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# Getting ready for the next pandemic: supply-side policies to escape the health-vs-economy dilemma.

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CAM Risk

# Getting ready for the next pandemic: supply-side policies to escape the health-vs-economy dilemma.

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**Abstract**

In our simple macroeconomic model, firms have the option of reallocating output between contact-intensive and online retail trade, where the former contributes to the persistence of the pandemic shock while 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 (lockdown) and the conventional macroeconomic stabilisation objective (subsidy to the online retail sector). In fact, we observe a complementarity between the strength of the optimal subsidy that allows to stabilize consumption and the lockdown policy aimed at controlling the epidemic shock. This conclusion is strengthened if employment raises the persistence of the epidemic shock.

*JEL* : E62, H2, H3, H51, I18
*Keywords* : *Pandemic shock, lockdown, supply side policies, macroeconomic stabilisation, online retail trade*

## 1 Introduction

> *"What keeps me up at night ... Over and over, after time has passed from the appearance of an acute public health challenge ... the transition from being reactive to the dwindling challenge to being durably and consistently prepared for the next challenge seems to fall flat. Hopefully, corporate memory of COVID-19 will endure and trigger a sustained interest and support of both the scientific and public health buckets."*[1]

The COVID-19 pandemic is now subdued, but the risk of future outbreaks of infectious diseases is not. Understandably, this has triggered multidisciplinary research in the prevention and mitigation of pandemics (World Bank (2022), OECD (2023)). Bill Gates (2022) suggested the creation of an international pool of a few thousands experts from different fields, that would act as a reserve army ready to support at the first symptoms of the outbreak.

Our focus is on hitherto unexplored economic policies that contribute to the containment of the disease and to the mitigation of economic costs associated to non-pharmaceutical interventions, e.g. lockdowns. The key intuition behind the paper is based on a simple fact: the pandemic episode was associated with a surge in e-commerce (see figure 1). [2] This reallocation could have mitigated the severity of both the pandemic episode and the economic contraction, and a question naturally arises, concerning what public support to online trade could achieve by exploiting the apparent complementarity between economic stimulus and disease mitigation. To the best of our knowledge, this is the first attempt to investigate the normative implications of an apparently straightforward policy option.

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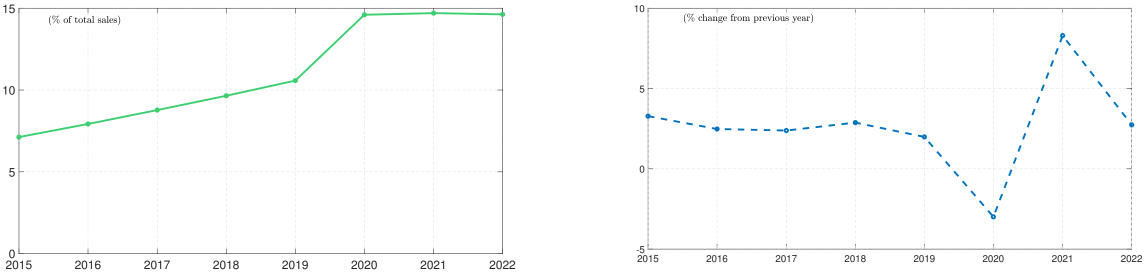
[1] Fauci (2023)

[2] A number of studies (Alfonso et al. (2021), Cavallo et al. (2022), Alcedo et al. (2022) and Gunay et al. (2023)) document the global dimension of this phenomenon.

Figure 1: **Online retail trade. US, EU and Worldwide.**

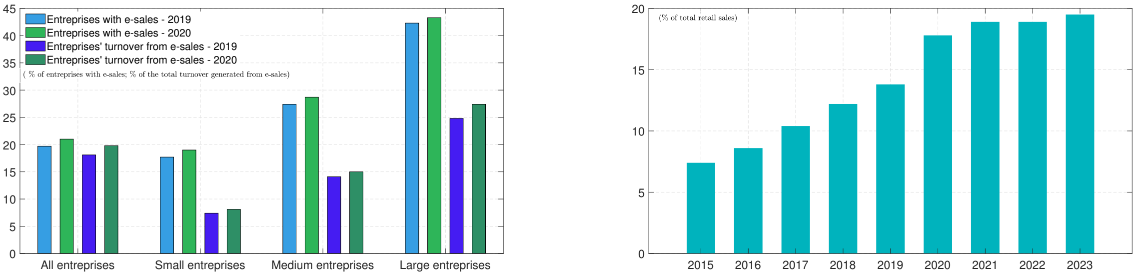
(a) E-commerce retail sales growth - US

(b) Real private consumption - US



(c) E-sales and turnover from e-sales by size - EU

(d) E-commerce retail sales - Worldwide



*Source*: panel 1a, 1b: U.S. Census Bureau; panel 1c: Eurostat; panel 1d: Statista.com.

We build on two strands of literature that rapidly emerged after the onset of the Covid-19 pandemic. The first one integrates macroeconomic and epidemiological models (Farboodi et al. (2021), Eichenbaum et al. (2021), Alvarez et al. (2021), Bloom et al. (2022)). We share with these works the importance of modelling the health-economy trade-off when implementing lockdowns or other public health policies. Another commonality is that individual responses do not fully internalise their effects on the persistence of the pandemic shock, paving the way for the analysis of optimal policies that must strike a balance between shock mitigation and the conventional macroeconomic stabilisation objective. Specifically related to our work, Krueger et al. (2022) argue that the shock tilts consumption choices towards less contact intensive sectors, but they also show that unnecessary deaths and a sub-optimally large decline in economic activity characterize a no-intervention policy.

The second strand of literature is relatively more concerned with the macroeconomic stabilization of pandemic shocks within a fairly standard business cycle framework. Corrado et al. (2021) interpret pandemic-induced recessions as the consequence of standard demand and supply shocks, exacerbated by adverse sector-specific disturbances in contact-intensive industries. Eichenbaum et al. (2022) argue that the Covid shock acts like an adverse shock to both consumption demand and labour supply. Lepetit and Fuentes-Albero (2022) argue that, as long as lockdowns are optimally designed, monetary policy should focus on strict inflation targeting. Other studies see the Covid shock as a source of new challenges for the conduct of macroeconomic policies. 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. Likewise, Woodford (2022) argues that a Covid shock, which is inherently sectoral, is prone to causing effective demand failures due to the network structure of payments, and monetary policy is inadequate to cope with this problem, but either fiscal transfers or government credit policy can have a mitigating effect. Bayer et al. (2023), 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. Adrian et al. (2023) argue that central bank responses played a crucial role in preventing a financial crisis.

Our contribution shares the concern for the sectoral nature of the pandemic shock, but we focus on a different fiscal tool that operates through a new transmission channel. We cast our analysis in the framework of a business cycle model subject to a supply shock, but we account for the fact that pursuing a standard macro-stabilization objective may not necessarily be the best choice in the middle of a pandemic, i.e. when the policy maker's pre-eminent goal is avoiding the spread of the disease (see Loayza and Pennings (2020) and Dupor (2020)). This concern is shared by contributions such as Eichenbaum et al. (2021), Eichenbaum et al. (2022) and Angelini et al. (2023) that merge the workhorse DSGE model with an epidemiological (SIR) model where the level of consumption influences the spread of the disease. In this framework, agents' decision to cut back on consumption and work reduces the severity of the epidemic but aggravates the size of the recession. This modelling strategy is particularly useful in contributions that investigate the economy's response to historical episodes, where the epidemiological block allows to pin down the infection-specific relation between economic activity and the spread of contagion. In our case, these features are by definition unknown, and the unavoidable complexity of the DSGE-SIR model could hinder the transparency of our analysis.

For this reason we propose a simpler macroeconomic model where the pandemic translates into an unconventional supply shock, whose endogenous persistence is driven by contact-intensive activities in the retail sector of the economy (as opposed to online retail trade) and by interactions at work. We therefore assume that the shock persistence increases in the size of both contact-intensive retail trade and total employment. In our framework, production requires intermediate goods, and retail firms have the option of reallocating retail trade from contact-intensive to online activities. By assumption, firms do not internalize the effects of contact-intensive trade on the persistence of the shock.

Three additional features of our model, typically neglected in macroeconomic models, should be mentioned right from the outset. First, our model accounts for the sharp increase in health expenditures after the shock, as documented in Mendoza et al. (2020). To the best of our knowledge, this is a new amplification channel of the macroeconomic adjustment to the shock. Second, our model accounts for the fact that older individuals, who do not participate in labour market decisions, are exposed to infectious diseases (Wagner and Weinberger (2020)). This has important implications for normative analysis, because wage setting and labour supply decisions do not internalize the effects of the endogenous shock persistence on the welfare of retired individuals. Third, we consider the non-economic costs of lockdowns, one important issue that is often neglected in the economic analyses of non-epidemiological responses to infectious diseases (The Economist (2021) Wood et al. (2022)).

Given that neither households nor firms internalize the implications of their choices for the persistence of the shock, we investigate the design of Ramsey-optimal fiscal policies, where the planner relies on two tools, a sectoral production subsidy and a lockdown-mimicking cost index that reduces efficiency of the contact intensive channel. Our focus here is on the identification of policies that should mitigate the effects of the shock and favour economic stabilization through a reallocation of retail trade towards online activities.

The first set of our results is based on the assumption that employment does not matter for shock persistence. In the no-intervention 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. Even if there is no sectoral reallocation, the fall in contact-intensive retail trade dampens the persistence of the shock. Relative to the market equilibrium, the Ramsey-optimal lockdown policy substantially mitigates the shock and reduces consumption losses. This happens because the lockdown induces firms to reallocate trade towards the online channel. The elderly protection motive strengthens the case for a substantial contraction in economic activity.

Both the elderly protection motive and the political costs of lockdowns call for reliance on subsidies to the online retail channel. In principle, substituting lockdowns with subsidies would generate large welfare gains, but this would imply implausibly large amounts of fiscal transfers. Further, lockdowns are necessary to restrict human interactions that occur for motives other than economic transactions. If we set limits to the admissible size of subsidies, lockdowns and subsidisation are complements. This implies that, taking as a benchmark the no-subsidy case, the fiscal transfers are exploited to reduce consumption losses and, even if lockdowns are politically costly, the planner chooses to (marginally) strengthen the lockdown policy in order to achieve a better control of the pandemic.

