sigma}} \right)^{\frac{1}{\eta}} \tag{A.1}$$

An increase in labor market flexibility, i.e. a lower η, translates into a stronger effect of the impact of the shock on the labor supply.

As a consequence, this effect also leads to a more severe economic recession, which mitigates the impact of the shock on the economy. As a matter of facts, for lower degrees of the reallocation frictions, the decentralised equilibrium is relatively more effective in managing the virus spread, through the stronger contraction in worked hours and aggregate output. As a consequence, the Ramsey planner decides for a weaker intervention. Our qualitative results are nevertheless confirmed.

[6]We present here only the equation for the contact-intensive labor supply, but the same argument holds for the other types of labor

B Adverse productivity shock

In this section, we present evidence that, when adopting a Ramsey-optimal approach, designing the pandemic shock uniquely as an adverse productivity shock à la Guerrieri et al. (2022) fails in generating the trade-off between mitigating the pandemic and dampening the economic contraction and the planner's incentives are quite different.
In line with Guerrieri et al. (2022), we assume that physical production suffers an increase in its production cost, τ_{rf}, while online trade is unaffected. The shock thus takes the following form:

$$\tau_{rf,t} = (1-\rho)\bar{\tau}_{rf} + \rho\tau_{rf,t-1} + \varepsilon_{\tau} \tag{B.1}$$

where ε_{τ} is a white noise exogenous shock to the physical production cost and ρ indicates the persistence of the shock. The shock is calibrated in order to have a 10% drop in the aggregate output. Figure 8 presents the results.

All simulations show that the planner's intervention produces almost the same effects of those obtained through the market mechanism; as a matter of fact, the increase in labor cost triggers a contraction in the production of the contact-intensive output, because firms are less willing to employ contact-intensive worked hours. The possibility to shift towards the online technology partially contains the recession, but this transition mechanism is not strong enough to avoid the fall of aggregate output. The mechanism here is that firms, facing a purely economic shock, move their production towards the unaffected technology, since it is now characterised by a lower marginal cost.
It is worth noting the response of the planner to the shock, in panels 7 and 9. The variation in the levels of the two instruments is very small due to the planner's willingness to correct the inefficiency implied by the presence of price stickiness. The shock triggers an increase in the production costs and hence also the inflation rises accordingly. The monetary policy chosen by the central authority is not tight enough to counteract the inflation, i.e. the increase in the interest rate is not high enough. Hence, the planner needs to intervene: through the negative online subsidy, in order to make this sector less productive and fight the increase in prices. Or, in the two instruments scenario, the intervention is obtained through taxation: in fact, the decreased overall productivity requires less labor effort.

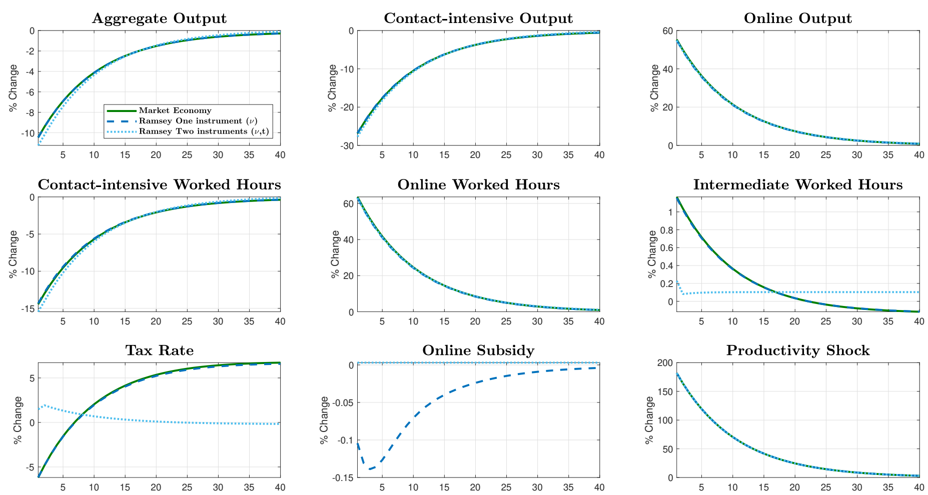

Figure 8: *IRFs to an adverse productivity shock, percentage deviations from steady state*

