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Quantifying the Macroeconomic Effects of the COVID-19 Lockdown: Comparative Simulations of the Estimated Galí-Smets-Wouters Model

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Abstract

This paper considers 3 scenarios regarding the duration of the COVID-19 pandemic lockdown, staying for 1, 2 or 3 quarters, and 2 types of exceptionally rare and devastating disruptions in employment modeled as adverse labor supply shocks, a temporary one with negligible loss in the labor force due to deaths or a permanent one, with significant loss from deaths. The temporary labor supply shock simulations delimit a lower bound, designed to match about 1/4 of the labor force unable to work, and an upper bound, matching about 3/4 of the labor force made economically inactive, broadly consistent with estimates. The permanent labor supply shock is designed to match, in 3 scenarios again, up to 1% loss of the labor force due to mortality, twice milder than the Spanish flu 2% death rate. Estimated calibrations of the Galí-Smets-Wouters (2012) model with indivisible labor for 5 major and most affected by the COVID-19 pandemic economies are simulated: the US, France, Germany, Italy and Spain. The simulations suggest that even in the most optimistic scenario of a brief (lasting for 1 quarter) and mild (with 1/4 of the labor force unable to work) lockdown, the loss of per-capita consumption (6-7% in annualized terms down from the long-run trend in the impact quarter) and per-capita output (3-4% down) will be quite damaging, but recoverable relatively quickly, in 1-2 years. In the most pessimistic simulated scenario of temporary loss the effects will be 10-15 times more devastating, and the loss of output and consumption will persist beyond 10-15 years. Permanent loss of up to 1.5 percentage points of per-capita consumption and output characterizes the simulated permanent labor supply shock.

Keywords: COVID-19 pandemic, simulated macroeconomic effects, medium-scale New Keynesian DSGE models, indivisible labor, shocks to the disutility of labor supply, calibration according to Bayesian estimates

JEL codes: C63, D58, E24, E27, E32, E37

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†First write-up: April 5, 2020. This is still a preliminary (and, possibly, incomplete) draft, without any exposure to feedback so far. Constructive comments and suggestions are, therefore, very welcome. All remaining errors or misinterpretations are my sole responsibility.

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"[...] Because the situation with COVID-19 is rapidly evolving, any analysis based on current data will quickly become out of date. However, any analysis based on available data is better than no analysis. [...]", Alexis Akira Toda (2020), p. 59, *Covid Economics, Vetted and Real-Time Papers* (CEPR), Issue 1, April 3, 2020

1 Introduction

A month or two ago, there were no research papers in (macro)economics on the COVID-19 pandemic. Now, as at the time of writing (April 10, 2020), there are many, perhaps about a dozen, or more (some of them cited further below). A new journal launched by the Centre for Economic Policy Research (CEPR), *Covid Economics: Vetted and Real-Time Papers*, just published its first issue on April 3, 2020. The present (urgently executed) paper contributes to this new "mushrooming" literature, with the pressing task to enrich the "databank" of available simulations and quantitative predictions, in order to inform and help policymakers in the current emergency of their crucial decision-making.

Among the papers that have very recently appeared in this novel field of macroeconomics, there is a variety of approaches in theoretical as well as empirical work, involving also economic history and simulations. On the theoretical front, Kaplan *et al.* (2020) consider the combination of health and economic policies (mostly macro but also micro) to explain the COVID-19 pandemics and the policymakers' response to it in a heterogeneous agent New Keynesian model. They find not only macroeconomic but also distributional effects under different health, monetary, fiscal and social insurance policies. A key takeaway is that the most exposed households due to the health policies having imposed the lockdown are those with the lowest liquidity, which may not be able to survive for long without financial help, thus affecting significantly policy tradeoffs. The study plots pandemic possibility frontiers under different scenarios of combination of health policies, expressed as lives (% of the population), and macroeconomic policies, expressed as prosperity of those alive (% of normal). Guerrieri *et al.* (2020) present a theory of what they call "Keynesian supply shocks": supply shocks that trigger changes in aggregate demand larger than the shocks themselves. They argue that the economic shocks associated to the COVID-19 epidemic shutdowns, layoffs, and firm exits may have this feature. In a two-sector model with incomplete markets they find that a 50% shock that hits all sectors is not the same as a 100% shock that hits half the economy. Incomplete markets make the conditions for Keynesian supply shocks more likely to be met. Firm exit and job destruction can amplify the initial effect, aggravating the recession. Optimal policy implies closing down contact-intensive sectors and providing full insurance payments to affected workers. Eichenbaum, Rebelo and Trabandt (2020, ERT henceforth) adapt the canonical SIR model in epidemiology due to Kermack and McKendrick (1927)[1] to study the

[1] A SIR model computes scenarios regarding the theoretical number of people infected with a contagious disease in a closed population over time. The labeling comes from the equations of the model relating

interaction between economic decisions and epidemics. They find that people's decision to cut back on consumption, modeled (in a shortcut) as "consumption tax", and work reduces the severity of the epidemic, as measured by total deaths, but exacerbates the size of the recession. The competitive equilibrium is not socially optimal because infected people do not fully internalize the effect of their economic decisions on the spread of the virus. In their benchmark, the best simple containment policy increases the severity of the recession but saves roughly half a million lives in the US.

On the empirical front, Toda (2020) estimates the susceptible-infected-recovered (SIR) epidemiological model for the novel COVID-19 disease, and finds that the transmission rate is heterogeneous across countries but exceeds by far the recovery rate, resulting in a fast spread. In his benchmark, 24.4% of the population may be simultaneously infected at the peak, potentially overwhelming the healthcare system, yet the optimal mitigation policy that controls the timing and intensity of social distancing can reduce the peak to 5.6%. Barro *et al.* (2020) conclude that mortality and economic contraction during the 1918-1920 "Great Influenza Pandemic" (also known as the "Spanish flu", even if it did not originte in Spain) provide plausible upper bounds for outcomes under COVID-19. Based on data for 43 countries, they report a death rate of 2% of the world population (39 million people then, corresponding to 150 million now) and estimate by regression analysis economic declines for per-capita output and consumption in the typical country of 6% and 8%, respectively, over 1918-1921. Dingel and Neiman (2020) classify the feasibility of working at home for all occupations and report that about 34% of US jobs, accounting for 44% of overall wages, can plausibly be performed at home, but this share varies considerably across cities and industries. Correia *et al.* (2020) point out to two main lessons from examining the economic history of the Spanish flu: (i) the pandemic depresses the economy, with 1 standard deviation increase in mortality (= 150 per 100,000 infected) leading to a fall of manufacturing employment by 6 percentage points; (ii) non-pharmaceutical interventions (such as social distancing) do not depress economic activity, with statistically as well as economically significant effects. According to Jordà *et al.* (2020), citing works in economic history by Clark (2007, 2010), the most devastating pandemic of the last millennium, the Black Death, left England with a 25% to 40% drop in labor supply, a roughly 100% increase in real wages, and a decline in rates of return on land from about 5% to 8%. But, as they also remark, such macroeconomic responses in the case of the Black Death are most probably not representative of large pandemics in general, and in particular the current COVID-19 one, as the modern world and its globalized economy are much different.[2]

the number of susceptible people $S(t)$, number of people infected $I(t)$, and number of people who have recovered $R(t)$.

[2]For other very recent work addressing various aspects of the COVID-19 pandemic, see, e.g., Alfaro *et al.* (2020), Baker *et al.* (2020 a, b), Benigno and Nistico (2020). As far as asset price markets are concerned, Baker *et al.* (2020 a) report that no previous infectious disease outbreak, including the Spanish flu, has impacted the stock market as powerfully as the COVID-19 pandemic.

In the recent few weeks, many webinars have provided discussion fora for the policy options in the emergency of the current response to the pandemic crisis, and most of the cited papers in the previous paragraphs have been presented in this new form of frequent worldwide online seminars. Among the mentioned studies, however, only ERT involves a DSGE-style modeling,[3] which develops a simpler model than GSW but with a purposeful SIR ingredient. It is hard to judge about the precision of the policy implications arising from these various models and methods. While it is certain that none of them can win absolute dominance as most reliable for forecasting and policymaking, it is valuable indeed that we now have an emerging portfolio of different types of studies trying to provide a plausible account of the COVID-19 pandemic, with its possible evolution and influence on the economy.

In the present paper, we consider 3 scenarios regarding the duration of the lockdown (1, 2 or 3 quarters) and 2 types of exceptionally rare adverse labor supply shocks, a temporary one without significant loss in the labor force due to mass deaths or a permanent/persistent one, with deaths and slow birth recovery of the labor force. The temporary labor supply shock simulations delimit the "bounds" of the plausible macroeconomic loss dynamics: a lower bound, designed to match about 1/4 of the labor force unable to work (for each respective scenario regarding the duration of the lockdown), and an upper bound, matching about 3/4 of the labor force made economically inactive, broadly consistent with the mentioned estimates regarding the fraction of jobs that can be performed from home in Dingel and Neiman (2020). The permanent labor supply shock is designed to match, in the same 3 scenarios for the lockdown duration again, up to 1% loss of the labor force due to mortality, consistent with a minimum at the current COVID-19 death rate of 0.01% (i.e., 1 basis point of world population) according to own estimates based on the Johns Hopkins University statistics online, and a maximum at the Spanish flu 2% death rate (according to Barro *et al.*, 2020). Estimated calibrations of the GSW model for 5 major and most affected by COVID-19 economies are simulated: the US, France, Germany, Italy and Spain.

The particular model for our simulations, namely that proposed by Galí, Smets and Wouters (2012, GSW hereafter), is chosen for a good reason: it is the only medium-scale New Keynesian DSGE model where labor supply shocks are modeled separately from wage markup shocks, via the felicity function. More precisely, labor supply shocks affect the weight of the disutility from work, hence employment and unemployment, and can be identified and estimated econometrically, and then plausibly quantified in simulation scenarios. These features make the GSW model appropriate to address the issue in the title. Yet, the GSW model has not been designed to interact with demographics and pandemics, and so certain adapting assumptions and shortcuts are employed in our simulations in

[3] For any noneconomist readers, DSGE stands for dynamic stochastic general equilibrium, an approach in medium-scale microfounded macromodeling that has been the workhorse of quantitative analysis and simulation across the profession (academics and policymakers included) for about 2 decades. DSGE modeling has, however, remained under criticisms, especially outside the current mainstream paradigm in macroeconomic theory and policy.

order to quantify the interactive dynamics of the labor force, output, consumption, investment, the central bank interest rate, inflation, wages and other macrovariables in general equilibrium.