Finally, we introduce the employment channel and show how this affects our results. Our key conclusion is that, even if this could generate a tension between stabilisation policies and control of the epidemic, this trade-off is unlikely to become relevant in practice, simply because the employment channel also strengthens the effectiveness of a lockdown. In fact, we find that the complementarity between the subsidisation policy and the lockdown increases with the strength of the employment channel.

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 and stabilize macroeconomic conditions.

We also contribute to a literature that relates sectoral reallocations to epidemic episodes. Bodenstein et al. (2022) focus on workers employed by producers of intermediate inputs that are difficult to replace. They show that protection of those workers whose tasks cannot be performed from home can both flatten the epidemiological curve and reduce economic costs. Shami and Lazebnik (2023) share the same concern for the protection of “essential workers”, including those employed in the healthcare system, and propose a “reserve model”approach to strengthen the resilience of the economy to future crisis episodes.

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

## 2 The model

Our model economy features households, intermediate and retail firms, labour packers, and the public sector. Perfectly competitive intermediate firms sell their $\left(S^{I}\right)$ goods to retail firms, that are monopolistically competitive and face nominal rigidities. Retail firms can exploit two different trading technologies, that we respectively define as contact-intensive $(S^{rc})$ and online $(S^{ro})$. To sharpen our focus on the supply side of the economy, we posit that households treat the goods sold through the two alternative channels as perfect substitutes.

The government levies lump-sum taxes that finance an exogenous amount of public goods and the fiscal responses to the shock, i.e. the additional health expenditures undertaken when the pandemic shock hits the economy, and a subsidy to the retail trade channel. In addition, the government can restrict human activity enforcing a lockdown policy whose economic effects are modelled as a loss of efficiency in the supply of $S^{rc}$.[3] The Central bank controls monetary policy. The interactions in our model economy are described in Figure 2.

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[3] We depart from Eichenbaum et al. (2022), who exploit a consumption tax to mimic lockdowns, and we entrust the planner with the power to impose mandatory restrictions on contact-intensive retail sales that affect the efficiency of the contact-intensive channel. This choice allows to neglect the government budget constraint.

We posit that a continuum of individuals of mass 1 populates the representative household. A fraction $\gamma$ (the elderly) consume the retail bundle $C_t = \left[\int_0^1 (c_t(z))^{\frac{\psi-1}{\psi}} dz\right]^{\frac{\psi}{\psi-1}}$ without working, the remaining $1-\gamma$ (the workers) consume and supply the bundle of individual labour types $N_t = \left[\int_0^1 (N_t(j))^{\frac{\psi^N-1}{\psi^N}} dj\right]^{\frac{\psi^N}{\psi^N-1}}$ to perfectly competitive labour packers. At the beginning of each period, the elderly cease to exist, and are replaced by an equal mass of individuals who are randomly extracted from the previous-period workers. At the same time, a new cohort of workers, with mass $\gamma$, enters the household. We assume that a risk-sharing scheme equalizes consumption across individuals. Household $i$ aggregates individual preferences

$$U_t(i) = \sum_{t=0}^{\infty} \mathbb{E}_t \beta^t \left\{ \ln C_t(i) - (1-\gamma)\alpha_t^N \chi \frac{N_t(i)^{1+\varphi}}{1+\varphi} - \gamma \Gamma_t \right\}, \tag{1}$$

Following Corrado et al. (2021) we posit that the pandemic shock raises the disutility from labour effort $\alpha_t^N$. To proxy the endogeneity of the pandemic to economic conditions, we need to model a persistence mechanism for $\alpha_t^N$. Eichenbaum et al. (2022) assume that individuals can become infected in three ways: by purchasing consumer goods, working, and through random interactions unrelated to economic activity. To sharpen our focus, we neglect human interactions driven by non-economic motives, and draw a distinction between the two retail channels, where we posit that online retail trade has no direct effect on $\alpha_t^N$; then we add a positive effect of total employment on $\alpha_t^N$. More specifically, we posit that the shock shrinks if contact-intensive activities and total employment fall relative to their steady-state values, $\overline{S^{rc}}$ and $\overline{N}$ respectively:

$$\alpha_t^N = \left(\alpha_{t-1}^N\right)^\rho \left(\frac{S_{t-1}^{rc}}{\overline{S^{rc}}}\right)^\Delta \left(\frac{N_{t-1}}{\overline{N}}\right)^{\Delta^N} \exp \varepsilon_t ; \varepsilon_t \sim N\left(0, \sigma_\varepsilon^2\right). \tag{2}$$

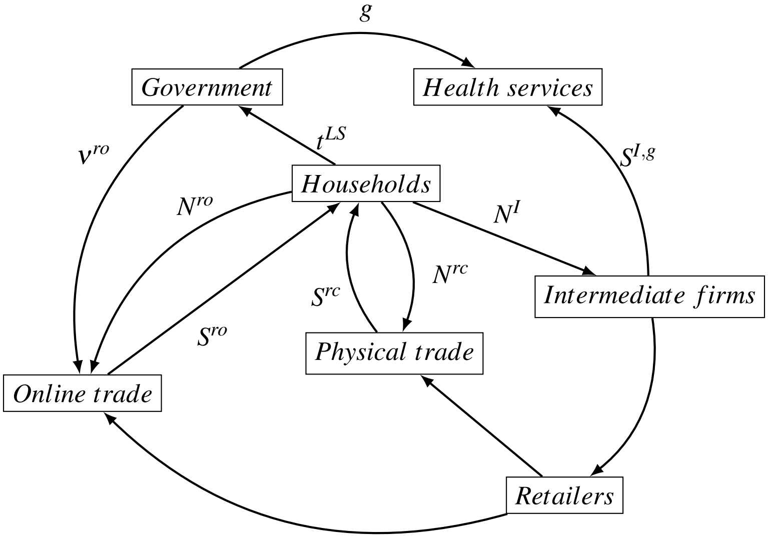
In our framework, the combined effect of contact-intensive consumption and total employment allows to incorporate a potential tension between the economic stabilization motive, that calls for subsidization of online retail trade, and the limitation of total economic activity which is necessary to control the shock.

The term

$$\Gamma_t = \psi^\Gamma \left(\alpha_t^N - 1\right)^2 \tag{3}$$

captures the effects of the shock on the welfare of the elderly. The model therefore incorporates two channels that pave the way for policy interventions: i) consumption decisions cannot internalize their impacts on $\alpha_t^N$ dynamics; ii) the shock unambiguously causes a labour-supply contraction, but the labour-market equilibrium does not internalize the effects on the welfare of the non-working population.

Figure 2: **Model economy.**



## 2.1 Households

The representative household maximises (1) subject to:

$$C_t(i) + b_t(i) = \frac{R_{t-1} b_{t-1}(i)}{\pi_t} + w_t N_t(i) + \Pi_t(i) - \Phi_t^N(j) - t_t^{LS} \tag{4}$$

where $b(i)$ defines real holdings of a nominally riskless government bond, $R_{t-1}$ is the nominal interest rate, $w_t$ is the real wage in consumption units, $\pi_t$ is the inflation rate of the retail price index, $\Pi_t(i)$ are real profits, $t_t^{LS}$ are lump-sum taxes.

Utility maximization yields the standard Euler equation for consumption

$$1 = E_t \Lambda_{t,t+1} \frac{R_t}{\pi_{t+1}} \tag{5}$$

where $\Lambda_{t,t+1} = \beta \left( \frac{C_t}{C_{t+1}} \right)$ stochastic discount factor.

The demand function for each variety $z$ in the consumption bundle is $c_t(z) = \left( \frac{P_t(z)}{P_t} \right)^{-\psi} C_t$, where $P_t$ is the retail price index.

## 2.2 Labour market

Labour packers assemble the bundle of labour services that is then sold to firms. In the market for labour type $j$, wage-setting decisions are delegated to a monopolistically competitive union that maximises (1) subject to the labor demand function

$$N_t(j) = \left( \frac{W_t(j)}{W_t} \right)^{-\psi^N} N_t,$$

and to the nominal wage adjustment cost

$$\Phi_t^N(j) = \frac{\gamma^w}{2}\left(\frac{W_t(j)}{W_{t-1}(j)} - 1\right)^2 P_t N_t,$$

where $W_t$ is the standard nominal wage index associated to the labour bundle. In the symmetrical equilibrium the union first-order condition is

$$\alpha_t^N \chi N_t^{\varphi} C_t - \frac{\psi^N - 1}{\psi^N} w_t = \frac{\gamma^w}{\psi^N}\left(\pi_t^w - 1\right)\pi_t^w - \beta \mathbb{E}_t\left[\Lambda_{t,t+1}\frac{\gamma^w}{\psi^N}\left(\pi_{t+1}^w - 1\right)\pi_{t+1}^w \frac{N_{t+1}}{N_t}\right] \tag{6}$$

where $\pi_t^w$ is the growth rate of nominal wages.