C Derivation of key equations

In this section the full derivation of the key equations is presented

C.0.1 Intermediate Firm

The problem of the intermediate firm is:

$$\max_{S_{I,t}} \Pi_{I,t} = p_{I,t} S_{I,t} - w_{I,t} N_{I,t}$$
$$s.t. \tag{C.1}$$
$$S_{I,t} = A N_{I,t}^{\alpha}$$

$\frac{\partial L}{\partial S_{I,t}} = 0$

$$\lambda_t = p_{I,t}$$

Recall that the Lagrangean multiplier λ_t can be seen as the marginal cost.
Hence, $\lambda_t = MC_{I,t}$. This yields to the standard relation for perfect competition:

$$MC_{I,t} = p_{I,t} \tag{C.2}$$

Through cost minimisation, the demand for intermediate labor, $N_{I,t}$, is obtained as follows:

$$\max_{N_{I,t}} \Pi_{I,t} = p_{I,t} S_{I,t} - w_{I,t} N_{I,t}$$
$$s.t. \tag{C.3}$$
$$S_{I,t} = A N_{I,t}^{\alpha}$$

$\frac{\partial L}{\partial N_{I,t}} = 0$

$$w_{I,t} = p_{I,t} \alpha A N_{I,t}^{\alpha-1} \tag{C.4}$$

C.0.2 Final Firms

The problem of the final producer is:

$$\max_{N^j_{rf,t},N^j_{ro,t},N^j_{I,t},S^j_{Irf,t},S^j_{Iro,t},p^j_t} \Pi^j_t = \frac{P^j_t}{P_t} S^j_t - (1-\nu_t)\left(w_{ro,t}N^j_{ro,t} + p_{I,t}S^j_{Iro,t}\right)$$

$$-w_{rf,t}N^j_{rf,t} - p_{I,t}S^j_{Irf,t} - \frac{\gamma}{2}\left(\frac{P^j_t}{P^j_{t-1}} - 1\right)^2 S_t$$

$$s.t. \tag{C.5}$$

$$S^j_{rf,t} = \left[\left(\frac{N^j_{rf,t}}{\tau_{rf}}\right)^{\alpha_r} (S^j_{Irf,t})^{1-\alpha_r}\right]^{\theta}$$

$$S^j_{ro,t} = \left[\left(\frac{N^j_{ro,t}}{\tau_{ro}}\right)^{\alpha_r} (S^j_{Iro,t})^{1-\alpha_r}\right]^{\theta}$$

$$S^j_t = S^j_{rf,t} + S^j_{ro,t}$$

$$S^j_t = S_t \left(\frac{P^j_t}{P_t}\right)^{-\psi}$$

The Lagrangean is:

$$L = \frac{P^j_t}{P_t} S_t - (1-\nu_t)\left(w_{ro,t}N^j_{ro,t} + p_{I,t}S^j_{Iro,t}\right) - w_{rf,t}N_{rf,t} - p_{I,t}S^j_{Irf,t} - \frac{\gamma}{2}\left(\frac{P^j_t}{P^j_{t-1}} - 1\right)^2 S_t$$

$$-\frac{P^j_t}{P_t} MC_t \left[S^j_t - \left[\left(\frac{N^j_{rf,t}}{\tau_{rf}}\right)^{\alpha_r} (S^j_{Irf,t})^{1-\alpha_r}\right]^{\theta} - \left[\left(\frac{N^j_{ro,t}}{\tau_{ro}}\right)^{\alpha_r} (S^j_{Iro,t})^{1-\alpha_r}\right]^{\theta}\right]$$

The first order conditions are:

$\frac{\partial L}{\partial N^j_{rf,t}} = 0$

$$N^j_{rf,t} = \frac{\theta \alpha_r MC_t S^j_{rf,t}}{(1-\nu_t) w_{rf,t}} \tag{C.6}$$