In the calibration of the parameters for our simulations, we use the GSW estimates based on quarterly observables for the US for the time period 1966Q1-2007Q4 as well as our own analogous estimates for France, Germany, Italy and Spain in Mihailov, Razzu and Wang (2019, MRW hereafter) for the time period 1999Q1-2017Q4. GSW reformulate the medium-scale New Keynesian DSGE model proposed by Smets and Wouters (2007, SW henceforth) by embedding the theory of unemployment based on Galí (2011 a, b). While there are other papers modeling unemployment in DSGE setups differently (see, e.g., Blanchard and Galí, 2007; Christiano *et al.*, 2007; Gertler *et al.*, 2008; and Christiano *et al.*, 2011 a, b), the GSW framework has the advantage of preserving the convenience of the representative household paradigm and allowing to determine the equilibrium levels of the labor force, employment and unemployment, as well as a number of other macroeconomic variables of interest.

The main contribution of the present paper consists in undertaking a set of simulations of a slightly modified version of the GSW medium-scale New Keynesian DSGE model with unemployment in order to quantify – albeit in a preliminary and imperfect exercise – the likely macroeconomic consequences of the COVID-19 pandemic. The simulations suggest that even in the most optimistic scenario of a brief (lasting for 1 quarter) and mild (with 1/4 of the labor force unable to work) lockdown, the loss of per-capita consumption (6-7% in annualized terms down from the long-run trend in the impact quarter) and per-capita output (3-4% down) will be quite damaging, but recoverable relatively quickly, in 1-2 years. In the most pessimistic simulated scenario of temporary loss the effects will be 10-15 times more devastating, and the loss of output and consumption will persist beyond 10-15 years. Permanent loss of up to 1.5 percentage points of per-capita consumption and output characterizes the simulated permanent labor supply shock. The key findings of our quantitative general equilibrium analysis will be of immediate use to policymakers in informing better their urgent actions during these long-forgotten times of health and economic havoc the world is nowadays living through again.

The rest of the paper is organized as follows. The next section focuses on the microfoundations of unemployment, employment and the labor force specific to the GSW model and the related log-linearized equations, which makes clear the logic behind the subsequent key assumptions we adopt in order to link the GSW model to our simulation study of the macroeconomic implications of the COVID-19 pandemic. Section 3 outlines our simulation design, pointing explicitly to its main advantages as well as weaknesses, and section 4 then reports and interprets our simulation results. Section 5 concludes, while appendix A presents the remaining log-linearized equilibrium conditions of the GSW model, on which our simulations are based.

2 Microfoundations of Unemployment

To better understand the logic behind our simulation design, and the embodied central assumption in it regarding the driving force of the simulated scenarios, it is worthwhile to begin with outlining the microfoundations of labor supply shocks and how they enter the utility function in the GSW model. The GSW model proposes a reformulation of the wage-setting block of the SW model. That is, in GSW labor is "indivisible" and all variation in hours worked occurs "on the extensive margin", so that people either work or are unemployed involuntarily, as in Galí (2011 a, b) and broadly consistent with features of the data. By contrast, in SW and most DSGE models labor is "divisible" and all variation in labor supply takes place in terms of hours worked, i.e., "on the intensive margin", as in the wage-setting block of the Erceg et al. (2000) model SW build upon. For the purposes of simulating the lockdown in terms of a fraction of the labor force that is unable to work during it, as we do later on here, the assumption of indivisible labor seems the better approach.

GSW note that their modified version differs from the original SW model in the following dimensions:

1. It reformulates the wage equation in terms of unemployment.

2. With respect to the data on which the estimation is based, GSW use employment rather than hours worked, and redefine the wage as the wage per worker rather than the wage per hour, consistent with their key labor market assumption. GSW also combine two alternative wage measures in the estimation, obtained via (i) employee compensation and (ii) average wage earnings, and model explicitly their discrepancy.

3. GSW generalize the utility function in a way that allows them to parameterize the strength of the short-run wealth effect on labor supply, as discussed in Jaimovich and Rebelo (2009), which results in a better fit of the joint behavior of employment and the labor force.

4. For simplicity, GSW revert to a Dixit-Stiglitz (1977) price and wage aggregator rather than the Kimball (1995) aggregator used in SW.

In this section, we highlight the novel features introduced by GSW, mostly with regard to the utility function and the labor market, and the resulting log-linearized equations.[4] All variables denoted by a "hat" are log-linearized around their respective steady-state values, denoted by a "star" subscript.

The key innovation relative to the huge New Keynesian DSGE literature in GSW involves the utility function. They assume that there is a (large) representative household

[4]The microfoundations of the other aspects of the full nonlinear model can be found in GSW and SW, whereas appendix A completes the list of log-linearized equilibrium conditions we then use in the simulation code (implemented in Dynare and MATLAB, and available upon request).

with a continuum of members represented by the unit square and indexed by a pair $(i, j) \in 0, 1] \times 0, 1]$. Individual utility then is of the following form,

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\ln \widetilde{C}_t(i,j) - 1_t(i,j) \chi_t \Theta_t j^{\varphi} \right], \tag{1}$$

where

$$\widetilde{C}_t(i,j) \equiv C_t(i,j) - h\overline{C}_{t-1}.$$

$\overline{C}_{t-1}$ denotes lagged *aggregate* (hence the "bar" notation) consumption (taken as given by each household) so that $h \in 0, 1]$ captures *external* habit in consumption, as is common in New Keynesian DSGE setups.

What is novel in the GSW model, though, relative to this literature is reflected in the second argument of the (additively separable period and intertemporal) utility function. In it, $1_t(i, j)$ is an indicator function specifying the microfoundations of unemployment: it takes a value equal to one if individual (i, j) is employed in period t, and zero otherwise. The first dimension of the unit square, $i \in 0, 1]$, that indexes the continuum of individuals in the representative household represents the type of labor service in which a given household member is specialized. The second dimension, indexed by $j \in 0, 1]$, determines her disutility from work, which is given by $\chi_t \Theta_t j^{\varphi}$ if she is employed and zero otherwise. $\chi_t > 0$ is an *exogenous* preference shifter we would refer to, following GSW, as a "labor supply shock": it plays the role of a single exogenous driving force in the design, coding and interpretation of our simulations. Θ_t is an *endogenous* preference shifter, to be defined further down, taken as given by each individual household, and $\varphi \geq 0$ is a parameter determining the shape of the distribution of work disutilities across individuals. Full risk sharing is assumed among households, as in Merz (1995), so that $C_t(i, j) = C_t$ for all $(i, j) \in 0, 1] \times \in 0, 1]$ and t. Then, GSW derive the household utility as the integral over the utility of the continuum of household members (assuming a special form with a log-consumption component and a complicated disutility-from-work component):

$$\begin{aligned} & \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t U_t \left(C_t, \{N_t(i)\} \right) \\ \equiv \quad & \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\ln \widetilde{C}_t - \chi_t \Theta_t \int_0^1 \int_0^{N_t(i)} j^{\varphi} dj di \right] \\ = \quad & \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\ln \widetilde{C}_t - \chi_t \Theta_t \int_0^1 \frac{N_t(i)^{1+\varphi}}{1+\varphi} di \right]. \end{aligned} \tag{2}$$

The term $\int_0^1 \int_0^{N_t(i)} j^{\varphi} dj di$ represents the disutility from work in period t for workers in all labor types i, where $N_t(i) \in 0, 1]$ denotes the employment rate in period t among workers specialized in type i labor. $\widetilde{C}_t = C_t - h\overline{C}_{t-1}$ while φ is, now more specifically, given the functional form in (2), also the inverse of the Frisch elasticity of intertemporal substitution in labor supply for those employed in period t.

As mentioned, GSW introduce χ_t as an exogenous preference shifter that affects the marginal disutility from work and refer to it as a "labor supply shock". They also introduce Θ_t as an endogenous preference shifter that affects as well the marginal disutility from work, taken as given by each household and defined by:

$$\Theta_t = \frac{Z_t}{\overline{C}_t - h\overline{C}_{t-1}}, \tag{3}$$

$$Z_t = Z_{t-1}^{1-\upsilon}\left(\overline{C}_t - h\overline{C}_{t-1}\right)^{\upsilon} \tag{4}$$

As GSW suggest, Z_t can be interpreted as a "smooth" trend for (quasi-differenced) aggregate consumption. The preference specification embodied in (3) and (4) implies a "consumption externality" on labor supply: during aggregate consumption booms (when $\overline{C}_t - h\overline{C}_{t-1}$ is above its trend value Z_t), it can be seen from (3) that individual (and representative household) marginal disutility from work declines (at any given level of employment) and labor supply in consequence increases.

GSW emphasize that the specification above generalizes the preferences assumed in SW by allowing for an exogenous labor supply shock χ_t as well as for an endogenous labor supply preference shifter Θ_t. This formal modeling of labor supply preferences plays an important role that implies a corresponding economic interpretation: it helps reconcile the existence of a long-run balanced growth path with an arbitrarily small short-term wealth effect. The importance of this wealth effect is determined by the parameter $\upsilon \in 0, 1]$. GSW argue that this model feature, which is related, but not identical, to the one proposed in Jaimovich and Rebelo (2009), is needed to match the joint behavior of the labor force, consumption and the wage (per worker) over the business cycle.

As in SW, being the ultimate owner of firms and the capital stock, the representative household chooses (real) consumption C_t, investment in physical capital I_t, financial wealth in the form of savings in one-period discount bonds B_t, and the degree of capital utilization v_t, now also choosing to enter or not the labor force (rather than how many hours to work), so as to maximize the specified objective function (2) subject to a sequence of period budget constraints written in real terms,

$$C_t + I_t + \frac{B_t}{\varepsilon_t^b R_t P_t} - T_t \leq \frac{B_{t-1}}{P_t} + \frac{W_t N_t}{P_t} + \frac{\Pi_t}{P_t} + \left(\frac{R_t^k v_t \overline{K}_{t-1}}{P_t} - a\left(v_t\right)\overline{K}_{t-1}\right), \tag{5}$$

and to a sequence of capital accumulation equations

$$K_t = (1-\delta)\,K_{t-1} + \varepsilon_t^i\left[1 - \Psi\left(\frac{I_t}{I_{t-1}}\right)\right] I_t. \tag{6}$$

The sources of real income in the right-hand side of (5) consist of four components: income from past-period savings $\frac{B_{t-1}}{P_t}$, labor income $\frac{W_t N_t}{P_t}$, dividends from the profits of firms distributed by the labor unions $\frac{\Pi_t}{P_t}$, and the return from renting the real capital stock $\frac{R_t^k v_t \overline{K}_{t-1}}{P_t}$ minus the cost associated with variations in the degree of capital utilization,

$a(v_t)\overline{K}_{t-1}$. T_t is net (lump-sum) transfers (taxes or subsidies) from the government. R_t is the gross nominal interest rate paid on the discount bonds and ε_t^b is an exogenous premium in the return to bonds that may capture – as SW suggest – inefficiencies in the financial sector generating a premium of the deposit rate over the risk free policy rate set by the central bank, or a risk premium that households require to hold the discount bond. This risk premium, as most of the exogenous stochastic processes in the SW and GSW models, is assumed to follow an AR(1) law of motion in natural logs, $\widehat{\varepsilon}_t^b \equiv \ln \varepsilon_t^b$, that is:

$$\widehat{\varepsilon}_t^b = \rho_b \widehat{\varepsilon}_{t-1}^b + \eta_t^b, \text{ with } \eta_t^b \sim \mathcal{N}(0, \sigma_b). \tag{7}$$

As is standard, in (6) δ is the rate of depreciation of the capital stock, $\Psi(\cdot)$ is the investment adjustment cost function, with $\Psi(\tau) = \Psi'(\tau) = 0$, where τ denotes the balanced (gross) trend growth rate of the economy, but $\Psi''(\cdot) > 0$. ε_t^i is a stochastic shock to the price of investment relative to consumption goods, and follows the same process in natural logs, $\widehat{\varepsilon}_t^i \equiv \ln \varepsilon_t^i$, as $\widehat{\varepsilon}_t^b$ in (7) but with superscripts and subscripts i replacing b.