## 2.3 Intermediate Firms

Fully competitive firms have access to the following production function:

$$S_t^I = A N_t^I \tag{7}$$

where $N_t^I$ is the labour used as productive factor in the intermediate production and $A$ defines the level of productivity. In the market equilibrium, the intermediate-good price in consumption units, $p_t^I$, is

$$p_t^I = \frac{w_t}{A} \tag{8}$$

## 2.4 Retail Firms

The representative firm $z$ can exploit both the contact-intensive and the online channel to sell her goods subject to two symmetrical production functions that require intermediate goods and labour:

$$S_t^h(z) = \left[\left(\frac{N_t^h(z)}{\alpha_t^h \tau^h}\right)^{\alpha_r}\left(S_t^{I,h}(z)\right)^{1-\alpha_r}\right]^{\theta}, \theta < 1 \tag{9}$$

where $h \in \{rc, ro\}$, $\tau^h$ is a channel-specific efficiency parameter, and $\alpha_t^h$ captures the effects of the Ramsey planner's lockdown policy on firms efficiency. Note that $\alpha_t^{ro} = 1$ and the sequence $\{\alpha_t^{rc}\}_{t=0}^{\infty}$ solves the planner's problem. The firm's profit function is:

$$\Pi_t(z) = \frac{P_t(z)}{P_t}\omega S_t(z) - \left[\left(1 - \nu_t^{ro}\right)\left(w_t N_t^{ro}(z) + p_t^I S_t^{I,ro}(z)\right) - \left(w_t N_t^{rc}(z) + p_t^I S_t^{I,rc}(z)\right)\right] - \Phi_t^{\pi} \tag{10}$$

where $\Phi_t^{\pi} = \frac{\gamma^{\pi}}{2}\left(\frac{P_t(z)}{P_{t-1}(z)} - 1\right)^2 S_t$ is a standard price adjustment cost, $\omega$ is a time-invariant subsidy meant to offset the monopolistic distortions in steady state and $\nu_t^{ro}$ is a time-varying subsidy implemented in response to the shock.[4] For each trade channel, the representative firm's marginal cost is:

$$MC_t^h = \frac{x_t^h}{\theta}\left(\frac{\alpha_t^h \tau^h w_t}{\alpha_r}\right)^{\alpha_r}\left(\frac{p_t^I}{(1-\alpha_r)}\right)^{1-\alpha_r}\left(S_t^h\right)^{\frac{1-\theta}{\theta}}. \tag{11}$$

where $x_t^{rc} = 1$ and $x_t^{ro} = (1-\nu_t^{ro})$. The optimal allocation of retail trade to the two channel implies the equalization of marginal costs. Straightforward manipulations yield.

$$MC_t = \frac{1}{\theta}x_t^{ro}\left(\frac{\tau^{ro} w_t}{\alpha_r}\right)^{\alpha_r}\left(\frac{p_t^I}{(1-\alpha_r)}\right)^{1-\alpha_r}\left(\frac{S_t}{1+\left[x_t^{ro}\left(\frac{\tau^{ro}}{\alpha_t^{rc}\tau^{rc}}\right)^{\alpha_r}\right]^{\frac{\theta}{1-\theta}}}\right)^{\frac{1-\theta}{\theta}}. \tag{12}$$

$$S_t = S_t^{rc} + S_t^{ro}$$

Note that decreasing returns to scale allow to identify the firms optimal choice between online and contact-intensive retail trade and, the smaller the value of $\theta$, the larger is the cost of endogenously reallocating retail trade to the online sector when a lockdown policy is in place.[5]

The optimal price-setting condition denotes the New Keynesian Phillips Curve:

$$(1-\psi) + \psi(1-\omega)MC_t + \gamma^{\pi}\mathbb{E}_t\left\{\Lambda_{t.t+1}\left[(\pi_{t+1}-1)\pi_{t+1}\frac{S_{t+1}}{S_t}\right]\right\} = \gamma^{\pi}(\pi_t - 1)\pi_t. \tag{13}$$

The solution to the cost minimisation problem of the firm also yields the channel-specific demands for inputs:

$$N_t^h(z) = \frac{\theta\alpha_r MC_t S_t^h}{x_t^h w_t} \tag{14}$$

$$S_t^{I,h}(z) = \frac{\theta(1-\alpha_r)MC_t S_t^h}{x_t^h p_t^I} \tag{15}$$

## 2.5 Public sector

The Central Bank implements a strict inflation targeting rule:

$$R_t = \overline{R}\pi_t^{\theta^{\pi}} \tag{16}$$

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[4] The subsidy $\omega$ is introduced to sharpen the Ramsey planner's focus on the response to the shock.

[5] Buera et al. (2021) model the lockdown as an exogenous shutdown to a subset of entrepreneurs that operate in the economy, and contemporaneously impose an exogenous productivity increase for online trading firms to match the observed sectoral reallocation away from contact-intensive activities.

where $\overline{R}$ is the steady state value of the nominal interest rate.

In normal times the government supplies a constant amount of public goods, $\overline{g}$. The shock $\alpha_t^N$ triggers an increase in demand for public health expenditures that we model as follows:

$$g_t - \overline{g} = \gamma^g \left(g_{t-1} - \overline{g}\right) + \left(1 - \gamma^g\right) \left[1 - \left(\frac{1}{\alpha_{t-1}^N}\right)^{\phi^g}\right] \tag{17}$$

To supply $g_t$, the government needs to purchase intermediate goods:[6]

$$S_t^{I,g} = g_t \tag{18}$$

A Ramsey planner is in charge of policy responses to the shock, with the following objective function:

$$V_t = \sum_{t=0}^{\infty} \mathbb{E}_t \beta^t \left\{ \ln C_t - (1-\gamma)\left(1+\alpha_t^N\right) \chi \frac{N_t^{1+\varphi}}{1+\varphi} - \gamma \Gamma_t - \Phi_t^L \right\}, \tag{19}$$

which internalizes the "market failures"just discussed, and incorporates the political costs of lockdown policies $\Phi_t^L = \gamma^\Phi \left(\frac{\overline{S^{rc}}}{S_t^{rc}} - 1\right)^2$.

## 2.6 Market clearing

To close the model we need that the market clearing conditions in the retail and intermediate sectors hold:

$$S_t = C_t, \tag{20}$$

$$S_t^I = S_t^{I,ro} + S_t^{I,rc} + S_t^{I,g}. \tag{21}$$

# 3 Results

We present our results sequentially. To begin with, we posit that employment does not matter for shock persistence and focus on the response of online trade to different policy regimes, as a tool to both stabilize the economy and reduce the persistence of the shock. At this stage we first compare the outcomes of an optimal lockdown policy with a no-intervention scenario, and then we investigate the potential contribution of subsidising online retail trade. Then we incorporate the employment effect in the transmission of the shock, and unveil the potential trade-off between shock reduction and macroeconomic stabilization. Our results are based on numerical simulations, and this requires a careful discussion of calibration details.

## 3.1 Model calibration

Households preferences are quite standard, the discount factor $\beta$ is 0.99 and the Frisch elasticity parameter, $\varphi$, is set at 1. The numerical value set for the labour supply weight in (1), $\chi$, pins down the steady state labour supply at 1.

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[6] The lump-sum taxes assumption allows to neglect the government budget constraint.

The fraction of the elderly in the population, $\gamma$, is set at 17.3%, according to the fraction of individuals above 65 of age in the US (United Health Foundation (2022)). We set $\tau^{rc}$, $\tau^{ro}$, and the productivity shifter in the intermediate goods sector, $A$, to calibrate the sectoral retail output ratios in steady state and to normalize the total amount of output $\overline{C}+\overline{g}$ at 1, conditional to having set $\overline{g}$ to obtain a steady state value of $\frac{\overline{g}}{\overline{C}+\overline{g}} = 21\%$, in line with the US corresponding expenditure ratio in 2019. We set the steady-state ratio between contact-intensive and online retail trade, $\frac{\overline{S^{rc}}}{\overline{S^{ro}}} = 9$, in line with the data observed in the US for the year 2019 US Census Bureau (2022). The share of labour in the retail goods production function is assumed to be $\alpha_r = 0.66$. We choose decreasing returns that are at the lower end of the range considered in Basu and Fernald (1997), $\theta = 0.88$. By doing this we impose a relative large cost on retail trade reallocation towards the online sector, “staking the cards”against the desirability of sectoral reallocation policies. The Taylor rule parameter, $\theta^{\pi} = 1.5$, is quite standard.

The elasticities of substitution across goods and labour types, $\psi$ and $\psi^{N}$, are set at the standard value of 6. The calibration of price and wage Rotemberg adjustment costs requires a careful discussion. Up to first order approximation, Rotemberg adjustment costs yield slopes of the price and wage Phillips curves that are identical to those obtained under Calvo nominal rigidities, and the Rotemberg adjustment costs can therefore be related to the empirically measurable duration of “Calvo contracts”. In our calibration, we assume a duration of 4 quarters for both prices and wages. Following the mapping functions provided in Keen and Wang (2007) and Born and Pfeifer (2020) respectively, this implies that $\gamma^{\pi} = 58$ and $\gamma^{w} = 349$. Table 2 summarises the calibration details.

We set $\phi^{g} = 0.03$ and $\gamma^{g} = 0.8$ to match the observed response of public health expenditures to the pandemic (see Table 1). Given our choice of confining the discussion of employment effects on shock persistence at the final part of this section, we initially set $\Delta^{N} = 0$, and calibrate the other parameters that characterize shock dynamics, $(\varepsilon, \Delta, \rho)$, the political costs of lockdown, $\gamma^{\Phi}$, and the sensitivity of the elderly to the infection, $\psi^{\Gamma}$, so that the optimal lockdown policy (without any subsidy to the online retail sector) replicates the observed responses of online sales and total consumption after the first year of the Covid-19 pandemic in the US. Finally, we reconsider our results under the assumption that the shock elasticity to employment, $\Delta^{N}$, takes values in a range between 0.3 and 0.7. This choice is purely suggestive and our purpose highlights the effects of increasing contagion through interactions at work.

Table 1: **Key variables, model predicted vs observed.**

| *Variable* | *Model prediction* | *Observed in 2020* |
|---|---|---|
| Real Consumption growth | -3.02% | -2.99% |
| Online retail sales growth | 4.1% | 4% |
| Health expenditure growth | 1.88% | 1.58% |
| Inflation | 1.3% | 0.11% |

*Source*: US Census Bureau and KFF analysis of National Health Expenditure (NHE). Data as of sept. 2023.