$\frac{\partial L}{\partial N^j_{ro,t}} = 0$

$$N^j_{ro,t} = \frac{\theta \alpha_r MC_t S^j_{ro,t}}{(1-\nu_t)\, w_{ro,t}} \tag{C.7}$$

$\frac{\partial L}{\partial S^j_{Irf,t}} = 0$

$$S^j_{Irf,t} = \frac{\theta(1-\alpha_r)MC_t S^j_{rf,t}}{p_{I,t}} \tag{C.8}$$

$\frac{\partial L}{\partial S^j_{Iro,t}} = 0$

$$S^j_{Iro,t} = \frac{\theta(1-\alpha_r)MC_t S^j_{ro,t}}{(1-\nu_t)\, p_{I,t}} \tag{C.9}$$

$\frac{\partial L}{\partial p^j_t} = 0$

$$(1-\psi)\, S_t \frac{P_t^{j-\psi}}{P_t^{1-\psi}} - \gamma \left(\frac{P^j_t}{P^j_{t-1}} - 1 \right) \frac{1}{P^j_{t-1}} S_t + \gamma \left(\frac{P^j_{t+1}}{P^j_t} - 1 \right) \frac{1}{P_t^{j2}} S_{t+1} - \psi MC_t S_t \frac{P_t^{j-\psi-1}}{P_t^{-\psi}} = 0$$

Consider a symmetric equilibrium where $P^j_t = P_t$ and set $\frac{P^j_t}{P^j_{t-1}} = \pi_t$

$$(1-\psi)\, S_t \frac{1}{P_t} - \psi MC_t S_t \frac{1}{P_t} - \gamma(\pi_t - 1)\frac{1}{P_{t-1}} S_t + \gamma(\pi_{t+1}-1)\frac{1}{P_t^2} S_{t+1} = 0$$

Now multiply for P_t and divide for S_t

$$(1-\psi) - \psi MC_t - \gamma(\pi_t - 1)\pi_t + \gamma(\pi_{t+1}-1)\pi_{t+1}\frac{S_{t+1}}{S_t} = 0$$

Hence, by considering the anti-monopolistic subsidy ω_t, we finally obtain:

$$(1-\psi) + \psi(1-\omega_t)MC_t + \gamma \mathbb{E}_t \Lambda_t \left[(\pi_{t+1}-1)\pi_{t+1}\frac{S_{t+1}}{S_t} \right] = \gamma(\pi_t - 1)\pi_t \frac{S_{t+1}}{S_t} \tag{C.10}$$

C.0.3 Marginal cost

In order to derive the equation for the marginal cost, we consider the cost minimisation problem of the final firm:

$$\max_{N^j_{ro,t},S^j_{ro,t}} \Pi^j_t = \frac{P^j_t}{P_t} S^j_t - (1-\nu_t)\left(w_{ro,t}N^j_{ro,t} + p_{I,t}S^j_{Iro,t}\right) - w_{rf,t}N^j_{rf,t} - p_{I,t}S^j_{Irf,t} - \frac{\gamma}{2}\left(\frac{P^j_t}{P^j_{t-1}} - 1\right)^2 S_t$$

For the online production, we will have that the first order condition with respect to $N_{ro,t}$ is:

$$N_{ro,t} = \frac{\theta \alpha_r \lambda_{ro,t} S_{ro,t}}{(1-\nu_t) w_{ro,t}} \tag{C.11}$$

while the first order condition with respect to $S_{Iro,t}$ is:

$$S_{Iro,t} = \frac{\theta(1-\alpha_r)\lambda_{ro,t} S_{ro,t}}{(1-\nu_t) p_{I,t}} \tag{C.12}$$

Equating equations (C.11) and (C.12) (through the $\lambda_{ro,t}$) yields:

$$\frac{N_{ro,t}(1-\nu_t)w_{ro,t}}{\theta \alpha_r S_{ro,t}} = \frac{S_{Iro,t}(1-\nu_t)p_{I,t}}{\theta(1-\alpha_r)S_{ro,t}}$$

$$\frac{N_{ro,t} w_{ro,t}}{\alpha_r} = \frac{S_{Iro,t}\, p_{I,t}}{(1-\alpha_r)}$$