Under the GSW preferences outlined above, the marginal rate of substitution, $MRS_t(i)$, between consumption and employment that is relevant to households for type i workers in period t is given by

$$\begin{aligned} MRS_t(i) &\equiv -\frac{U_{n(i),t}}{U_{c,t}} \\ &= \chi_t \Theta_t \widetilde{C}_t N_t(i)^{\varphi} \\ &= \chi_t Z_t N_t(i)^{\varphi}, \end{aligned}$$

where the last equality results in the symmetric equilibrium with $\overline{C}_t = C_t$. Next, by integrating over all labor types, GSW derive in log-linear approximation the average (log) marginal rate of substitution $mrs_t \equiv \int_0^1 mrs_t(i)\, di$ as

$$mrs_t = z_t + \varphi n_t + \xi_t, \tag{8}$$

where $n_t \equiv \int_0^1 n_t(i)\, di$ is (log) aggregate employment and $\xi_t \equiv \ln \chi_t$ is the log-labor supply shock process, the central exogenous forcing variable in our simulation design and implementation. GSW further assume that nominal wages are set by "unions" for each type of labor i, acting in an uncoordinated way. Their modeling follows Calvo (1983) and Erceg et al. (2000), and implies partial indexation of wages to past price inflation, in a way that parallels price-setting and price inflation indexation. Log-linearizing around a perfect foresight steady state the first-order condition associated with the wage-setting problem and the aggregate wage index and combining the resulting expressions, GSW derive the following equation for wage inflation, $\pi_t^w \equiv w_t - w_{t-1}$:

$$\pi_t^w = (1-\beta)\left[(1-\gamma_w)\pi_* + \tau\right] + \gamma_w \pi_{t-1}^p + \beta \mathbb{E}_t\left\{\pi_{t+1}^w - \gamma_w \pi_t^p\right\} - \frac{(1-\beta\theta_w)(1-\theta_w)}{\theta_w(1+\varepsilon_w\varphi)}\left(\mu_{w,t} - \mu_{w,t}^n\right), \tag{9}$$

where γ_w measures the degree of wage indexation to past price inflation, π_{t-1}^p, defined as $\pi_t^p \equiv p_t - p_{t-1}$, π_* is the steady-state (net) price inflation rate;[5] further, β is the time-discount factor applied by households, θ_w is the Calvo degree of wage stickiness, $\varepsilon_{w,t}$ is the period t elasticity of substitution across differentiated specialized labor types in a Dixit-Stiglitz (1977) aggregator, defining the (log) *natural* (optimal or desired) wage markup under monopolistic competition in labor markets (i.e., the wage markup that would result by optimal labor supply decisions of households in an economy with fully flexible prices and wages),

$$\mu_{w,t}^n \equiv \ln \mathcal{M}_{w,t}^n \equiv \ln \frac{\varepsilon_{w,t}}{\varepsilon_{w,t}-1} \tag{10}$$

and

$$\mu_{w,t} \equiv \ln \mathcal{M}_{w,t} \equiv \ln \frac{W_t}{P_t} - \ln MRS_t = (w_p - p_t) - mrs_t \tag{11}$$

is the (log) *average* wage markup in the economy (i.e., the log difference between the average real wage and the average marginal rate of substitution between consumption and employment in period t), with $\varepsilon_w \equiv \frac{\mathcal{M}_w}{\mathcal{M}_w - 1}$ and, equivalently, $\mathcal{M}_w \equiv \frac{\varepsilon_w}{\varepsilon_w - 1}$ being the steady-state constant (gross) wage markup. Equation (9) shows how changes in wage inflation above and beyond those resulting from indexation to past price inflation arise from deviations of the average wage markup from its natural level. The intuition GSW suggest is that these deviations put pressure on workers who currently set their wages to adjust them accordingly.

Unemployment is, next, introduced by GSW into the SW model in the following way. Using household welfare as a criterion and taking as given current labor market conditions, as summarized by the prevailing wage for her labor type, an individual specialized in type i and with disutility of work $\chi_t \Theta_t i^\varphi$ will find it optimal to participate in the labor market in period t if and only if

$$\frac{1}{\widetilde{C}_t}\frac{W_t(i)}{P_t} \geq \chi_t \Theta_t i^\varphi, \tag{12}$$

that is, she will stay in or enter the labor force only if the benefit for her, captured by the product of the marginal utility of consumption and the real wage for her type of labor i in (12), outweighs the utility cost. The above condition is, then, evaluated at the symmetric equilibrium as

$$\frac{W_t(i)}{P_t} = \chi_t Z_t L_t(i)^\varphi,$$

[5] GSW denote π_* as π^p in that equation, their eq. (3) on p. 335; and also use π^x in it instead of τ to denote the (gross) steady-state growth rate of productivity in the economy.

with the marginal supplier of type i labor denoted as $L_t(i)$. Taking logs and integrating,

$$w_t - p_t = z_t + \varphi l_t - n_t, \tag{13}$$

where $l_t \equiv \int_0^1 l_t(i)\, di$ can be interpreted, as GSW suggest, as the aggregate (log) participation rate or labor force. Following Galí (2011 a, b), the unemployment rate is defined in a standard way as

$$u_t \equiv l_t - n_t. \tag{14}$$

Equation (14) defines *involuntary* unemployment, since it includes individuals who would like to work, given the current labor market conditions as summarized by the real wage, but cannot find employment. Combining (11), (13) and (14), GSW also derive a simple link between the average wage markup in the economy and the unemployment rate, via the inverse of the Frisch elasticity of labor supply:

$$\mu_{w,t} = \varphi u_t. \tag{15}$$

Similarly,

$$\mu_{w,t}^n = \varphi u_t^n, \tag{16}$$

i.e., the natural rates of the average wage markup and the unemployment rate are proportional, via φ, too.

Further combining (9) and (15), GSW obtain an equation relating wage inflation to price inflation, the unemployment rate and the natural wage markup:

$$\begin{aligned} \pi_t^w \;=\; & (1-\beta)\left[(1-\gamma_w)\pi_* + \tau\right] + \gamma_w \pi_{t-1}^p + \beta \mathbb{E}_t\left\{\pi_{t+1}^w - \gamma_w \pi_t^p\right\} \\ & - \frac{(1-\beta\theta_w)(1-\theta_w)}{\theta_w(1+\varepsilon_w\varphi)}\varphi u_t - \frac{(1-\beta\theta_w)(1-\theta_w)}{\theta_w(1+\varepsilon_w\varphi)}\mu_{w,t}^n. \end{aligned} \tag{17}$$

Equation (17) derived in GSW[6] provides a key novelty and insight into the dynamics of wage inflation as related to the unemployment rate and the natural wage markup: differently from SW and related papers, the error term in (17) captures exclusively shocks to the natural wage markup, and not preference shocks (no matter that the latter have been considered in the GSW model). This novel feature in reformulating the wage inflation equation has enabled GSW, and then MRW, to use the unemployment rate as another observable in estimation. This has further allowed them to overcome the identification problem raised by Chari *et al.* (2009) in their criticism of New Keynesian models and to obtain better estimation results with this additional observable variable relative to SW.

[6]Again, GSW use a slightly different notation, replacing in their identical eq. (8), p. 336, π_* by π^p and τ by π^x.

3 Calibration and Simulation Assumptions

The log-linearized version of the GSW model presented in section 2 and appendix A is estimated with Bayesian techniques on quarterly data for the US (1966Q1–2007Q4) by GSW and for four major European Monetary Union (EMU) countries, namely, France, Germany, Italy and Spain (1999Q1–2017Q4), by MRW. For each country, the data set consists of eight key macroeconomic quarterly time series: the log difference of real GDP, the log difference of real consumption, the log difference of real investment, the log difference of the GDP deflator (i.e., a measure for price inflation), the Federal funds rate (GSW/US) or the ECB interest rate on lending facilities (MRW/EMU) as a measure for the central bank policy rate, log employment (relative to a base quarter), the unemployment rate (defined in the standard way, as difference between the labor force and those employed), and the log difference of the real wage rate (i.e., a measure for wage inflation).[7] We calibrate the structural parameters in the simulated versions of the GSW model described further below exactly to the values of the respective estimates (see Table 2 for the assumed priors per parameter, its notation and interpretation, and Table 3 for the obtained estimates by GSW for the US and by MRW for the four EMU economies, which we use in our calibration).

[Tables 2 and 3 about here]

3.1 Calibration Consistent with Estimated Parameter Posteriors

Our calibration and simulation requires a bold choice of a few (related) implementation assumptions, explicit below, which we acknowledge as a cause of potential imprecision. Yet such "shortcuts", translating a model into a code with appropriate interpretation, are inevitable in any similar exercise of simulating an unprecedented event, the more so in an emergency situation with lack of precise data and vision of what could possibly happen, and how fast and deep.

3.2 Simulation Design and Implementation

Our simulations are performed starting from the same source of disruption in the economy, identified as a huge adverse labor supply shock in the GSW log-linearized model, $\widehat{\varepsilon}_t^{\chi}$ in equation (26) in appendix A. More precisely, this shock increases tremendously the weight of the disutility from work in the felicity function of the representative agent, χ_t in equation (2) before the log-linearization. In reality, the supply of labor was forced to stay at home – and work from home (in so far as this was possible for some professions, but

[7] The aggregate real variables (real GDP, real consumption, real investment and employment) are expressed per capita by dividing with the population over 15. MRW use only one of the two measures of the real wage rate in GSW, namely the total compensation of employees that is available for the EMU countries on a comparable basis (as GSW note, their results using two real wage measures as observables do not differ much if they use just the measure MRW use too). A more detailed description of the data, with definitions and transformations, is given in GSW and MRW, respectively.

not for other) – by the lockdown measures to contain drastically the exponential spread of the COVID-19 pandemic and, in particular, save capacity in the hospitals for those people with the worst condition.