Table 2: **Parameter calibration.**

(i)

| *Parameter* | *Value* | *Description* |
|---|---|---|
| **Households** | | |
| $\beta$ | 0.99 | Households discount factor |
| $\varphi$ | 1 | Inverse of Frisch elasticity |
| $\chi$ | 0.64 | Labour sensitivity |
| $\gamma^w$ | 349.05 | Rotenberg wage parameter |
| $\psi^N$ | 6 | Labor elasticity of substitution |
| $\gamma$ | 17.3 | Percentage of elderly |
| **Firms** | | |
| $\alpha$ | 1 | Returns to scale intermediate production |
| $A$ | 11.55 | Total factor productivity |
| $\alpha_r$ | 0.66 | Labour share |
| $\theta$ | 0.88 | Returns to scale final production |
| $\tau^{rc}$ | 1.86 | Physical sector productivity |
| $\tau^{ro}$ | 2.92 | Online sector productivity |
| $\gamma^\pi$ | 58 | Rotemberg menu cost |
| $\psi$ | 6 | Goods elasticity of substitution |
| **Central bank and Government** | | |
| $\theta^\pi$ | 1.5 | Taylor rule: inflation |
| $\phi^g$ | 0.03 | Covid implied Public expenditure |
| $\gamma^g$ | 0.8 | Persistence of public expenditure |
| **Planner** | | |
| $\gamma^\Phi$ | 170 | Weight of lockdown implementation political costs |
| $\gamma\psi^\Gamma$ | 3.5 | Importance of elderly lives |
| **Shock** | | |
| $\rho$ | 0.8 | Shock persistence |
| $\Delta$ | 3.5 | Sensitivity of the shock to variation in $S_t^{rc}$ |

(ii)

| Steady State ratio | Value | Definition |
|---|---|---|
| $\frac{Src}{Sro}$ | 9 | Ratio physical to online output |
| $\frac{C}{Y}$ | 82.5% | Consumption over GDP ratio |
| $\overline{g}$ | 21% | Public expenditure |

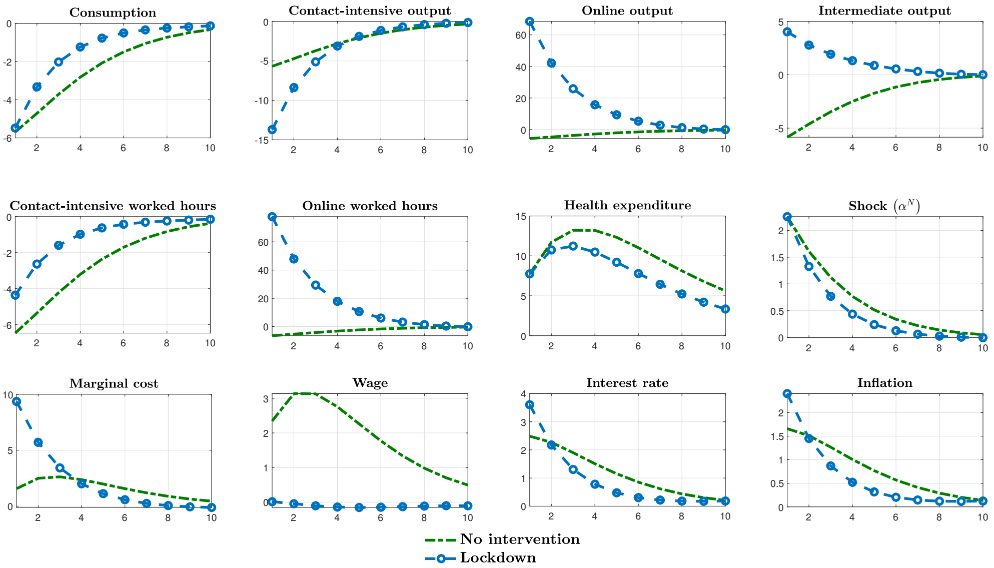
## 3.2 The lockdown policy vs the no-intervention case

To begin with, we characterize the Ramsey-optimal lockdown policy and highlight the key incentives and transmission channels that shape it. At this stage we do not consider subsidies to the online retail sector and, for the sake of simplicity, we neglect the contribution of employment to the persistence of the shock. The planner chooses the optimal sequence $\{\alpha_t^{rc} \geq 1, \nu_t^{ro} = 0\}_{t=0}^{\infty}$ that maximises the objective function 19, subject to conditions (3), (5), (6), (7), (8), (9), (12), (13) (14), (15), (16), (17), (18), (20), (21).

Table 1 shows that the model does a good job in matching the responses of consumption, online retail sales and health expenditures observed in the US during the first year of the pandemic. By contrast, predicted inflation overshoots the inflation response. This is probably due to the large drop in energy prices, that our model does not account for (Khan et al. (2022)).

In figure 3 we compare the IRFs obtained when the lockdown policy is enforced and in the no-intervention case.

Figure 3: **Irfs of no intervention vs lockdown.**



*Note*: quarterly observations. Percentage deviations from steady state. The shock is reported in absolute value.

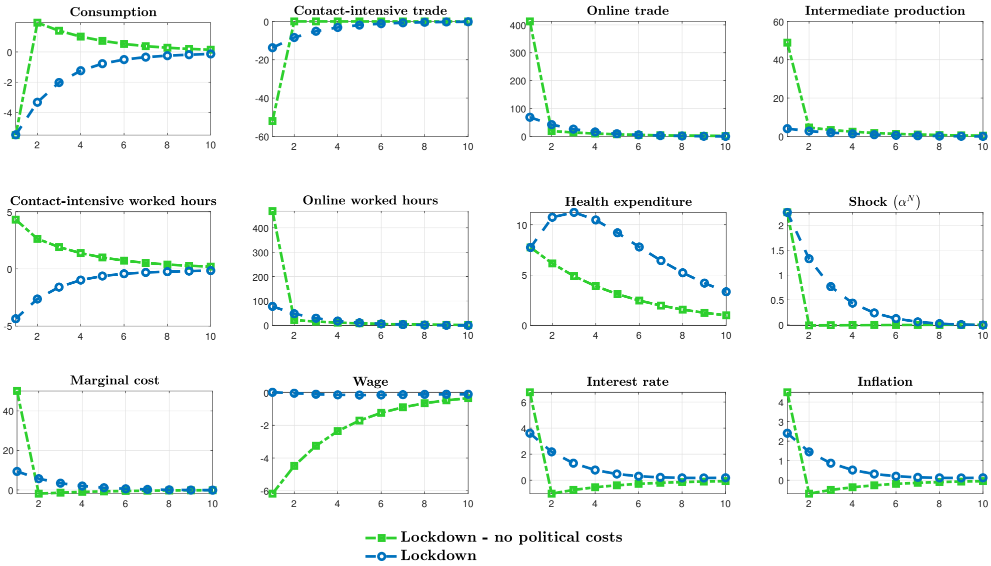
In the *no intervention* scenario the market economy reacts to a standard adverse labour supply shock, and we observe a symmetrical plunge in both retail sectors because the firms' optimal allocation of production is driven by the equalization of marginal costs. In fact, without policy intervention firms do not internalize the effect of contact-intensive retail trade on the shock persistence, and there is no incentive to reallocate towards online trade. Without intervention, the adverse labour supply shock has standard implications for the inflation rate, that immediately increases and persistently remains above steady state.

The lockdown policy is crucial to contain the spread of the disease. The planner raises the contact-intensive marginal cost schedule (11), inducing retail firms to relocate production towards the online channel. Total demand for consumption goods, that is driven by permanent income considerations and by the interest rate response to higher inflation, falls on impact and then gradually recovers.

Overall, the lockdown policy generates a faster correction of the shock, a more favourable consumption path, and limits the surge in health expenditures. The real wage response is almost muted, essentially due to the dampening effect of the lockdown on $\alpha_t^N$ dynamics. On impact, the lockdown generates a faster inflation response. This happens because the stronger retail trade reallocation towards the online sector unambiguously strengthens the increase in marginal costs.

Figure 4 shows that, absent the political cost $\Phi_t^P$, the planner would strengthen the lockdown and force a quick collapse of $\alpha_t^N$. Online retail trade would symmetrically increase, but for a very short period. The strength of the (short-lived) lockdown would also allow to save a large amount of the resources otherwise devoted to public health expenditures.

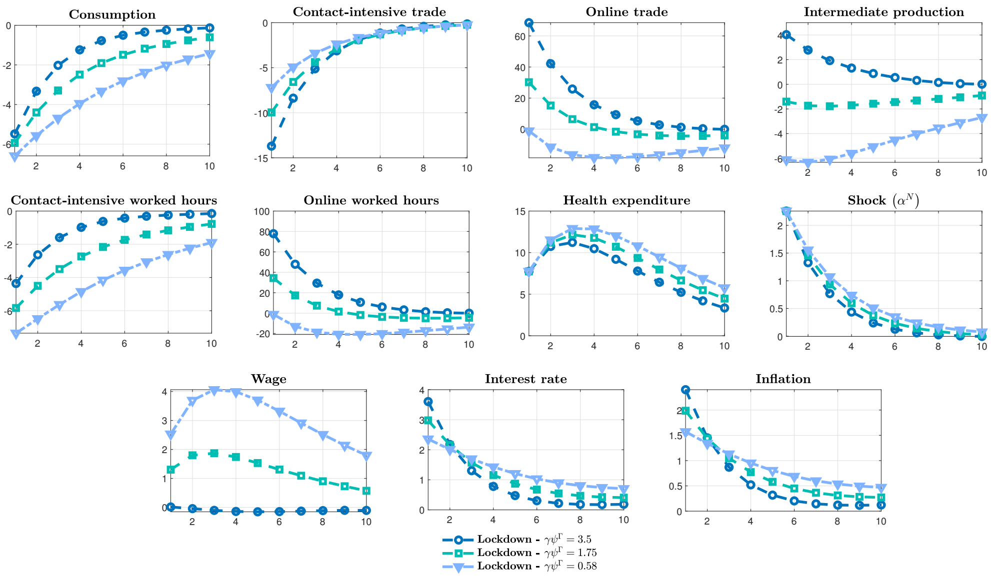
Figure 4: **Irfs of lockdown vs lockdown with no political costs.**



*Note*: Quarterly observations. Percentage deviations from steady state. The shock is reported in absolute value.

Figure 5 shows that concern for the welfare of the elderly substantially affects the planner's incentives. In fact, when we reduce the planner's concern for elderly protection, the lockdown policy generates a path for contact-intensive trade that is less contractionary than in the no-intervention case. On impact, this policy is associated with milder inflationary pressures, but the slower pace of shock reduction implies that inflation remains above the no-intervention case for a prolonged period after the 4th quarter. This, in turn, implies that the monetary policy stance is expected to be, on average, more contractionary than under the no-intervention case. As a result, the fall in total consumption is larger. The real wage response is also stronger, due to the persistence of $\alpha_t^N$. In fact, the increase in $w_t$ induces firms to limit the increase in online trade.