Express $S_{Iro,t}$ as a function of $N_{ro,t}$

$$S_{Iro,t} = (N_{ro,t})\, w_{ro,t} \frac{(1-\alpha_r)}{\alpha_r p_{I,t}} \tag{C.13}$$

Now, recall that the equation for the total (online) costs is:

$$TC_{ro,t} = (1 - \nu_t)\left(w_{ro,t}N_{ro,t} + p_{I,t}SI_{ro,t}\right) \tag{C.14}$$

Now, substitute equation (C.13) into equation (C.14):

$$TC_{ro,t} = (1-\nu_t)w_{ro,t}N_{ro,t} + (1-\nu_t)p_{I,t}\left(N_{ro,t}\right)w_{ro,t}\frac{(1-\alpha_r)}{\alpha_r p_{I,t}}$$

$$TC_{ro,t} = (1-\nu_t)w_{ro,t}N_{ro,t}\left(1 + \frac{1-\alpha_r}{\alpha_r}\right)$$

$$TC_{ro,t} = \frac{(1-\nu_t)w_{ro,t}N_{ro,t}}{\alpha_r} \tag{C.15}$$

this is the real production cost.

Substitute again equation (C.13) into the online production function:

$$S_{ro,t} = \left[N_{ro,t}\left(\frac{1}{\tau_{ro}}\right)^{\alpha_r}\left(w_{ro,t}\frac{1-\alpha_r}{\alpha_r p_{I,t}}\right)^{1-\alpha_r}\right]^{\theta}$$

Therefore

$$N_{ro,t} = \frac{\left(S_{ro,t}\right)^{\frac{1}{\theta}}}{\left(\frac{1}{\tau_{ro}}\right)^{\alpha_r}\left(w_{ro,t}\frac{1-\alpha_r}{\alpha_r p_{I,t}}\right)^{1-\alpha_r}}$$

Therefore

$$TC_{ro,t} = (1-\nu_t)\left(\tau_{ro}\right)^{\alpha_r}\left(\frac{w_{ro,t}}{\alpha_r}\right)^{\alpha_r}\left(\frac{p_{I,t}}{(1-\alpha_r)}\right)^{1-\alpha_r}\left(S_{ro,t}\right)^{\frac{1}{\theta}}$$

Now we can obtain the marginal cost by taking the partial derivative of total cost with respect to the quantity produced:

$$MC_{ro,t} = \frac{\partial TC_{ro,t}}{\partial S_{ro,t}}$$

This yields:

$$MC_{ro,t} = \frac{1}{\theta}(1-\nu_t)(\tau_{ro})^{\alpha_r}\left(\frac{w_{ro,t}}{\alpha_r}\right)^{\alpha_r}\left(\frac{p_{I,t}}{(1-\alpha_r)}\right)^{1-\alpha_r}(S_{ro,t})^{\frac{1-\theta}{\theta}} \tag{C.16}$$

but it must hold that:

$$MC_{ro,t} = MC_{rf,t}$$

hence:

$$\frac{1}{\theta}(1-\nu_t)(\tau_{ro})^{\alpha_r}\left(\frac{w_{ro,t}}{\alpha_r}\right)^{\alpha_r}\left(\frac{p_{I,t}}{(1-\alpha_r)}\right)^{1-\alpha_r}(S_{ro,t})^{\frac{1-\theta}{\theta}} = \frac{1}{\theta}\left(\tau_{rf}\right)^{\alpha_r}\left(\frac{w_{rf,t}}{\alpha_r}\right)^{\alpha_r}\left(\frac{p_{I,t}}{(1-\alpha_r)}\right)^{1-\alpha_r}\left(S_{rf,t}\right)^{\frac{1-\theta}{\theta}}$$

and finally:

$$\frac{S_{rf,t}}{S_{ro,t}} = \left[(1-\nu_t)\left(\frac{\tau_{ro}}{\tau_{rf}}\right)^{\alpha_r}\left(\frac{w_{ro,t}}{w_{rf,t}}\right)^{\alpha_r}\right]^{\frac{\theta}{1-\theta}}$$