Our simulation design consists of two steps, the first assuming and coding a temporary shock, the second assuming and coding a permanent shock, each with some scenarios of variation. In the first step, we assume that, when the shock is temporary, implying a return to the initial steady state (SS) of the disutility from work, the shock equals either 100 standard deviations (SD), implying 1.2 times higher disutility from work (e.g., due to risk of contagion and death in the current COVID-19 lockdown context) and chosen to match a resulting 1/4 drop in the labor force (i.e., our most optimistic version of the ability to work from home or on the workplace for the remaining 3/4 of the labor force, given the varied practices across countries in the world nowadays) and providing what we refer to as the "lower bound of the temporary macroeconomic loss" from it; or 300 SD (3.5 times higher disutility to work chosen to match a resulting 3/4 drop in the labor force), providing the "upper bound of the temporary macroeconomic loss"; the SD is measured by the estimated posterior mean of the SD of the innovation in the labor supply shock in the US sample of GSW ($\sigma_{ls} = 1.17\%$, see Table 3). For each of these "bounds of the temporary macroeconomic loss", lower and upper, we then simulate 3 scenarios, labeled as: (i) "optimistic", defined by 1 quarter assumed duration of the lockdown; (ii) "baseline", 2 quarters of duration; and (iii) "pessimistic", 3 quarters of duration. Our "benchmark" simulation is for the US economy, with the parameter values calibrated according to the GSW estimates. We then also compare to the US benchmark analogous simulation scenarios for the largest European Union (EU) economies, and at the same time the most affected European countries by the COVID-19 pandemic, France, Germany, Italy and Spain, with the respective model parameters now calibrated according to our own estimates for each of these EU countries in MRW.

In the second step of our simulations we assume that the shock is permanent, theoretically and in the code. Implicitly, and linking the modeling shortcut and interpretation with the actual developments worldwide, we incorporate in this worse possible scenario a plausible death rate of the labor force; it is assumed to correspond roughly to the reported range in the literature and at present: from the still unrealistic/unsaturated minimum of the current death rate of about 5.4% of the infected worldwide and 0.01% of the world population;[8] to the unlikely/perhaps maximum (given the worldwide containment measures and the higher efficiency nowadays of public health capacity, equipment and policy) of 0.66% loss of the US population[9] and 2% loss of the world population[10] due to the Spanish flu pandemic a century ago. Yet, this technically "permanent" shock in the simulation code (implying, in reality, significant deaths in the labor force) will, more

[8]Own estimate (as noted in the Introduction) based on the COVID-19 database of the Johns Hopkins University, available online (with latest data update of April 5, 2020, taken in the calculation, and accessed on April 10, 2020).

[9]Estimate in Correia *et al.* (2020).

[10]Estimate in Barro *et al.* (2020), as we also noted in the Introduction.

precisely, correspond in actual economies to a shock with long(er)-lasting duration and consequences. Such a shock could be otherwise also called "highly persistent", but in our case this will be not true to the coding, since we have set the persistence of the shock to zero (at the opposite extreme of the assumed value of 0.999 in GSW), a first difference from the underlying estimated GSW model; the second difference from GSW is that for the US benchmark as well as the compared four EU economies we use the model/code structure as in our own estimation in MRW, where the model is slightly simplified.[11] This radical change, from 0.999 to 0, in the persistence of the labor supply shock we simulate is justified by the nature of the implications we study quantitatively. While in normal times, as in GSW, the labor supply shock could well be highly persistent, the type of the forced labor supply shock during the COVID-19 lockdown is quite different. Literally "overnight" the labor supply was forced to shrink. There is no reason to assume that once the lockdown is over, even if gradually for certain sectors or jobs, those people who are allowed to go back to work will not do it "overnight" again. On both accounts, imposing and releasing the forced lockdown, assuming a (near-)zero persistence of this huge novel type of labor supply shock appears, therefore, justified in performing our simulations.

3.3 Strengths and Weaknesses of Our Simulation Approach

We are, of course, aware that some of our central assumptions in the simulations (as was discussed above) are critical to our reported results. Moreover, these critical assumptions are to some extent imprecise, and depend on many potential future developments of economic and noneconomic nature one could hardly predict and take into account into a more structured and detailed version of our simulations. On the other hand, there is the urgent need right now to provide some orientation and guidance to policymakers of what could (plausibly) happen. Understanding this tradeoff, we agree that our simulation approach and design may suffer from some drawbacks, yet it does carry much realism and quantitative general equilibrium usefulness too, we would hope.

We here list explicitly, but perhaps not exhaustively, the key benefits and weaknesses of our simulation design, and hence of the reported results, according to our own perception and assessment; such pros and cons will be true, of course, for any other simulation approach: more complicated, staged and detailed (with the risk of getting some details totally wrong); or more parsimonious (with the risk of being perhaps too simplistic a shortcut); and we have been observing many such alternative forecasts in the emerging literature and the numerous webinars on the topic being held weekly across the world since late March 2020.

[11] To 8 observables and shocks, as in MRW, rather than 9 observables and shocks, as in GSW – which we briefly mentioned in an earlier footnote; for more details, see MRW.

3.3.1 Key Advantages

1. GSW is the only model that separates analytically labor supply shocks from wage markup shocks, and so is appropriate to quantify, based on identified Bayesian estimates for the calibrated parameters in our simulations, the COVID-19 lockdown, here modeled as a huge adverse labor supply shock (by its origin, although it also immediately induces a consumption and aggregate demand shock).

2. GSW incorporates general equilibrium effects in a rich, "workhorse" medium-scale New Keynesian DSGE model with indivisible labor, as seems more appropriate when simulating the forced economic inactivity during the lockdown.

3. As mentioned in 1. just above, but let us emphasize it now separately, estimated posterior means of the parameters are used for the calibration in the simulation exercise.

4. Our simulation approach constitutes a rich model-based, and hopefully plausible, account and prediction of what can be expected, given some baseline assumptions regarding the key unknowns (magnitude of the forced work inactivity and duration of the lockdown, in particular).

5. It informs policymakers in (almost) real time and in a complementary way to the currently emerging early models and forecasts of the macroeconomic effects of the COVID-19 pandemic.

3.3.2 Key Limitations

1. GSW assumes rational expectations: nonrational expectations, including fears or panic in the population, will very likely worsen our scenarios.

2. Modeling explicitly the pandemic spread, via a SIR-addition, as in ERT (2020), to the GSW model we employed will very likely result in more accurate simulations.

3. A better adjusted/updated calibration – however, nearly impossible ex ante and in real time – of the magnitude of the lockdown (modeled as labor supply, here) shock and its duration will improve the realism of our scenarios.

4. The quarterly frequency of the GSW model and its estimates for the US in GSW and for France, Germany, Italy and Spain in MRW may not be quite suitable for simulating high(er)-frequency developments, very relevant to the spread of the COVID-19 pandemic: indeed, the macro-SIR model in ERT assumes a week as the relevant time period in dynamics.

4 Simulation Results

4.1 Temporary Labor Supply Shock

4.1.1 "Lower Bound of Temporary Loss"

US Benchmark: Simulations in 3 Scenarios Figure 1 and the top panel of Table 1 document our simulation results denoted as "lower bound of the temporary macroeconomic loss" from the COVID-19 pandemic for the US benchmark, first without assuming considerable death rate of the labor force, i.e., a huge but temporary adverse labor supply shock, in 3 scenarios: (i) optimistic (1 quarter duration of the lockdown, blue simulation curve); (ii) baseline (2 quarters of lockdown, red simulation curve); and (iii) pessimistic (3 quarters of lockdown, dark yellow simulation curve).

[Figure 1 and Table 1 about here]

As can be seen in the respective panels of the figure, the mildest scenario (blue simulation curves) implies, on impact, unemployment rate higher (yes, the interpretation of the plunge on the relevant panel should be in the opposite direction, since the shock is modeled in GSW as people going out of the labor force, see the adjacent panel, which in the present context of the simulation is equivalent to becoming involuntarily unemployed, with a correction for those who can work from home)[12] by 25 percentage points (p.p.) from trend, and natural output (i.e., the notional and latent flexible-price output in the New Keynesian modeling sense) lower by about 30 p.p. from trend. Assuming that the central bank follows its generalized Taylor rule, eq. (34) in appendix A, as in GSW – another potential weakness of this model, as in such conditions in the real world we have seen central banks to react, at least initially, in the opposite way – a contractionary monetary policy in terms of a rise in the policy rate by above 6 p.p. from trend and a corresponding contraction of the money supply (not illustrated in the figure) to match (but less than one-to-one) the plunge in natural output, Figure 1 depicts a rise in inflation (expectations) of about 0.5 p.p. above trend and a resulting huge positive output gap commensurate with the plunge of the labor force participation rate (LFPR, equivalent in our interpretation with a nearly identical rise in forced unemployment or inability to work from home, as mentioned). Furthermore, consumption (per capita) drops by about 1.5 p.p. below trend in the impact quarter, but recovers by the end of the first year, and then stabilizes at trend after a marginal "booming" in the third year. Investment (per capita) follows a somewhat more favorable dynamics, and output (per capita) averages out the dynamics of these two main components of aggregate demand (per capita). As experience shows with earlier pandemics (e.g., after the Spanish flu in 1918-1920), the

[12] It is important to note here that the plunge in the labor force participation rate (LFPR, originating in the adverse labor supply shock that causes a spike in the disutility from work, according to the propagation mechanism of the model and code) is equivalent in the interpretation of the simulated dynamics to a spike, not plunge (as depicted) in involuntary unemployment, because people actually are unable to work during the lockdown rather than having exited the labor force (as depicted).

wage rate tends to increase (also consistent with long-run findings over centuries of history of pandemics in Jordà *et al.*, 2020), on impact by about 2.5 p.p. (per worker) above trend in our most optimistic (blue curve temporary labor supply shock) simulation, and then goes back to trend in about 3 years.

The baseline (red curve) magnifies and prolongs the outlined effects on (per-capita) consumption, investment and output, and on inflation and wages by about 2 times, without much difference on the plunge in natural output and the LFPR, as a proxy for forced or partial unemployment during the lockdown. The pessimistic (dark yellow curve) scenario further exacerbates the simulated path of the US macroeconomy: (per-capita) consumption drops to 20 p.p. in annualized terms below trend in the impact quarter and does not fully recover until 4-5 years later, with even more losses of (per-capita) investment and output before recovery to trend, about the same time with consumption.

Comparative Simulations in Our Baseline Scenario: 4 EMU Countries against the US Figure 2 now compares our baseline simulation (red curves in the preceding section) for the US benchmark with analogous ones, where – for comparability – the same common global shock of the size assumed in the US simulations is used, for four EMU economies, namely the largest EMU economies and the most affected EMU countries by the COVID-19 disease. As one can see in the last two bottom-right panels, the same (global) magnitude of the huge adverse shock on the (weight of the) disutility from work in the felicity function we use as a modeling shortcut of the forced plunge in labor supply during the lockdown in response to the COVID-19 pandemic results in a much stronger contraction of the LFPR in Italy than in the other three countries, which may reflect some exposure of Italy to a more vulnerable economic structure (notably, tourism) than the other countries picked up by the calibration of the parameters at their estimated posterior means in MRW. Yet, France and Germany tend to experience very similar simulation profiles, with a higher amplitude of the fluctuations of output, investment and consumption for 5-10 years before returning to trend; Italy and Spain look similar with each other too in the simulated dynamics, but not as much as France and Germany. The US economy is different from the EMU ones in almost all panels, featuring the mildest loss of output and employment but at the cost of higher inflation and policy rate, which may well reflect the dual mandate of the Fed versus the inflation priority of the ECB.