Figure 5: **Irfs of lockdown with diminishing elderly protection.**

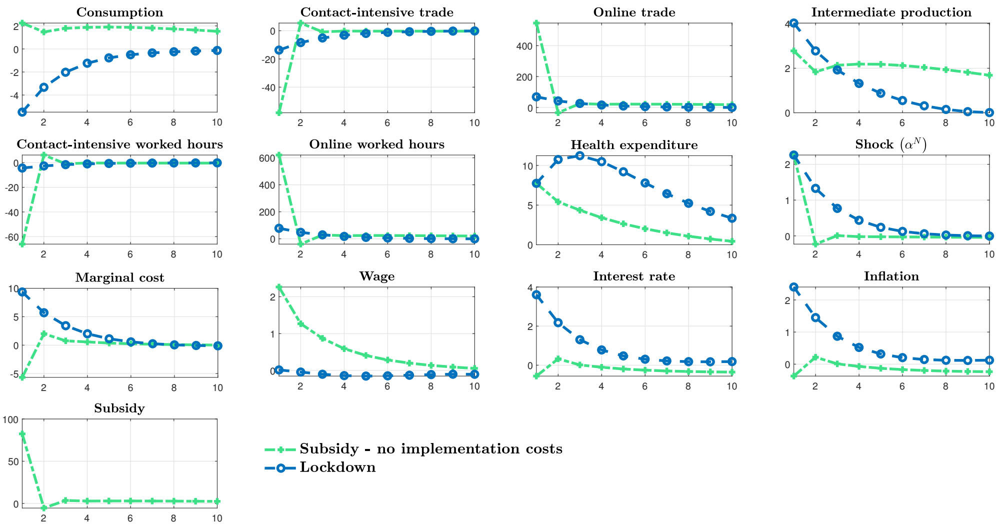


*Note*: quarterly observations. Percentage deviations from steady state. The shock is reported in absolute value.

## 3.3 Subsidy to the online retail sector

Consider a Ramsey-optimal subsidy to online retail trade. In this case the planner's tool is the optimal sequence $\{v_t^{ro} \geq 0, \alpha_t^{rc} = 1\}_{t=0}^{\infty}$ subject to (3), (5), (6), (7), (8), (9), (12), (13) (14), (15), (16), (17), (18), (20), (21). and to the constraint $0 \leq v_t^{ro} < 1$.

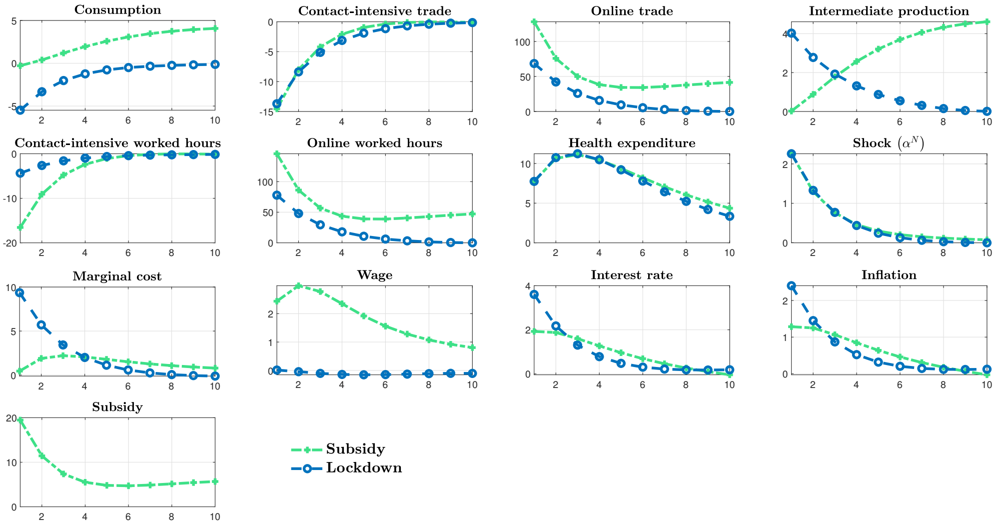
Figure 6: **Irfs of Ramsey optimal policies: subsidy vs lockdown.**



*Note*: quarterly observations. Percentage deviations from steady state. The shock is reported in absolute value.

Figure 6 compares the results with what obtains under the lockdown policy. The subsidy induces a large reallocation of retail trade away from the contact-intensive channel, which must reduce its marginal cost, and the shock shrinks in just two quarters. Some features of the transition closely resemble those obtained when the lockdown policy does not bear political costs, but there are some important differences, because the subsidy generates a consumption boom combined with an immediate fall in inflation.

Figure 7: **Irfs of same-welfare Ramsey policies: lockdown vs subsidy**



*Note*: quarterly observations. Percentage deviations from steady state. The shock is reported in absolute value.

To facilitate a direct comparison with the lockdown scenario depicted in Figure 3, we artificially limit the planners ability to subsidize the economy in each period, so that the sequence $\{S_t^{ro}\}_{t=0}^{\infty}$ generates the same welfare obtained under the baseline lockdown scenario (see Figure 7).[7] Matching the welfare loss obtained under the lockdown policy would require an initial subsidy at about 20%, that would then be reduced to 5% within the fourth quarter and remain persistently positive thereafter. It is easy to see that the subsidy turns a contractionary policy stance into an expansionary one. This happens because the subsidy allows to reallocate retail trade towards the online channel *and* to generate a lower inflation response that, in turn, triggers a real interest rate fall [8].

One important shortcoming of the Ramsey-optimal subsidy is that the sequence $\{S_t^{ro}\}_{t=0}^{\infty}$ is achieved by setting an initial subsidy as high as 82%. Another important shortcoming of a policy that fully replaced the lockdown with a subsidy to online retail trade is that a lockdown is effective insofar as it restricts human activities other than contact-intensive retail trade. In this sense it is more effective for shock containment than the subsidy policy that, by definition, has no direct effect on human interactions that are unrelated to purchase of consumption goods (see our discussion in the introduction).

To further investigate the possibility of raising welfare by combining the subsidy and the lockdown policy, we are left with two alternatives. The first one requires that we identify a plausible subsidy implementation cost which

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[7] Technically, we impose an implementation cost in labour units that is increasing in the size of the subsidy.

[8] One might ask why the two scenarios yield the same welfare when the subsidy policy avoids the contraction associated with the lockdown. The answer is simple: the subsidy causes consumption overshooting and the subsidy implementation cost induces the planner to subsidize the online channel for a prolonged period after the shock to $\alpha_t^N$ has dissipated.

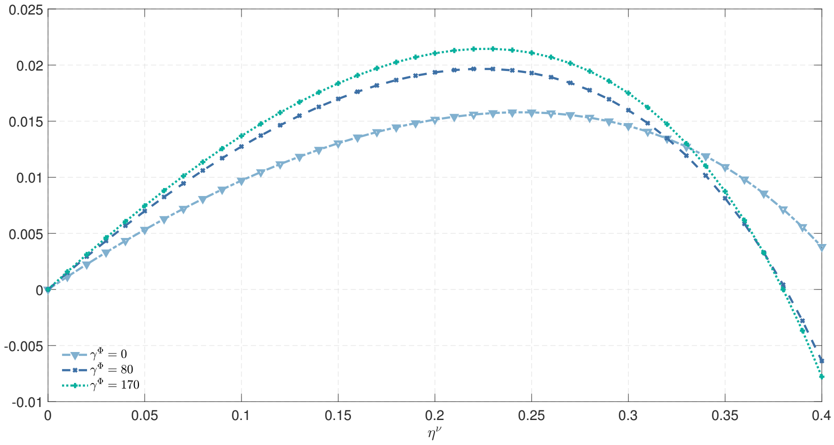
limits the planner's reliance on this tool, otherwise the policy experiment in the context of our model would inevitably suggest that lockdowns are utterly unnecessary. The second one combines the Ramsey-optimal lockdown with a simple, ad-hoc implementation rule for the subsidy.[9] Given the lack of evidence about subsidy implementation costs, we opted for the latter option. We therefore posit that the subsidy policy follows a simple rule of the form:

$$v_t^{ro} = \left(\alpha_t^N\right)^{\eta^v} - 1 \tag{22}$$

where we calibrate the parameter $\eta^v$ to investigate different paths of the subsidy during the transition and their impacts on the planner's optimal lockdown policy.

The implementation of (22) implies that, while setting the optimal lockdown, the planner internalizes the contribution of the subsidy to the trade reallocation across the two channels. To begin with, note that in our benchmark simulation ($\gamma^\Phi = 170$) the subsidy rule $\eta^v \approxeq 0.23$ yields the largest welfare gain, and the optimal value of $\eta^v$ is inversely related to $\gamma^\Phi$ (Figure 8).

Figure 8: **Consumption-equivalent welfare gain at different political costs of lockdowns.**



*Note*: on the y-axis we plot the welfare gain of each scenario relative to the case with $\eta^v = 0$.

To illustrate the non-monotonic welfare contribution of the subsidy rule, in Figure 9 we report model dynamics for our benchmark simulation when $\eta^v = 0.23$ and 0.36, where the latter value generates a suboptimal outcome. As one would expect, the stronger the subsidization rule, the larger the reallocation towards the online retail channel and the immediate fall in inflation. The key result is that the subsidization policy does not soften the lockdown policy. To the contrary, the restriction on contact-intensive retail trade strengthens with $\eta^v$. This happens because the fall in inflation triggers an expansionary monetary policy stance, and for this reason the planner chooses to strengthen the lockdown even if this bears a larger political cost. It is for this reason that the rule based on $\eta^v = 0.36$ is suboptimal.

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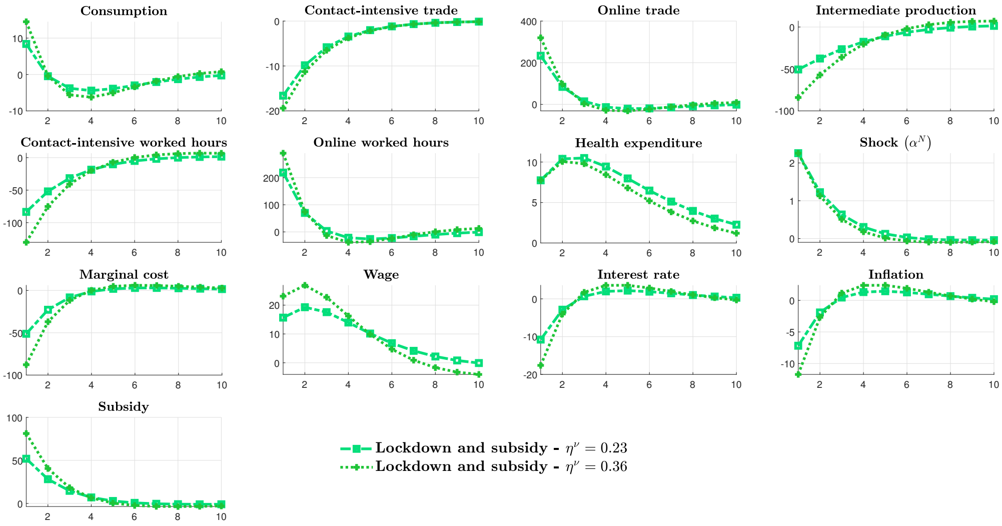
[9] This choice is also computationally convenient.