In addition, considering the aggregation condition of equation (5) yields:

$$S_t = \left[(1-\nu_t)\left(\frac{\tau_{ro}}{\tau_{rf}}\right)^{\alpha_r}\left(\frac{w_{ro,t}}{w_{rf,t}}\right)^{\alpha_r}\right]^{\frac{\theta}{1-\theta}} S_{ro,t} + S_{ro,t}$$

$$S_t = \left[1 + \left[(1-\nu_t)\left(\frac{\tau_{ro}}{\tau_{rf}}\right)^{\alpha_r}\left(\frac{w_{ro,t}}{w_{rf,t}}\right)^{\alpha_r}\right]^{\frac{\theta}{1-\theta}}\right] S_{ro,t}$$

$$S_{ro,t} = \frac{S_t}{1 + \left[(1-\nu_t)\left(\frac{\tau_{ro}}{\tau_{rf}}\right)^{\alpha_r}\left(\frac{w_{ro,t}}{w_{rf,t}}\right)^{\alpha_r}\right]^{\frac{\theta}{1-\theta}}}$$

Substituting this last result into equation (C.16) yields the final marginal cost equation:

$$MC_t = \frac{1}{\theta}(1-\nu_t)(\tau_{ro})^{\alpha_r}\left(\frac{w_{ro,t}}{\alpha_r}\right)^{\alpha_r}\left(\frac{p_{I,t}}{(1-\alpha_r)}\right)^{1-\alpha_r}\left(\frac{S_t}{1+\left[(1-\nu_t)\frac{(\tau_{ro})^{\alpha_r}}{\left(\tau_{rf}\right)^{\alpha_r}}\left(\frac{w_{ro,t}}{w_{rf,t}}\right)^{\alpha_r}\right]^{\frac{\theta}{1-\theta}}}\right)^{\frac{1-\theta}{\theta}} \tag{C.17}$$

C.0.4 Households

The households problem assumes the following form:

$$\max_{S_t,b_t,N_{rf,t},N_{ro,t},N_{I,t}} U_t = E_0\sum_{t=0}^{\infty}\beta^t\left\{\frac{(S_t)^{1-\sigma}}{1-\sigma} - \frac{\alpha_t^N}{1+k}\left[\chi_1\left(N_{rf,t}\right)^{1+\eta} + \chi_2\left(N_{ro,t}\right)^{1+\eta} + \chi_3\left(N_{I,t}\right)^{1+\eta}\right]^{\frac{1+\kappa}{1+\eta}}\right\}$$

$$s.t. \tag{C.18}$$

$$S_t + b_t = \frac{R_{t-1}b_{t-1}}{\pi_t} + (1-t_t)\left[w_{rf,t}N_{rf,t} + w_{ro,t}N_{ro,t} + w_{I,t}N_{I,t}\right]$$

The Lagrangean of the problem is:

$$\text{L=E}_t\beta^t\left\{\begin{array}{c} \frac{(S_t)^{1-\sigma}}{1-\sigma} - \frac{\alpha_t^N}{1+\kappa}\left[\chi_1(N_{rf,t})^{1+\eta} + \frac{\chi_2}{\chi}(N_{ro,t})^{1+\eta} + \chi_3(N_{I,t})^{1+\eta}\right]^{\frac{1+\kappa}{1+\eta}} \\ -\lambda_t\left[S_t + b_t - \frac{R_{t-1}b_{t-1}}{\pi_t} - (1-t_t)\left[w_{rf,t}N_{rf,t} + w_{ro,t}N_{ro,t} + w_{I,t}N_{I,t}\right]\right] \end{array}\right\}$$

The first order conditions are:

$I.\ \frac{\partial L}{\partial S_t} = 0$

$$\lambda_t = S_t^{-\sigma}$$

$II.\ \frac{\partial L}{\partial B_t} = 0$

$$-\lambda_t\beta^t + \lambda_{t+1}\beta^{t+1}\frac{R_t}{\pi_{t+1}} = 0$$

$III.\ \frac{\partial L}{\partial N_{rf,t}} = 0$

$$\left(\alpha_t^N\right)\left[\chi_1(N_{rf,t})^{1+\eta}+\chi_2(N_{ro,t})^{1+\eta}+\chi_3(N_{I,t})^{1+\eta}\right]^{\frac{\kappa-\eta}{1+\eta}}\chi_1(N_{rf,t})^{\eta}=\lambda_t(1-t_t)w_{rf,t}$$

$IV.\ \frac{\partial L}{\partial N_{ro,t}}=0$

$$\left(\alpha_t^N\right)\left[\chi_1(N_{rf,t})^{1+\eta}+\chi_2(N_{ro,t})^{1+\eta}+\chi_3(N_{I,t})^{1+\eta}\right]^{\frac{\kappa-\eta}{1+\eta}}\chi_2(N_{ro,t})^{\eta}=\lambda_t(1-t_t)w_{ro,t}$$

$V.\ \frac{\partial L}{\partial N_{I,t}}=0$

$$\left(\alpha_t^N\right)\left[\chi_1(N_{rf,t})^{1+\eta}+\chi_2(N_{ro,t})^{1+\eta}+\chi_3(N_{I,t})^{1+\eta}\right]^{\frac{\kappa-\eta}{1+\eta}}\chi_3(N_{I,t})^{\eta}=\lambda_t(1-t_t)w_{I,t}$$

Plug I into II to obtain the Euler equation

$$S_t^{-\sigma}\beta^t=S_{t+1}^{-\sigma}\beta^{t+1}\frac{R_t}{\pi_{t+1}}$$

$$R_t=\pi_t\frac{S_t^{-\sigma}}{S_{t+1}^{-\sigma}}\frac{\beta^t}{\beta^{t+1}}$$

$$\frac{1}{R_t}=\beta\left[\pi_{t+1}^{-1}\left(\frac{S_{t+1}}{S_t}\right)^{-\sigma}\right] \tag{C.19}$$

Plug I into III, IV and V to obtain the three labor supplies:

$$(1-t_t)w_{rf,t}=\left(\alpha_t^N\right)\chi_1\left[\chi_1(N_{rf,t})^{1+\eta}+\chi_2(N_{ro,t})^{1+\eta}+\chi_3(N_{I,t})^{1+\eta}\right]^{\frac{\kappa-\eta}{1+\eta}}(N_{rf,t})^{\eta}(S_t)^{\sigma} \tag{C.20}$$

and

$$(1-t_t)w_{ro,t}=\left(\alpha_t^N\right)\chi_2\left[\chi_1(N_{rf,t})^{1+\eta}+\chi_2(N_{ro,t})^{1+\eta}+\chi_3(N_{I,t})^{1+\eta}\right]^{\frac{\kappa-\eta}{1+\eta}}(N_{ro,t})^{\eta}(S_t)^{\sigma} \tag{C.21}$$

and

$$(1-t_t)w_{I,t}=\left(\alpha_t^N\right)\chi_3\left[\chi_1(N_{rf,t})^{1+\eta}+\chi_2(N_{ro,t})^{1+\eta}+\chi_3(N_{I,t})^{1+\eta}\right]^{\frac{\kappa-\eta}{1+\eta}}(N_{I,t})^{\eta}(S_t)^{\sigma} \tag{C.22}$$

D List of equations

This section present the full set of equations.