[Figure 2 about here]

All in all, we believe that the value of these (highly uncertain) simulations (due to the enormous ambiguity of what has been happening in March and April of 2020 across the world, and especially to what is going to happen by the end of the year) is to capture some typical and common patterns, rather than details and tiny differences across countries. In this sense, the five country simulation curves in our baseline scenario for the "lower bound of the temporary macroeconomic loss" in Figure 2 may be viewed as some sort of robustness exercise too.

4.1.2 "Upper Bound of Temporary Loss"

US Benchmark: Simulations in 3 Scenarios This next set of simulations differs from the previous "lower bound" one by only increasing the size of the shock 3 times, from 100 SD to 300 SD, intended to match a (perhaps) more realistic scenario of about 3/4 of the labor force unable to perform its usual work tasks from home, i.e., during the COVID-19 lockdown (consistent with the estimates in Dingel and Neiman, 2020, we referred to earlier): in this sense it is considered as an "upper bound" of the potential macroeconomic losses, still under a temporary labor supply shock assumption (implicitly not accounting for a significant death rate in the labor force). Figure 3 and the middle panel of Table 1 present the simulation results.

[Figure 3 about here]

A quick comparison of the respective columns and rows in this middle panel in the table with its top panel makes clear the gravity of these three "upper-bound temporary loss" scenarios: as the numbers in the table and the curves in the panels of the figure indicate, we are now in dire conditions for the world economy over a 10-15 year period, with losses of per-capita output, consumption and investment that are several times higher than the mild initial set of scenarios. More precisely, the loss of cumulative per-capita output during the 4 quarters of the first year in the baseline (red curves) scenario of 2 quarters of lockdown duration is about 14-15%, compared to 5-6% in the same scenario under the "lower-bound temporary loss" assumption in the preceding subsection.

4.2 Permanent Labor Supply Shock

US Benchmark: Simulations in 3 Scenarios Finally, Figure 4 and the bottom panel of Table 1 report our simulation findings for the case of a (nearly) permanent, i.e., long-lasting labor supply shock, coded as a transition to a new, even if minimally different, trend (or SS): of the disutility from work (higher permanently up to 6%) and, hence, of the LFPR (down permanently up to 1%).

[Figure 4 about here]

The difference in the simulations now is that the labor supply shock is modeled as permanent, or more realistically, highly persistent (and not temporary, as in the preceding section), to account for potential significant losses of the labor force due to mass deaths. Mass deaths may well mean less than 1% of the labor force, i.e., twice lower than during the Spanish flu. We calibrate this final simulation set in 3 scenarios, again: (i) optimistic (blue curve), where the size of the permanent labor supply shock is 1 US SD, the new SS of the disutility from work is a little bit above 1 p.p. from the initial SS, and that of the LFPR is a bit less than 0.3 p.p. below the initial SS; (ii) baseline (red curve), where the corresponding assumptions are 3 US SD, about 3.5 p.p. above SS for the disutility from work, and about 0.6 p.p. below SS for the LFPR; and (iii) pessimistic (dark yellow curve), where the analogous assumptions are still less favorable, respectively: 5 US SD, nearly 6 p.p. higher disutility from labor, and about 1 p.p. lower LFPR in the terminal SS.

What is a crucial difference with respect to the simulations in the preceding subsection and figures is that now, in Figure 4, (per-capita) consumption, investment and output are permanently lower than the initial SS (which is depicted in the respective panels for 15 years, the horizon of the simulation). The losses of consumption, investment and output are now far more significant and long-run, as quantified in the bottom panel of Table 1.

5 Concluding Remarks

Using the theoretical framework of the GSW medium-scale DSGE model, this paper simulated 3 scenarios regarding the duration of the lockdown (1, 2 or 3 quarters) and 2 types of exceptionally rare adverse labor supply shocks, a temporary one without significant loss in the labor force due to mass deaths or a permanent/persistent one, with deaths and slow birth recovery of the labor force. The temporary labor supply shock simulations delimited the "bounds" of the plausible macroeconomic loss dynamics: a lower bound, designed to match about 1/4 of the labor force unable to work (for each respective scenario regarding the duration of the lockdown), and an upper bound, intended to match about 3/4 of the labor force made economically inactive, broadly consistent with estimates regarding the fraction of jobs that can be performed from home in Dingel and Neiman (2020). The permanent labor supply shock was designed to match, in the same 3 scenarios for the lockdown duration again, up to 1% loss of the labor force due to mortality, consistent with a minimum at the current COVID-19 death rate of 0.01% (1 basis point) of world population according to the Johns Hopkins University statistics online, and the Spanish flu 2% death rate (according to Barro *et al.*, 2020) as a maximum. Estimated calibrations for 5 major and most affected by COVID-19 countries were presented and discussed: the US (as benchmark), France, Germany, Italy and Spain (for comparative and robustness purposes).

Our main contribution consists in quantifying in a broad, plausible range the likely macroeconomic consequences of the COVID-19 pandemic. The simulations suggest that even in the most optimistic scenario of a brief (lasting for 1 quarter) and mild (with 1/4 of the labor force unable to work) lockdown, the loss of per-capita consumption (6-7% in annualized terms down from the long-run trend in the impact quarter) and per-capita output (3-4% down) will be quite damaging, but recoverable relatively quickly, in 1-2 years. In the most pessimistic simulated scenario of temporary loss the effects will be 10-15 times more devastating, and the loss of output and consumption will persist beyond 10-15 years. The simulated worst-case scenarios of a permanent labor supply shock indicate a permanent loss of up to 1.5 percentage points of per-capita consumption and output.

We admit explicitly here that one has to be humble with any such attempt to look into the near future, as huge ambiguity is hanging all around, including when attempt is made for simulations through the lens of a benchmark New Keynesian DSGE model, as it has not been specially designed for the purpose. We acknowledged all simplifying assumptions and modeling shortcuts, as well as the likely need for novel models for the daunting task at hand, namely examining the interactions between the pandemic and the response to it by both health and macroeconomic policies. Given the urgency of the pressure to policymakers, with citizens locked down at home, to provide some idea of what might happen under the most likely (even if imperfect and not fully informed or updated) scenarios, and to act quickly, responsibly and efficiently, we took the (professional/qualified/prudent) risk of performing – and making public – the reported simulations. While these are certainly not precise, or better than other forecasts, they have their advantages and limitations, as we stated openly and clearly. It is essential that more such work becomes available before crucial decisions are taken by policymakers under the emergency the world has suddenly found itself in nowadays.

Of course, we intend to delve deeper into the integration of epidemiological SIR models into New Keynesian models with heterogeneous agents, incomplete markets, bounded rationality and other "bells and whistles", to gain realism and perhaps more precision. But that will require time, and the pressure of the moment urged for simulations and predictions, employing various approaches and methods; and, here with this paper, the advantage of our approach was microfounded general equilibrium, in a quite rich medium-scale DSGE model with optimal indivisible labor choices. Further, such models could also incorporate behavioral issues, e.g., how agents' perceptions, uncertainty, fear affect economic decisions, policies and institutions. Comparison to other pandemics and their (macro)economic implications and how policymakers cope with such situations, including issues of "rescue of last resort" by the central bank and the implied monetization of government deficits and issue of emergency public debt (e.g., bonds with maturity of 50 or 100 years, possibly with return just compensating for inflation) are also intended as avenues of future research.

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Appendix

A Estimated Log-Linearized Model

The remaining equations that complete the description of the log-linearized equilibrium conditions in the GSW model are presented next, in a denser summary. As GSW point out, they are identical to the respective equations in the SW model but now specialized to logarithmic consumption utility.

For households, and as standard, the dynamics of consumption is given by (a model-consistent variant of) the consumption Euler equation

$$\widehat{c}_t = \frac{\frac{h}{\tau}}{1+\frac{h}{\tau}}\widehat{c}_{t-1} + \frac{1}{1+\frac{h}{\tau}}\mathbb{E}_t\left\{\widehat{c}_{t+1}\right\} - \frac{1-\frac{h}{\tau}}{1+\frac{h}{\tau}}\left(\widehat{r}_t - \mathbb{E}_t\left\{\widehat{\pi}_{t+1}\right\} + \widehat{\varepsilon}_t^b\right). \tag{18}$$

Current consumption $\widehat{c}_t$ depends on a weighted average of past and expected future consumption and on the ex-ante real interest rate $\widehat{r}_t - \mathbb{E}_t\left\{\widehat{\pi}_{t+1}\right\}$, as well as on an exogenous stochastic process interpreted as risk premium shock, $\widehat{\varepsilon}_t^b \equiv \ln \varepsilon_t^b$. As is common in the DSGE literature, and as was mentioned, the parameter h captures external habit in consumption and is incorporated in order to improve model fit, while τ denotes the trend (gross) growth rate of the economy (as well as of labor-augmenting technological progress in production). The risk premium drives a wedge between the interest rate controlled by the central bank and the return on assets held by the households. A positive shock to this wedge increases the required return on assets and reduces current consumption. At the same time, it also increases the cost of capital and reduces the value of capital and investment. As is standard, this risk premium shock is assumed to follow an AR(1) process with an IID-Normal innovation term – see eq. (7).

The dynamics of investment is given by (a variant of) the investment Euler equation

$$\widehat{i}_t = \frac{1}{1+\beta}\widehat{i}_{t-1} + \frac{\beta}{1+\beta}\mathbb{E}_t\left\{\widehat{i}_{t+1}\right\} + \frac{1}{1+\beta}\frac{1}{\tau^2\Psi}\widehat{q}_t + \widehat{\varepsilon}_t^q, \tag{19}$$

where β is the time discount factor used by households and Ψ is the elasticity of the capital adjustment cost function. As in Christiano *et al.* (2005), a higher elasticity of the cost of adjusting capital reduces the sensitivity of investment $\widehat{i}_t$ to the real value of the existing capital stock $\widehat{q}_t$. $\widehat{\varepsilon}_t^q$ is the exogenous stochastic process for investment-specific technology assumed to follow an AR(1) process with an IID-Normal innovation: $\widehat{\varepsilon}_t^q = \rho_q \widehat{\varepsilon}_{t-1}^q + \eta_t^q$.