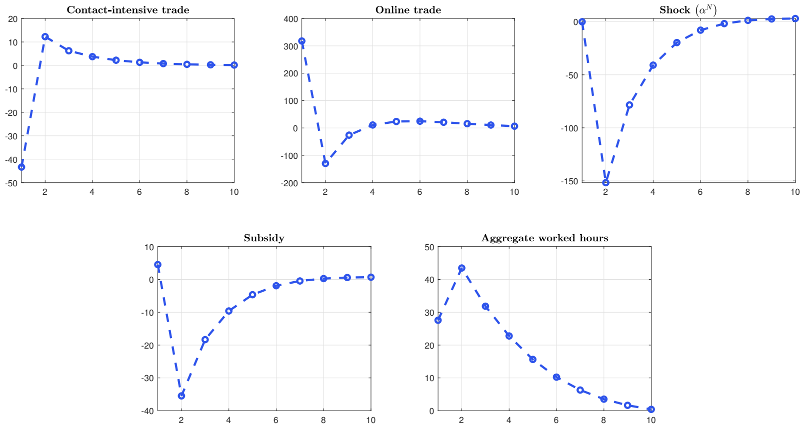
Figure 9: **Irfs of Lockdown policies with increasing strength of the online subsidy rule.**



*Note*: quarterly observations. Percentage deviations from steady state. The shock is reported in absolute value.

The next step, is a comparison of the IRFs obtained under the welfare-maximizing subsidisation rules associated to $\gamma^\Phi = 0$ and 170, i.e. $\eta^\nu = 0.25$ and 0.23 (Figure 10). As expected, absent the political cost, the planner strengthens the initial lockdown, with immediate beneficial effects on the shock. Perhaps surprisingly, in this case the planner also chooses to implement a strong subsidization policy even if the shock is quickly brought under control. Thus, the lower the political cost of a lockdown, the stronger the complementarity in the use of the two policy tools.

Figure 10: **IRFs gaps for $\gamma^\Phi = 0$ and $\gamma^\Phi = 170$.**

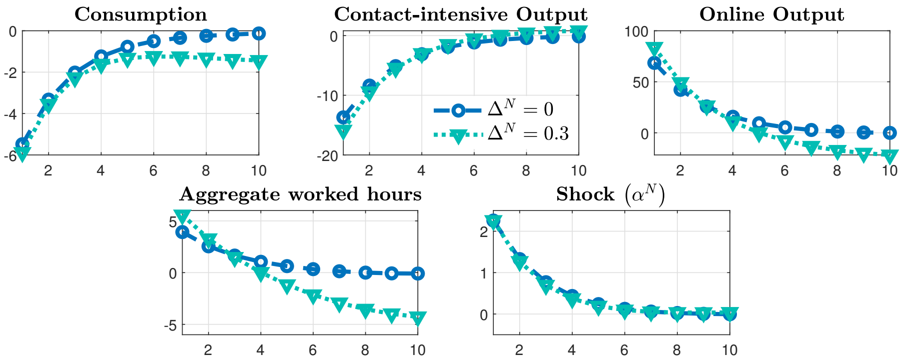


## 3.4 Optimal policies under labour contagion

By adding an employment effect to the shock persistence condition (2), we have a twofold effect on the planner incentives: a lockdown has a stronger offsetting impact on the shock in so far as it lowers employment, but the implications of the subsidy on shock persistence are ambiguous because the substitution effect (away from contact-intensive retail trade) could be limited or offset by the positive contribution of the subsidy to employment.

Figure 11 plots the IRFs under the optimal lockdown policy (no subsidy), when employment affects shock persistence.

Figure 11: **The effect of labour contagion on the lockdown policy.**

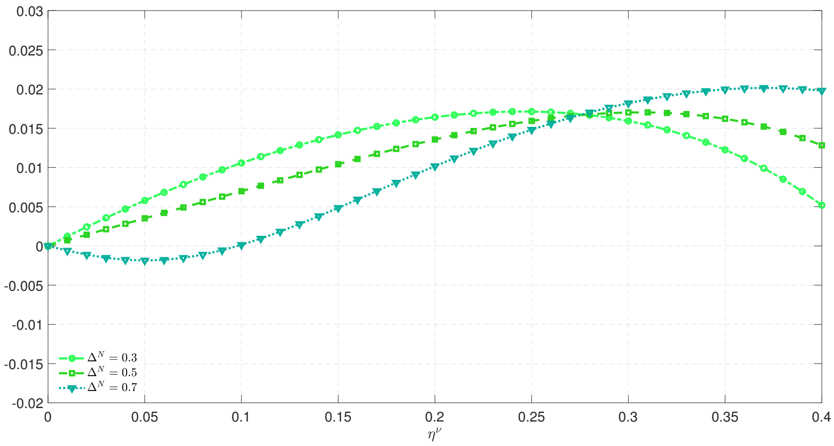


*Note*: quarterly observations. Percentage deviations from steady state. The shock is reported in absolute value.

It is easy to see that the planner strengthens the initial lockdown, triggering a sharper initial increase in online trade.

Figure 12 shows that is is optimal to raise the strength of the subsidization rule if the economy is more exposed the employment effect on contagion.

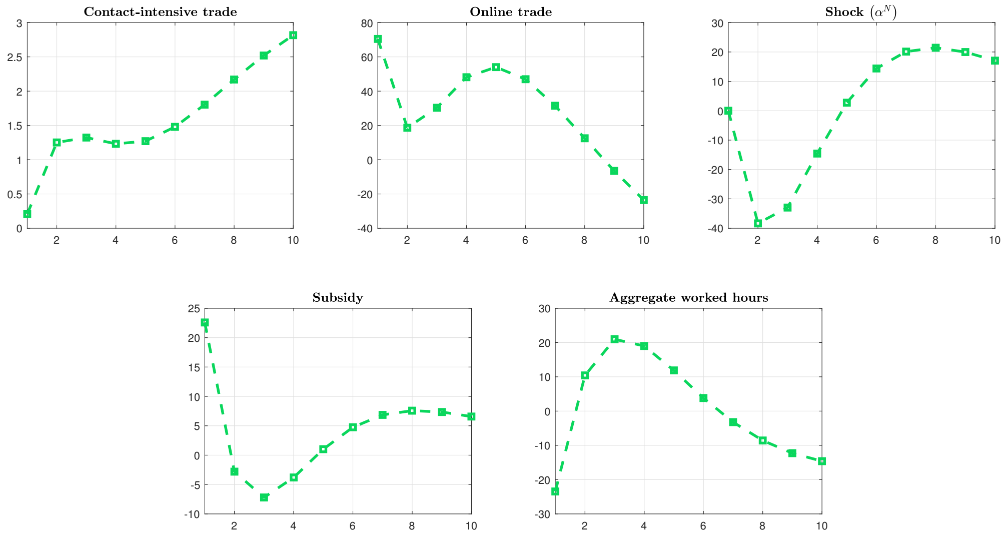
Figure 12: **Consumption-equivalent welfare gain of the subsidy rule with increasing strength labour contagion.**



*Note*: on the y-axis we plot the welfare gain of each scenario relative to the case with $\eta^v = 0$ .

From the IRFs gaps reported in Figure 13 we see that for a relatively stronger employment effect, the planner chooses a slightly milder lockdown associated with an initial surge in the subsidy. On impact, this is consistent with a fall in employment which is sufficient to reduce the relative size of the shock after two periods.

Figure 13: **Optimal lockdown and subsidy with increasing deltaN.**



*Note*: quarterly observations. Percentage deviations from steady state. The shock is reported in absolute value.

# 4 Conclusions

The model allows to investigate 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 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. The Ramsey planner improves the trade-off between macroeconomic stabilisation and infection mitigation, engineering a reallocation away from contact-intensive retail trade. In this regard, a production subsidy for online trade turns out to be very effective, and we do find strong complementarity between the strength of the subsidy and the severity of the lockdown, even if stabilizing employment adds to the persistence of the shock.

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# Appendix

## .1 List of equations

### .1.1 No intervention model

- Euler equation

$$1 = E_t \Lambda_{t,t+1} \frac{R_t}{\pi_{t+1}}$$

- Stochastic discount factor

$$\Lambda_{t,t+1} = \beta \left( \frac{C_t}{C_{t+1}} \right)$$

- Sectoral wage inflation

$$\alpha_t^N \chi N_t^{\varphi} C_t - \frac{\psi^N - 1}{\psi^N} w_t = \frac{\gamma^w}{\psi^N} \left( \pi_t^w - 1 \right) \pi_t^w - \beta \mathbb{E}_t \left[ \Lambda_{t,t+1} \frac{\gamma^w}{\psi^N} \left( \pi_{t+1}^w - 1 \right) \pi_{t+1}^w \frac{N_{t+1}}{N_t} \right]$$

- Wage dynamics

$$w_t = w_{t-1} \frac{\pi_t^w}{\pi_t}$$

- Intermediate production function

$$S_t^I = A N_t^I$$

- Intermediate labor demand

$$p_t^I = \frac{w_t}{A}$$

- Contact-intensive production function

$$S_t^{rc} = \left[ \left( \frac{N_t^{rc}}{\alpha^{rc} \tau^{rc}} \right)^{\alpha_r} \left( S_t^{I,rc} \right)^{1-\alpha_r} \right]^{\theta}$$

- Contact-intensive intermediate input demand

$$S_t^{I,rc} = \frac{\theta (1 - \alpha_r) MC_t S_t^{rc}}{p_t^I}$$

- Contact-intensive labour demand

$$N_t^{rc} = \frac{\theta \alpha_r MC_t S_t^{rc}}{w_t}$$

- Online production function

$$S_t^{ro} = \left[ \left( \frac{N_t^{rc}}{\tau^{ro}} \right)^{\alpha_r} \left( S_t^{I,ro} \right)^{1-\alpha_r} \right]^{\theta}$$