- Euler equation
$$\frac{1}{R_t} = \beta\left[\pi_{t+1}^{-1}\left(\frac{S_{t+1}}{S_t}\right)^{-\sigma}\right]$$
- Contact-intensive labor supply
$$(1-t_t)w_{rf,t} = \left(\alpha_t^N\right)\chi_1(N_{rf,t})^{\eta}\left(S_t\right)^{\sigma}$$
- Online labor supply
$$(1-t_t)w_{ro,t} = \left(\alpha_t^N\right)\chi_2(N_{ro,t})^{\eta}\left(S_t\right)^{\sigma}$$
- Intermediate labor supply
$$(1-t_t)w_{I,t} = \left(\alpha_t^N\right)\chi_3(N_{I,t})^{\eta}\left(S_t\right)^{\sigma}$$
- Intermediate production function
$$S_{I,t} = AN_{I,t}^{\alpha}$$
- Intermediate labor demand
$$w_{I,t} = p_{I,t}\alpha AN_{I,t}^{\alpha-1}$$
- Contact-intensive intermediate input demand
$$S_{Irf,t}^{j} = \frac{\theta(1-\alpha_r)MC_t^j S_{rf,t}^j}{p_{I,t}}$$
- Online intermediate input demand
$$S_{Iro,t}^{j} = \frac{\theta(1-\alpha_r)MC_t^j S_{ro,t}^j}{(1-\nu_t)p_{I,t}}$$
- Contact-intensive labor demand
$$N_{rf,t}^{j} = \frac{\theta\alpha_r MC_t^j S_{rf,t}^j}{w_{rf,t}}$$

- Online labor demand

$$N_{ro,t}^j = \frac{\theta \alpha_r MC_t^j S_{ro,t}^j}{(1-\nu_t) w_{ro,t}}$$

- Marginal cost

$$MC_t = \frac{1}{\theta}(1-\nu_t)(\tau_{ro})^{\alpha_r}\left(\frac{w_{ro,t}}{\alpha_r}\right)^{\alpha_r}\left(\frac{p_{I,t}}{(1-\alpha_r)}\right)^{1-\alpha_r}\left(\frac{S_t}{1+\left[(1-\nu_t)\frac{(\tau_{ro})^{\alpha_r}}{\left(\tau_{rf}\right)^{\alpha_r}}\left(\frac{w_{ro,t}}{w_{rf,t}}\right)^{\alpha_r}\right]^{\frac{\theta}{1-\theta}}}\right)^{\frac{1-\theta}{\theta}}$$

- Contact-intensive output

$$S_{rf,t}^j = \left[\left(\frac{N_{rf,t}^j}{\tau_{rf}}\right)^{\alpha_r}\left(S_{Irf,t}^j\right)^{1-\alpha_r}\right]^{\theta}$$

- Online output

$$S_{ro,t}^j = \left[\left(\frac{N_{ro,t}^j}{\tau_{ro}}\right)^{\alpha_r}\left(S_{Iro,t}^j\right)^{1-\alpha_r}\right]^{\theta}$$

- NKPC

$$(1-\psi)+\psi(1-\omega_t)MC_t+\gamma\mathbb{E}_t\Lambda_t\left[(\pi_{t+1}-1)\pi_{t+1}\frac{S_{t+1}}{S_t}\right]=\gamma(\pi_t-1)\pi_t\frac{S_{t+1}}{S_t}$$

- Taylor rule

$$\frac{R}{\bar{R}} = \left(\frac{\pi_t}{\bar{\pi}}\right)^{\theta_\pi}\left(\frac{S_t}{\bar{S}}\right)^{\theta_S}$$

- Intermediate inputs clearing

$$S_{I,t} = S_{Irf,t} + S_{Iro,t} + S_{Ig,t}$$

- Health goods demand function

$$g_t = \bar{g} + \left[1-\left(\frac{\bar{\alpha}^N}{\alpha_{t-1}^N}\right)^{\phi_g}\right]$$

- Health goods supply function

$$g_t = (S_{Ig,t})^{\alpha_g}$$

- Aggregate resource constraint

$$S_t = C_t + g_t$$

- Government budget constraint

$$\nu_t S_{ro,t} + \frac{R_{t-1} b_{t-1}}{\pi_t} + g_t = t_t \left(w_{rf,t} N_{rf,t} + w_{ro,t} N_{ro,t} + w_{I,t} N_{I,t} \right) + b_t$$

- Tax rule

$$\frac{t_t}{\bar{t}} = \left(\frac{b_{t-1}}{\bar{b}} \right)^{\xi}$$

- Pandemic shock

$$\alpha_t^N = \left(\alpha_{t-1}^N \right)^{\rho} \left(\frac{S_{rf,t}}{S_{rf,t-1}} \right)^{\Delta(1-\rho)} \exp \varepsilon_t$$