The corresponding arbitrage equation for the value of capital is given by:

$$\widehat{q}_t = \left[1 - \frac{r^k}{r^k + (1-\delta)}\right]\mathbb{E}_t\left\{\widehat{q}_{t+1}\right\} + \frac{r^k}{r^k+(1-\delta)}\mathbb{E}_t\left\{\widehat{r}_{t+1}^k\right\} - \left(\widehat{r}_t - \mathbb{E}_t\left\{\widehat{\pi}_{t+1}\right\} + \widehat{\varepsilon}_t^b\right). \tag{20}$$

The current value of the capital stock $\widehat{q}_t$ depends positively on its expected future value and the expected real rental rate on capital $\mathbb{E}_t\left\{\widehat{r}_{t+1}^k\right\}$, and negatively on the ex-ante real interest rate and the risk premium shock.

Goods market clearing implies

$$\widehat{y}_t = \frac{c_*}{y_*}\widehat{c}_t + \frac{i_*}{y_*}\widehat{i}_t + \frac{r^k_* k_*}{y_*}\widehat{v}_t + \widehat{\varepsilon}^g_t = \mathcal{M}_p\left[\alpha\widehat{k}_t + (1-\alpha)\,\widehat{n}_t + \widehat{\varepsilon}^a_t\right]. \tag{21}$$

Output is produced using capital services $\widehat{k}_t$ and labor services, employment $\widehat{n}_t$. Disturbances in neutral technology, or total factor productivity (TFP), are captured by the stochastic process $\widehat{\varepsilon}^a_t = \rho_a\widehat{\varepsilon}^a_{t-1} + \eta^a_t$, which follows an AR(1) law of motion with an IID-Normal innovation term η^a_t. $\mathcal{M}_p$ denotes the degree of returns to scale, GSW assume it to correspond to the price markup in steady state. The term $\frac{r^k_* k_*}{y_*}\widehat{v}_t$ measures the cost associated with variable capital utilization, where r^k_* is the steady-state rental rate of capital and $\widehat{v}_t$ is the capital utilization rate. Following GSW, we assume that $\widehat{\varepsilon}^g_t$ captures not only government expenditure, but rather all exogenous components of aggregate demand and follows an AR(1) process with an IID-Normal error term also affected by TFP shocks: $\widehat{\varepsilon}^g_t = \rho_g\widehat{\varepsilon}^g_{t-1} + \eta^g_t + \rho_{ga}\eta^a_t$. As GSW note, the latter is empirically motivated by the fact that, in estimation, exogenous spending also includes net exports, which may be affected by domestic productivity developments. In this sense, the GSW model is not a closed-economy New Keynesian DSGE model in a strict sense, but indeed captures an open-economy channel through the exogenous component of exports and imports of goods and services.

Price-setting under the Calvo (1983) model with indexation to past inflation results in the following New Keynesian Phillips Curve (NKPC) for price inflation:

$$\widehat{\pi}^p_t - \gamma_p\widehat{\pi}^p_{t-1} = \beta\mathbb{E}_t\left\{\widehat{\pi}^p_{t+1} - \gamma_p\widehat{\pi}^p_t\right\} - \tfrac{(1-\beta\theta_p)(1-\theta_p)}{\theta_p(\mathcal{M}_p-1)\varepsilon_p}\left(\widehat{\mu}_{p,t} - \widehat{\mu}^n_{p,t}\right), \tag{22}$$

where ε_p (analogous to ε_w) measures the curvature of the Dixit-Stiglitz (1977) price aggregator, and the other variables and parameters parallel those in the analogous wage inflation equation (9) introduced earlier.

The average and natural price markups are, respectively,

$$\widehat{\mu}_{p,t} = -(1-\alpha)\,\widehat{\omega}_t - \alpha\widehat{r}^k_t + \widehat{\varepsilon}^a_t, \tag{23}$$

where $\omega_t \equiv w_t - p_t$ defines the (log) real wage, and

$$\widehat{\mu}^n_{p,t} = 100 \times \widehat{\varepsilon}^p_t. \tag{24}$$

Wage-setting under the Calvo model with indexation to past price inflation, as already discussed in more detail in the main text, results in the following NKPC for wage inflation, now written in deviations from steady-state values (with "hats"):

$$\widehat{\pi}^w_t - \gamma_w\widehat{\pi}^p_{t-1} = \beta\mathbb{E}_t\left\{\widehat{\pi}^w_{t+1}\right\} - \tfrac{(1-\beta\theta_w)(1-\theta_w)}{\theta_w(1+\varepsilon_w\varphi)}\left(\widehat{\mu}_{w,t} - \widehat{\mu}^n_{w,t}\right). \tag{25}$$

The average and natural wage markups and the natural rate of unemployment are, respectively,

$$\widehat{\mu}_{w,t} = \widehat{\omega}_t - \left(\widehat{z}_t + \widehat{\varepsilon}_t^{\chi} + \varphi \widehat{n}_t\right), \tag{26}$$

and

$$\widehat{\mu}_{w,t}^n = 100 \times \widehat{\varepsilon}_t^w \tag{27}$$
$$= \varphi \widehat{u}_t^n, \tag{28}$$

where

$$\widehat{z}_t = (1-\upsilon)\,\widehat{z}_{t-1} + \upsilon \left[\frac{1}{1-\frac{h}{\gamma}} \widehat{c}_t - \frac{\frac{h}{\gamma}}{1-\frac{h}{\gamma}} \widehat{c}_{t-1} \right]. \tag{29}$$

Capital accumulation evolves according to

$$\widehat{\overline{k}}_t = \left(1 - \frac{i_*}{\overline{k}_*}\right) \widehat{\overline{k}}_{t-1} + \frac{i_*}{\overline{k}_*} \widehat{i}_t + \frac{i_*}{\overline{k}_*} (1+\beta)\, \tau^2 \Psi \widehat{\varepsilon}_t^q, \tag{30}$$

and capital services used in production are defined as

$$\widehat{k}_t = \widehat{v}_t + \widehat{\overline{k}}_{t-1}. \tag{31}$$

The optimal capital utilization condition reads,

$$\widehat{v}_t = \frac{1-\psi}{\psi} \widehat{r}_t^k, \tag{32}$$

where ψ is the elasticity of capital utilization cost function with respect to capital inputs. The optimal input choice is given by

$$\widehat{k}_t = \widehat{\omega}_t - \widehat{r}_t^k + \widehat{n}_t. \tag{33}$$

Finally, the monetary authority follows an empirically motivated generalized Taylor rule in setting the short-term (gross) nominal interest rate $\widehat{r}_t$ (in log-deviation from the (gross) steady-state nominal interest rate) in response to the lagged interest rate, current price inflation, and the current level and change in the output gap; in addition to this systematic component of monetary policy, an exogenous stochastic shock capturing monetary policy "surprises" is assumed to follow an AR(1) process with an IID-Normal innovation, $\widehat{\varepsilon}_t^r = \rho_r \widehat{\varepsilon}_{t-1}^r + \eta_t^r$:

$$\widehat{r}_t = \rho_r \widehat{r}_{t-1} + \left(1-\rho_r\right)\left[r_\pi \widehat{\pi}_t^p + r_y\left(\widehat{y}_t - \widehat{y}_t^n\right)\right] + r_{\Delta y}\left[\left(\widehat{y}_t - \widehat{y}_t^n\right) - \left(\widehat{y}_{t-1} - \widehat{y}_{t-1}^n\right)\right] + \widehat{\varepsilon}_t^r. \tag{34}$$

ρ_r captures the degree of interest rate smoothing, and r_π, r_y and $r_{\Delta y}$ capture the policy feedback to, respectively, price inflation $\widehat{\pi}_t^p$, the output gap, $\widehat{y}_t - \widehat{y}_t^n$, and the change in the output gap, $\left(\widehat{y}_t - \widehat{y}_t^n\right) - \left(\widehat{y}_{t-1} - \widehat{y}_{t-1}^n\right)$.

US, Temporary Shock	output			consumption			investment			inflation		
Quarters ↓												
LB Loss Scenarios ⟶	1Q	2Q	3Q	1Q	2Q	3Q	1Q	2Q	3Q	1Q	2Q	3Q
1	-0.84	-1.93	-3.14	-1.37	-2.68	-3.86	-0.36	-2.08	-4.71	0.34	0.74	1.10
2	-0.05	-1.90	-4.03	-0.44	-2.89	-5.13	0.66	-1.56	-5.78	0.45	0.97	1.47
3	0.31	-0.68	-3.44	0.02	-1.35	-4.46	1.11	-0.17	-4.73	0.43	0.90	1.41
4	0.43	-0.13	-1.92	0.20	-0.58	-2.58	1.21	-0.58	-3.02	0.37	0.74	1.12
5	0.42	0.07	-1.17	0.24	-0.24	-1.55	1.13	0.40	-2.21	0.30	0.56	0.82
6	0.35	0.10	-0.83	0.21	-0.12	-1.04	0.97	0.53	-1.85	0.23	0.40	0.55
7	0.27	0.05	-0.69	0.16	-0.10	-0.79	0.77	0.44	-1.69	0.17	0.27	0.34
8	0.19	-0.01	-0.62	0.11	-0.11	-0.66	0.58	0.27	-1.59	0.12	0.18	0.19
9	0.12	-0.07	-0.58	0.07	-0.14	-0.58	0.41	0.09	-1.49	0.08	0.11	0.09
10	0.07	-0.11	-0.58	0.03	-0.15	-0.53	0.27	-0.05	-1.37	0.06	0.06	0.02
11	0.03	-0.13	-0.53	0.01	-0.15	-0.48	0.16	-0.15	-1.21	-0.04	0.03	-0.02
12	0.01	-0.13	-0.48	-0.00	-0.15	-0.53	0.08	-0.21	-1.03	-0.02	0.01	-0.04
UB Loss Scenarios	1Q	2Q	3Q	1Q	2Q	3Q	1Q	2Q	3Q	1Q	2Q	3Q
1	-2.52	-5.79	-9.41	-4.11	-8.04	-11.59	-1.07	-6.25	-14.12	1.08	2.23	3.31
2	-0.17	-5.69	-12.08	-1.31	-8.66	-15.39	1.98	-4.68	-17.33	1.35	2.91	4.42
3	0.92	-2.05	-10.3	0.04	-4.04	-13.68	3.31	-0.50	-14.18	1.29	2.71	4.23
4	1.28	-0.38	-5.76	0.60	-1.74	-7.74	3.63	1.20	-9.06	1.10	2.21	3.39
5	1.26	0.22	-3.52	0.73	-0.72	-4.65	3.40	1.58	-6.63	0.89	1.67	2.46
6	1.07	0.29	-2.50	0.64	-0.36	-3.12	2.90	1.31	-5.56	0.68	1.20	1.65
7	0.82	0.15	-2.06	0.49	-0.30	-2.37	2.32	0.80	-5.08	0.51	0.82	1.02
8	0.58	-0.04	-1.87	0.33	-0.34	-1.99	1.75	0.28	-4.78	0.37	0.53	0.57
9	0.37	-0.20	-1.74	0.20	-0.41	-1.77	1.24	-0.15	-4.48	0.25	0.32	0.26
10	0.21	-0.32	-1.61	0.10	-0.45	-1.60	0.82	-0.46	-4.10	0.17	0.17	0.06
11	0.09	-0.39	-1.45	0.03	-0.46	-1.44	0.50	-0.64	-3.63	0.11	0.08	-0.06
12	0.02	-0.40	-1.27	-0.00	-0.44	-1.29	0.25	-0.72	-3.09	0.07	0.02	-0.12
US, Permanent Shock	1SD	3SD	5SD	1SD	3SD	5SD	1SD	3SD	5SD	1SD	2SD	3SD
1	-0.10	-0.30	-0.51	-0.12	-0.36	-0.61	-0.11	-0.34	-0.57	0.01	0.02	0.04
2	-0.17	-0.50	-0.84	-0.20	-0.59	-1.00	-0.19	-0.58	-0.97	0.01	0.03	0.05
3	-0.21	-0.64	-1.06	-0.25	-0.75	-1.25	-0.25	-0.75	-1.25	0.01	0.03	0.05
4	-0.24	-0.73	-1.22	-0.29	-0.86	-1.43	-0.29	-0.87	-1.45	0.01	0.03	0.04
5	-0.26	-0.79	-1.32	-0.31	-0.92	-1.54	-0.32	-0.96	-1.59	0.01	0.02	0.03
6	-0.28	-0.83	-1.39	-0.32	-0.97	-1.62	-0.34	-1.01	-1.68	0.00	0.01	0.02
7	-0.29	-0.86	-1.43	-0.33	-1.00	-1.67	-0.35	-1.04	-1.74	0.00	0.01	0.02
8	-0.29	-0.87	-1.46	-0.34	-1.02	-1.70	-0.35	-1.06	-1.77	0.00	0.00	0.01
9	-0.29	-0.88	-1.47	-0.34	-1.03	-1.72	-0.35	-1.06	-1.77	-0.00	0.00	0.00
10	-0.30	-0.87	-1.48	-0.35	-1.04	-1.74	-0.35	-1.06	-1.76	-0.00	-0.00	-0.00
11	-0.30	-0.88	-1.48	-0.35	-1.05	-1.75	-0.35	-1.04	-1.74	-0.00	-0.00	-0.00
12	-0.29	-0.88	-1.47	-0.35	-1.05	-1.75	-0.34	-1.02	-1.71	-0.00	-0.00	-0.01