- Online intermediate input demand

$$S_t^{I,ro} = \frac{\theta (1 - \alpha_r) MC_t S_t^{ro}}{x_t^{ro} p_t^I}$$

- Online labour demand

$$N_t^{ro} = \frac{\theta \alpha_r MC_t S_t^{ro}}{x_t^{ro} w_t}$$

- Marginal cost

$$MC_t = \frac{1}{\theta} x_t^{ro} \left( \frac{\tau^{ro} w_t}{\alpha_r} \right)^{\alpha_r} \left( \frac{p_t^I}{(1-\alpha_r)} \right)^{1-\alpha_r} \left( \frac{S_t}{1 + \left[ x_t^{ro} \left( \frac{\tau^{ro}}{\alpha_t^{rc} \tau^{rc}} \right)^{\alpha_r} \right]^{\frac{\theta}{1-\theta}}} \right)^{\frac{1-\theta}{\theta}}$$

- Aggregate supply of goods

$$S_t = S_t^{rc} + S_t^{ro}$$

- Market clearing

$$S_t = C_t$$

- NKPC

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

- Taylor rule

$$R_t = \bar{R} \pi_t^{\theta^{\pi}}$$

- Aggregate intermediate production

$$S_t^I = S_t^{I,ro} + S_t^{I,rc} + S_t^{I,g}$$

- Health goods demand function

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

- Health goods supply function

$$g_t = S_t^{I,g}$$

- Aggregate resource constraint

$$Y_t = C_t + g_t$$

- Aggregate labour constraint

$$N_t = N_t^{rc} + N_t^{ro} + N_t^I$$

- Pandemic shock

$$\alpha_t^N = \left( \alpha_{t-1}^N \right)^{\rho} \left( \frac{S_{t-1}^{rc}}{\overline{S^{rc}}} \right)^{\Delta} \left( \frac{N_{t-1}}{\overline{N}} \right)^{\Delta^N} \exp \varepsilon_t$$

## .2 Derivation of key equations

### .2.1 Households

The households problem is:

$$\max_{C_t, b_t, N_t} U_t(i) = \sum_{t=0}^{\infty} \mathbb{E}_t \beta^t \left\{ \ln C_t(i) - (1-\gamma) \alpha_t^N \chi \frac{N_t(i)^{1+\varphi}}{1+\varphi} - \gamma \Gamma_t \right\},$$

$$s.t. \tag{.1}$$

$$C_t(i)+b_t(i)=\frac{R_{t-1}b_{t-1}(i)}{\pi_t}+w_tN_t(i)+\Pi_t(i)-\Phi_t^N(j)-t_t^{LS}$$

The Lagrangean of the problem for $t$ and $t+1$ is:

$$L=\mathbb{E}_t\left\{\begin{array}{c}\beta^t\left\{\ln C_t(i)-(1-\gamma)\alpha_t^N\chi\frac{N_t(i)^{1+\varphi}}{1+\varphi}-\gamma\Gamma_t\right\}\\ -\beta^t\lambda_t\left[C_t(i)+b_t(i)-\frac{R_{t-1}b_{t-1}(i)}{\pi_t}-w_tN_t(i)-\Pi_t(i)+\Phi_t^N(j)+t_t^{LS}\right]\\ +\beta^{t+1}\left\{\ln C_{t+1}(i)-(1-\gamma)\alpha_{t+1}^N\chi\frac{N_{t+1}(i)^{1+\varphi}}{1+\varphi}-\gamma\Gamma_{t+1}\right\}\\ -\beta^{t+1}\lambda_{t+1}\left[C_{t+1}(i)+b_{t+1}(i)-\frac{R_tb_t(i)}{\pi_{t+1}}-w_{t+1}N_{t+1}(i)-\Pi_{t+1}(i)+\Phi_{t+1}^N(j)+t_{t+1}^{LS}\right]\end{array}\right\}$$

The first order conditions are:

*I.* $\frac{\partial L}{\partial C_t(i)}=0$

$$\beta^t\lambda_t=\frac{\beta^t}{C_t(i)}\rightarrow\lambda_t=\frac{1}{C_t(i)} \tag{.2}$$

*II.* $\frac{\partial L}{\partial b_t(i)}=0$

$$-\lambda_t\beta^t+\lambda_{t+1}\beta^{t+1}\frac{R_t}{\pi_{t+1}}=0\rightarrow 1=\beta\left(\frac{C_t(i)}{C_{t+1}(i)}\right)\frac{R_t}{\pi_{t+1}} \tag{.3}$$

### .2.2 Intermediate Firm

The problem of the intermediate firm is:

$$\max_{S^{I,t}}\Pi_t^I=p_t^IS_t^I-w_tN_t^I$$

$$s.t. \tag{.4}$$

$$S_t^I=AN_t^I$$

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

$$\lambda_t=p_t^I$$

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

$$MC_t^I=p_t^I \tag{.5}$$

Through cost minimisation, the demand for intermediate labor, $N_t^I$, is obtained as follows:

$$\max_{N_t^I}\Pi_t^I=p_t^IS_t^I-w_tN_t^I$$

$$s.t. \tag{.6}$$

$$S_t^I=AN_t^I$$

$\frac{\partial L}{\partial N_t^I} = 0$

$$w_t = p_t^I A \tag{.7}$$

### .2.3 Final Firms

Remembering that $x_t^{ro} = 1 - v_t^{ro}$, the problem of the final producer is:

$$\max_{N_t^{rc}(z),N_t^{ro}(z),N_t^I(z),S_t^{I,rc}(z),S_t^{I,ro}(z),P_t(z)} \left\{ \begin{array}{c} \frac{P_t(j)}{P_t} S_t(z)\omega + \\ -\left[ \begin{array}{c} x_t^{ro}\left(w_t N_t^{ro}(z) + p_t^I S_t^{I,ro}(z)\right) + \\ w_t N_t^{rc}(z) + p_t^I S_t^{I,rc}(z) \end{array} \right] + \\ -\frac{\gamma}{2}\left(\frac{P_t(z)}{P_{t-1}(z)} - 1\right)^2 S_t \end{array} \right\}$$

$$s.t. \tag{.8}$$

$$S_t^{rc}(z) = \left[\left(\frac{N_t^{rc}(z)}{\alpha_t^{rc}\tau^{rc}}\right)^{\alpha_r} (S_t^{I,rc}(z))^{1-\alpha_r}\right]^{\theta}$$

$$S_t^{ro}(z) = \left[\left(\frac{N_t^{ro}(z)}{\tau^{ro}}\right)^{\alpha_r} (S_t^{I,ro}(z))^{1-\alpha_r}\right]^{\theta}$$

$$S_t(z) = S_t^{rc}(z) + S_t^{ro}(z)$$

$$S_t(z) = S_t\left(\frac{P_t(z)}{P_t}\right)^{-\psi}$$

Minimization of production cost . The Lagrangean is:

$$L_{MC} = \left\{ \begin{array}{c} \left[ \begin{array}{c} x_t^{ro}\left(w_t N^{ro,t}(z) + p_t^I S_z^{I,ro}(j)\right) \\ +w_t N_t^{rc} + p_t^I S_t^{I,rc}(z) \end{array} \right] + \\ \lambda_t^{MC}\left[S_t(z) - \left[\left(\frac{N_t^{rc}(z)}{\alpha^{rc}\tau^{rc}}\right)^{\alpha_r}(S_t^{I,rc}(z))^{1-\alpha_r}\right]^{\theta} - \left[\left(\frac{N_t^{ro}(z)}{\tau^{ro}}\right)^{\alpha_r}(S_t^{I,ro}(z))^{1-\alpha_r}\right]^{\theta}\right] \end{array} \right\}$$

The first order conditions are:

$\frac{\partial L_{MC}}{\partial N_t^{rc}(z)} = 0$

$$N_t^{rc}(z) = \frac{\theta\alpha_r\lambda_t^{MC}S_t^{rc}(z)}{w_t} \tag{.9}$$

$\frac{\partial L_{MC}}{\partial N_t^{ro}(z)} = 0$

$$N_t^{ro}(z) = \frac{\theta\alpha_r\lambda_t^{MC}S_t^{ro}(z)}{x_t^{ro}w_t} \tag{.10}$$

$\frac{\partial L_{MC}}{\partial S_t^{I,rc}(z)} = 0$

$$S_t^{I,rc}(z) = \frac{\theta(1-\alpha_r)\lambda_t^{MC} S_t^{rc}(z)}{p_t^I} \tag{.11}$$

$\frac{\partial L_{MC}}{\partial S_t^{I,ro}(z)} = 0$

$$S_t^{I,ro}(z) = \frac{\theta(1-\alpha_r)\lambda_t^{MC} S_t^{ro}(z)}{x_t^{ro} p_t^I} \tag{.12}$$

Rearranging .10 and plugging in .12 we must therefore have

$$S_t^{I,ro}(z) = (N_t^{ro}(z))\, w_t \frac{(1-\alpha_r)}{\alpha_r p_t^I} \tag{.13}$$

**Marginal costs**

Recall that the equation for the total (online) costs is:

$$TC_t^{ro} = x_t^{ro}\left(w_t N_t^{ro} + p_t^I S_t^{I,ro}\right) \tag{.14}$$

Now, substitute equation .13 into equation .14:

$$TC_t^{ro} = \left[x_t^{ro} w_t N_t^{ro} + x_t^{ro} p_t^I (N_t^{ro})\, w_t \frac{(1-\alpha_r)}{\alpha_r p_t^I}\right]$$

$$TC_t^{ro} = x_t^{ro} w_t N_t^{ro}\left(1 + \frac{1-\alpha_r}{\alpha_r}\right)$$

$$TC_t^{ro} = \frac{x_t^{ro} w_t N_t^{ro}}{\alpha_r}. \tag{.15}$$

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

$$S_t^{ro} = \left[N_t^{ro}\left(\frac{1}{\tau^{ro}}\right)^{\alpha_r}\left(w_t \frac{1-\alpha_r}{\alpha_r p_t^I}\right)^{1-\alpha_r}\right]^{\theta}$$

Therefore

$$N_t^{ro} = \frac{(S_t^{ro})^{\frac{1}{\theta}}}{\left(\frac{1}{\tau^{ro}}\right)^{\alpha_r}\left(w_t \frac{1-\alpha_r}{\alpha_r p_t^I}\right)^{1-\alpha_r}}$$

Therefore

$$TC_t^{ro} = x_t^{ro}\,(\tau^{ro})^{\alpha_r}\left(\frac{w_t}{\alpha_r}\right)^{\alpha_r}\left(\frac{p_t^I}{(1-\alpha_r)}\right)^{1-\alpha_r}(S_t^{ro})^{\frac{1}{\theta}} \tag{.16}$$