Note: LB = lower bound; UB = upper bound. The reported numbers are in % deviation from trend per quarter.

Table 1: US Benchmark: Scenarios in Numbers

	Notation	Economic Interpretation	Prior Distribution		
No			pdf	mean	SD
Structural Parameters					
1	Ψ	elasticity of capital adjustment cost	$\mathcal{N}$	4.00	1.00
2	h	external habit	$\mathcal{B}$	0.70	0.10
3	φ	inverse Frisch elasticity of labor supply	$\mathcal{N}$	2.00	1.00
4	υ	short-term wealth effect on labor supply	$\mathcal{B}$	0.50	0.20
5	θ_p	Calvo price stickiness	$\mathcal{B}$	0.50	0.15
6	θ_w	Calvo wage stickiness	$\mathcal{B}$	0.50	0.15
7	γ_p	price indexation	$\mathcal{B}$	0.50	0.15
8	γ_w	wage indexation	$\mathcal{B}$	0.50	0.15
9	ψ	capital utilization	$\mathcal{B}$	0.50	0.15
10	$\mathcal{M}_p$	(gross) price markup	$\mathcal{N}$	1.25	0.25
11	$\mathcal{M}_w$	(gross) wage markup	$\mathcal{N}$	1.25	0.25
12	ρ_r	interest-rate smoothing	$\mathcal{N}$	0.75	0.10
13	r_π	policy feedback to inflation	$\mathcal{N}$	1.50	0.25
14	r_y	policy feedback to output gap	$\mathcal{N}$	0.12	0.05
15	$r_{\Delta y}$	policy feedback to change in output gap	$\mathcal{N}$	0.12	0.05
16	$\overline{\pi}$	steady-state inflation	Γ	0.62	0.10
17	$100\left(\beta^{-1}-1\right)$	steady-state time discount factor	Γ	0.25	0.10
18	$\bar{l}$	steady-state employment	$\mathcal{N}$	0.00	2.01
19	τ	trend growth rate	$\mathcal{N}$	0.40	0.10
20	α	contribution of capital in production f-n	$\mathcal{N}$	0.30	0.05
Persistence of the Exogeneous Shock Processes: $\rho = AR(1)$, $\mu = MA(1)$					
21	ρ_a	neutral technology (TFP)	$\mathcal{B}$	0.50	0.20
22	ρ_b	risk premium	$\mathcal{B}$	0.50	0.20
23	ρ_g	aggregate net spending	$\mathcal{B}$	0.50	0.20
24	ρ_q	investment-specific technology	$\mathcal{B}$	0.50	0.20
25	ρ_r	monetary policy	$\mathcal{B}$	0.50	0.20
26	ρ_p	price markup	$\mathcal{B}$	0.50	0.20
27	ρ_w	wage markup	$\mathcal{B}$	0.50	0.20
28	μ_p	price markup	$\mathcal{B}$	0.50	0.20
29	μ_w	wage markup	$\mathcal{B}$	0.50	0.20
30	ρ_{ga}	spillover of TFP shocks on net spending	$\mathcal{N}$	0.50	0.25
Standard Deviation of the Innovations to the Exogenous Shock Processes					
31	σ_a	neutral technology (TFP)	$\mathcal{U}$	2.50	1.44
32	σ_b	risk premium	$\mathcal{U}$	2.50	1.44
33	σ_g	aggregate net spending	$\mathcal{U}$	2.50	1.44
34	σ_q	investment-specific technology	$\mathcal{U}$	2.50	1.44
35	σ_r	monetary policy	$\mathcal{U}$	2.50	1.44
36	σ_p	price markup	$\mathcal{U}$	2.50	1.44
37	σ_w	wage markup	$\mathcal{U}$	2.50	1.44
38	σ_{ls}	labor supply	$\mathcal{U}$	2.50	1.44

Note: The following parameters are not identified by the estimation procedure, and are therefore calibrated as in GSW: capital depreciation $\delta = 0.025$; curvature of price aggregator $\varepsilon_p = 10$; persistence of labor supply shock $\rho_{ls} = 0.999$.

Table 2: Economic Interpretation and Prior Distribution for the Parameters

		US	France	Germany	Italy	Spain
No	Notation	mean	mean	mean	mean	mean
Structural Parameters						
1	Ψ	3.96	3.99	4.04	5.82	5.41
2	h	0.75	0.52	0.47	0.80	0.58
3	φ	4.35	3.94	2.98	2.78	4.31
4	υ	0.58	0.64	0.83	0.78	0.76
5	θ_p	0.62	0.89	0.89	0.84	0.82
6	θ_w	0.55	0.76	0.65	0.74	0.84
7	γ_p	0.49	0.47	0.43	0.26	0.36
8	γ_w	0.18	0.22	0.19	0.23	0.26
9	ψ	0.56	0.66	0.53	0.63	0.81
10	$\mathcal{M}_p$	1.74	1.52	1.42	1.44	1.13
11	$\mathcal{M}_w$	1.22	1.35	1.18	1.22	1.54
12	ρ_r	0.86	0.87	0.93	0.95	0.94
13	r_π	1.89	1.31	1.20	1.14	1.38
14	r_y	0.16	0.19	0.20	0.20	0.11
15	$r_{\Delta y}$	0.25	0.02	0.04	0.05	0.05
16	$\overline{\pi}$	0.66	0.51	0.44	0.55	0.63
17	$100\left(\beta^{-1}-1\right)$	0.31	0.20	0.25	0.27	0.21
18	$\bar{l}$	-1.52	0.74	0.48	0.86	–3.12
19	τ	0.34	0.20	0.12	0.05	0.17
20	α	0.17	0.30	0.30	0.18	0.19
Persistence of the Exogeneous Shock Processes						
21	ρ_a	0.98	0.93	0.92	0.88	0.93
22	ρ_b	0.42	0.80	0.96	0.97	0.94
23	ρ_g	0.97	0.95	0.91	0.91	0.96
24	ρ_q	0.75	0.66	0.46	0.15	0.85
25	ρ_r	0.10	0.42	0.43	0.30	0.36
26	ρ_p	0.43	0.78	0.42	0.19	0.68
27	ρ_w	0.98	0.52	0.48	0.21	0.48
28	μ_p	0.57	0.90	0.72	0.61	0.59
29	μ_w	0.63	0.45	0.54	0.60	0.45
30	ρ_{ga}	0.69	0.19	0.36	0.24	0.23
Standard Deviation of the Innovations to the Exogenous Shock Processes						
31	σ_a	0.42	0.75	0.84	0.89	0.75
32	σ_b	1.60	0.36	0.15	0.16	0.20
33	σ_g	0.48	0.21	0.47	0.41	0.43
34	σ_q	0.42	0.23	0.77	0.77	0.24
35	σ_r	0.22	0.08	0.09	0.09	0.07
36	σ_p	0.11	1.01	1.76	1.52	0.20
37	σ_w	0.06	0.58	0.45	2.57	3.55
38	σ_{ls}	1.17	1.58	2.26	2.68	3.15

Note: GSW US sample: 1966Q1–2007Q4; MRW EMU sample 1999Q1–2017Q4.