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

$$MC_t^{ro} = \frac{x_t^{ro}\left(\tau^{ro}\right)^{\alpha_r}}{\theta}\left(\frac{w_t}{\alpha_r}\right)^{\alpha_r}\left(\frac{p_t^I}{(1-\alpha_r)}\right)^{1-\alpha_r}\left(S_t^{ro}\right)^{\frac{1}{\theta}-1}$$

This yields:

$$MC_t^{ro} = \frac{1}{\theta}x_t^{ro}\left(\tau^{ro}\right)^{\alpha_r}\left(\frac{w_t}{\alpha_r}\right)^{\alpha_r}\left(\frac{p_t^I}{(1-\alpha_r)}\right)^{1-\alpha_r}\left(S_t^{ro}\right)^{\frac{1-\theta}{\theta}} \tag{.17}$$

but it must hold that:

$$MC_t^{ro} = MC_t^{rc}$$

hence:

$$\frac{1}{\theta}x_t^{ro}\left(\tau^{ro}\right)^{\alpha_r}\left(\frac{w_t}{\alpha_r}\right)^{\alpha_r}\left(\frac{p_t^I}{(1-\alpha_r)}\right)^{1-\alpha_r}\left(S_t^{ro}\right)^{\frac{1-\theta}{\theta}} = \frac{1}{\theta}\left(\alpha^{rc}\tau^{rc}\right)^{\alpha_r}\left(\frac{w_t}{\alpha_r}\right)^{\alpha_r}\left(\frac{p_t^I}{(1-\alpha_r)}\right)^{1-\alpha_r}\left(S_t^{rc}\right)^{\frac{1-\theta}{\theta}}$$

and finally:

$$\frac{S_t^{rc}}{S_t^{ro}} = \left[x_t^{ro}\left(\frac{\tau^{ro}}{\alpha^{rc}\tau^{rc}}\right)^{\alpha_r}\right]^{\frac{\theta}{1-\theta}}$$

In addition, considering the aggregate supply of goods, we have:

$$S_t = \left[x_t^{ro}\left(\frac{\tau^{ro}}{\alpha^{rc}\tau^{rc}}\right)^{\alpha_r}\right]^{\frac{\theta}{1-\theta}} S_t^{ro} + S_t^{ro}$$

$$S_t = \left[1 + \left[x_t^{ro}\left(\frac{\tau^{ro}}{\alpha^{rc}\tau^{rc}}\right)^{\alpha_r}\right]^{\frac{\theta}{1-\theta}}\right] S_t^{ro}$$

$$S_t^{ro} = \frac{S_t}{1 + \left[x_t^{ro}\left(\frac{\tau^{ro}}{\alpha^{rc}\tau^{rc}}\right)^{\alpha_r}\right]^{\frac{\theta}{1-\theta}}}$$

Substituting this last result into equation (.16) yields the solutions for

$$TC_t^{ro} = x_t^{ro}\left(\tau^{ro}\right)^{\alpha_r}\left(\frac{w_t}{\alpha_r}\right)^{\alpha_r}\left(\frac{p_t^I}{(1-\alpha_r)}\right)^{1-\alpha_r}\left\{\frac{S_t}{1 + \left[x_t^{ro}\left(\frac{\tau^{ro}}{\alpha^{rc}\tau^{rc}}\right)^{\alpha_r}\right]^{\frac{\theta}{1-\theta}}}\right\}^{\frac{1}{\theta}}$$

and for the marginal cost:

$$MC_t^{ro} = \frac{1}{\theta} x_t^{ro} \left(\tau^{ro}\right)^{\alpha_r} \left(\frac{w_t}{\alpha_r}\right)^{\alpha_r} \left(\frac{p_t^I}{(1-\alpha_r)}\right)^{1-\alpha_r} \left(\frac{S_t}{1+\left[x_t^{ro} \frac{(\tau^{ro})^{\alpha_r}}{(\alpha^{rc}\tau^{rc})^{\alpha_r}}\right]^{\frac{\theta}{1-\theta}}}\right)^{\frac{1-\theta}{\theta}} \tag{.18}$$

**New keynesian Phillips curve**

Using the definition of profits

$$\Pi_t(z) = \left\{ \frac{P_t(z)}{P_t} S_t(z)\omega - TC_t(z) - \frac{\gamma^{\pi}}{2}\left(\frac{P_t(z)}{P_{t-1}(z)} - 1\right)^2 S_t \right\}$$

Optimal price setting decision requires

$$\begin{gathered} \max_{p_t(z)} \mathbb{E}_t \sum_{t=0}^{\infty} \beta^t \Pi_t(z) \\ s.t. \\ S_t(z) = S_t \left(\frac{P_t(z)}{P_t}\right)^{-\psi} \end{gathered} \tag{.19}$$

After imposing the simmetrical equibrium this yields the standard NKPC condition

$$\frac{\gamma}{\psi}(\pi_t - 1)\pi_t = \beta \mathbb{E}_t \left\{ \Lambda_{t.t+1} \frac{\gamma}{\psi}(\pi_{t+1} - 1)\pi_{t+1} \frac{S_{t+1}}{S_t} \right\} + \left(\frac{1-\psi}{\psi}\right)\omega + MC_t$$

where

$$\omega = \frac{\psi}{\psi - 1}$$

removes the stedy state distortion due to monopolistic competition in the retail sector.

## .3 Steady state derivation

Starting from the Euler equation we get

$$\overline{R} = \frac{1}{\beta}$$

Then, we set marginal cost:

$$\overline{MC} = 1$$

and inflation of prices and wages: $\pi = 1$ and $\pi^w = 1$. Since the planner is supposed not to intervene in steady state, the lockdown parameter $\alpha^{rc} = 1$.

From data, we calibrate the ratio between phisical and online production:

$$\frac{\overline{S}^{rc}}{\overline{S}^{ro}} = 9$$

We then set the final output $\overline{Y} = 1$, the aggregate labour supply $\overline{N} = 1$ and the quantity of the intermediate labour equal to the 35 % of the total labour, $\overline{N}^I = 0.35$. Finally, we calibrate the amount of public expenditure from data as the 17.5 % of the total output, $\overline{g} = 0.175$

Hence, we obtain:

$$\overline{C} = \overline{Y} - \overline{g}$$

Since it is implicitly defined in the marginal cost equation that $C_t = S_t^{rc} + S_t^{ro}$, we get that:

$$\overline{S}^{rc} = 0.9\overline{C}$$

and

$$\overline{S}^{ro} = 0.1\overline{C}$$

Setting the ratio $\frac{\overline{S}^{rc}}{\overline{S}^{ro}} = 9$ implies that $\frac{\overline{N}^{rc}}{\overline{N}^{ro}} = 9$. Hence, exploiting the definition of aggregate labour we get:

$$\overline{N} = \overline{N}^{I} + \overline{N}^{rc} + \overline{N}^{ro} \tag{.20}$$

$$1 = 0.35 + \overline{N}^{ro}\left(\frac{N^{rc}}{N^{ro}} + 1\right) \tag{.21}$$

$$1 = 0.35 + \overline{N}^{ro}(9+1) \tag{.22}$$

$$\overline{N}^{ro} = \frac{0.65}{10} = 0.065$$

Thus,

$$\overline{N}^{rc} = \overline{N} - \overline{N}^{I} - \overline{N}^{ro}$$

Exploiting the equation defining the government expenditure in public goods we get:

$$\overline{S}^{I,g} = (\overline{g})^{\frac{1}{\alpha_g}}$$

From the online labour demand we have:

$$\overline{w} = \frac{\theta\alpha_r}{\overline{N}^{ro}}\overline{S}^{ro}$$

Calibrating the techology parameter:

$$A = \frac{\overline{S}^{I,g}}{\left(\overline{N} - \overline{C}\frac{\theta(1-\alpha_r)}{\overline{w}}\right)}$$

we find

$$\overline{p}^{I} = \frac{\overline{w}}{A}$$

and

$$\overline{S}^{I} = A\overline{N}^{I}$$

The quantities of the intermediate goods demanded by both retailer sectors are:

$$\overline{S}^{I,rc} = \frac{\theta(1-\alpha_r)\overline{mc}}{\overline{p}^{I}}\overline{S}^{rc}$$

and

$$\overline{S}^{I,ro} = \frac{\theta(1-\alpha_r)\overline{mc}}{\overline{p}^{I}}\overline{S}^{ro}$$

We then calibrate the technological shifters for the physical and online retailers:

$$\frac{\overline{S}^{rc}}{\overline{S}^{ro}} = \left[\left(\frac{\overline{N}^{rc}\tau^{ro}}{\overline{N}^{ro}\tau^{rc}}\right)^{\alpha_r}\left(\frac{\overline{S}^{I,rc}}{\overline{S}^{I,ro}}\right)^{1-\alpha_r}\right]^{\theta} \tag{.23}$$

$$\frac{\overline{\tau^{ro}}}{\tau^{rc}} = \left(\frac{\overline{S}^{rc}}{\overline{S}^{ro}}\right)^{\frac{1}{\theta\alpha_r}}\left(\frac{\overline{S}^{I,rc}}{\overline{S}^{I,ro}}\right)^{-\frac{(1-\alpha_r)}{\alpha_r}}\left(\frac{\overline{N}^{rc}}{\overline{N}^{ro}}\right)^{-1}$$

The above ratio implies:

$$\tau^{ro}=\left(\frac{\overline{mc}}{\frac{1}{\theta}\left(1-\overline{v}\right)\left(\frac{\overline{w}}{\alpha_r}\right)^{\alpha_r}\left(\frac{\overline{p}^I}{1-\alpha_r}\right)^{1-\alpha_r}\left(\frac{\overline{C}}{1+\left[\left(\overline{\frac{\tau^{ro}}{\tau^{rc}}}\right)^{\alpha_r}\right]^{\frac{\theta}{1-\theta}}}\right)^{\frac{1-\theta}{\theta}}}\right)^{\frac{1}{\alpha_r}}$$

and

$$\tau^{rc}=\frac{\tau^{ro}}{\overline{\frac{\tau^{ro}}{\tau^{rc}}}}$$

and we conclude calibrating the labour disutility parameter:

$$\chi=\frac{\overline{w}}{\overline{C}}$$