Table 3: Posterior Distribution Mean Estimates for the Parameters

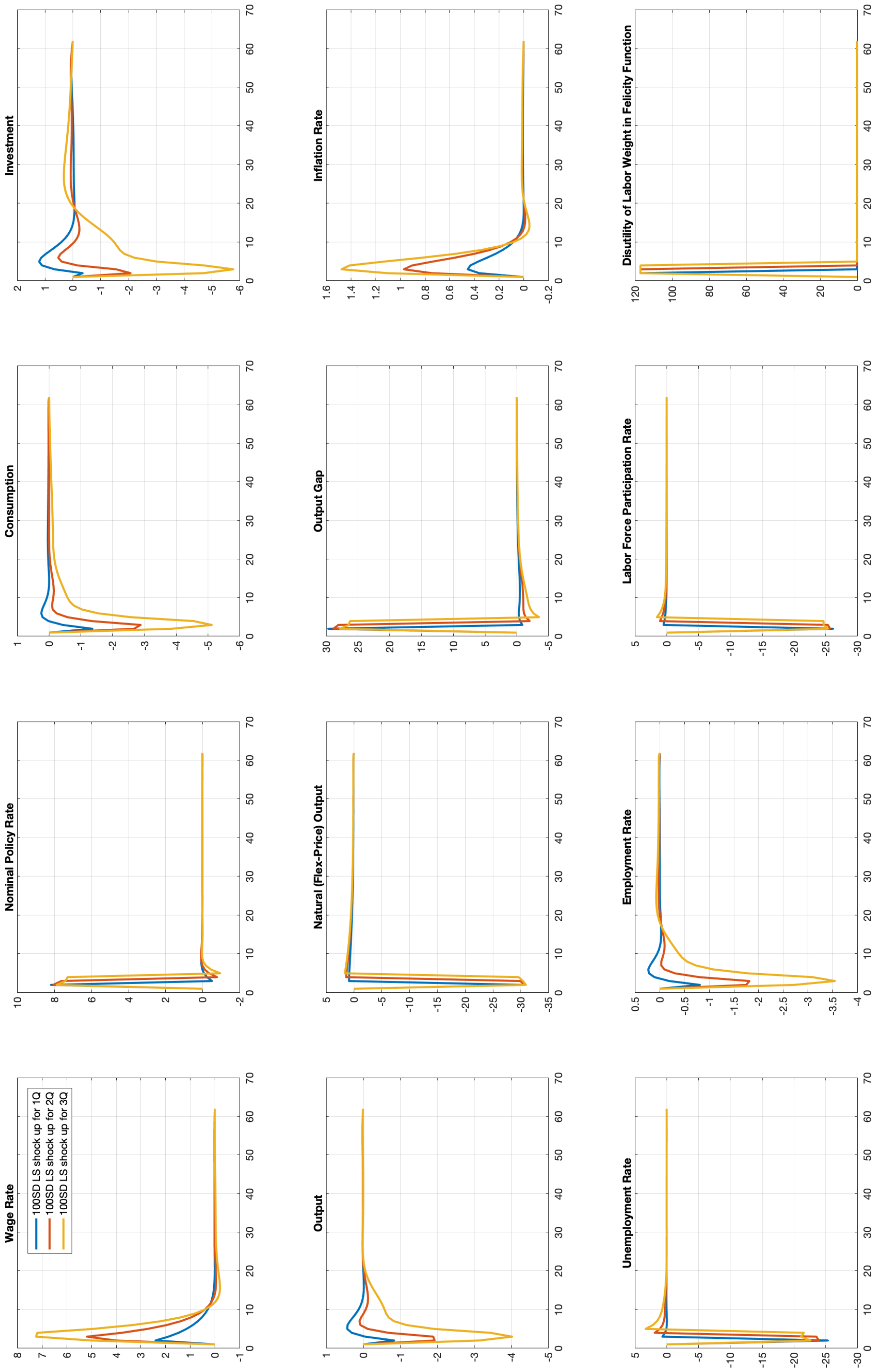

Figure 1: "Lower Bound of Temporary Loss" US Benchmark – 3 Scenarios. Simulated Effects of a 100 SD Adverse Labour Supply Shock to the US Economy (x-axis: time in quarters; y-axis: deviations from trend normalized at 0 in %)

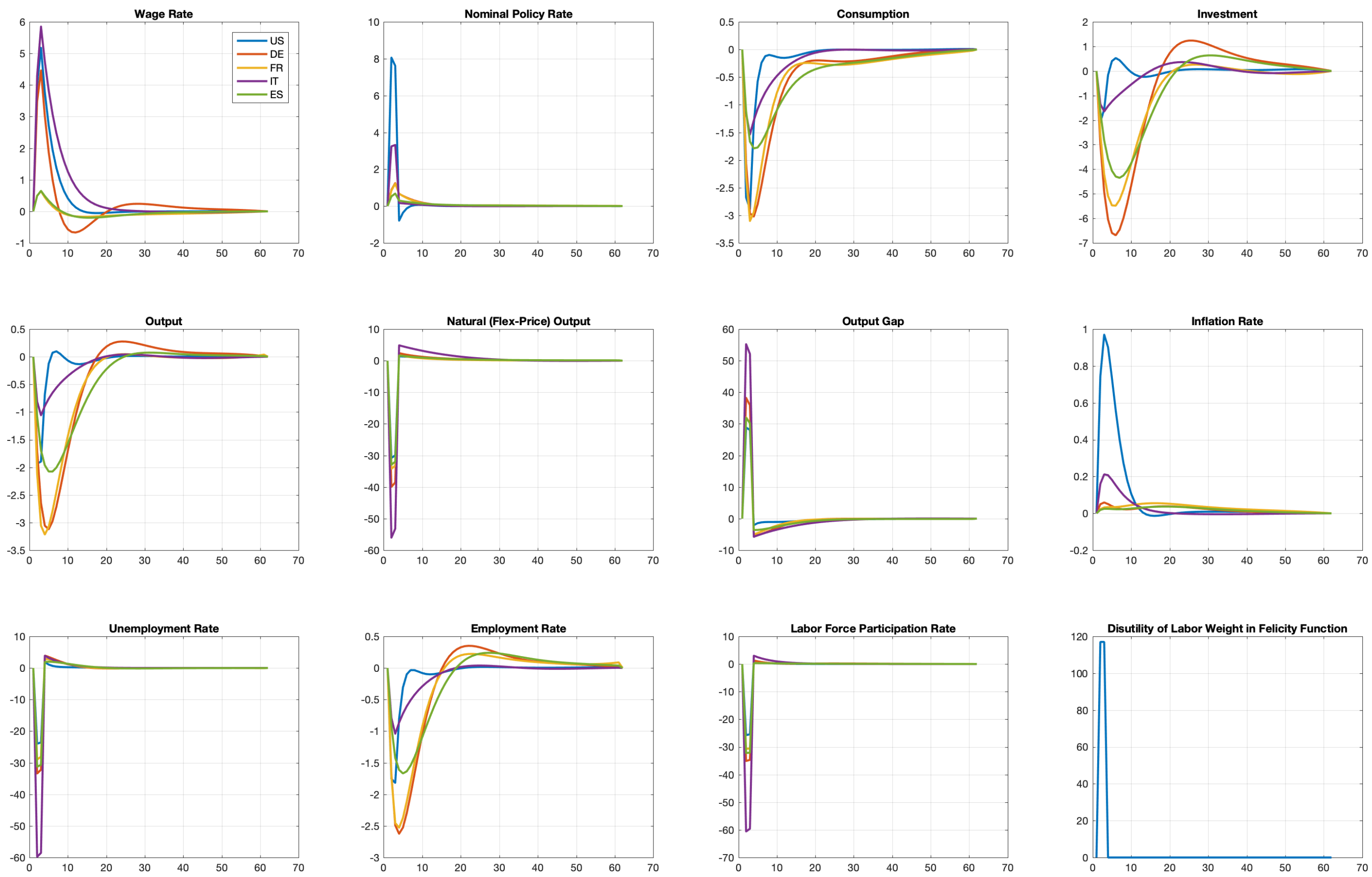

Figure 2: "Lower Bound of Temporary Loss", Baseline Scenario – 5 Major Economies. Simulated Effects of a Common 100 US SD Adverse Labor Supply Shock and Lockdown for 2 Quarters in 5 Major Economies (x-axis: time in quarters; y-axis: deviations from trend normalized at 0 in %)

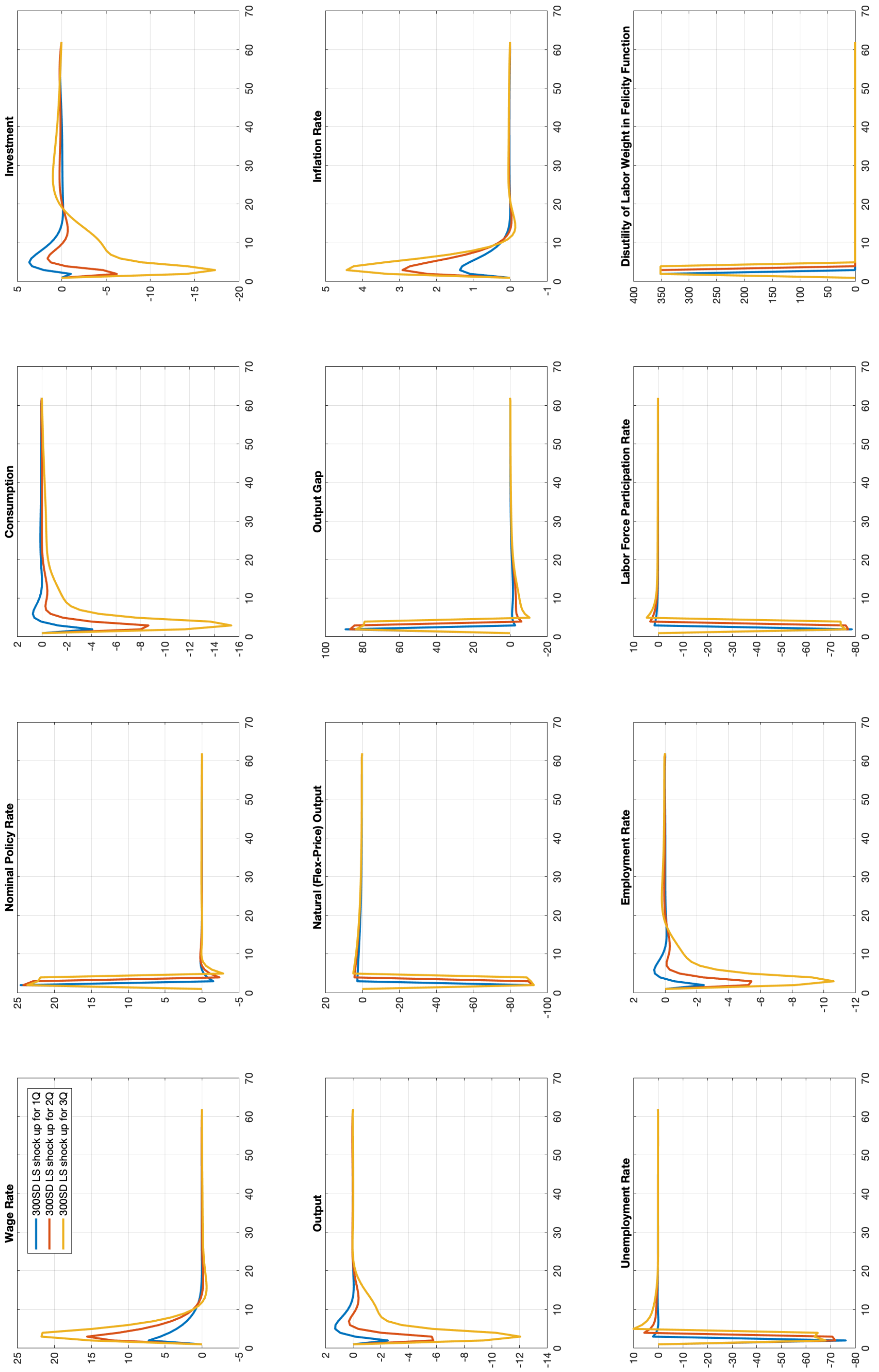

Figure 3: "Upper Bound of Temporary Loss", US Benchmark – 3 Scenarios. Simulated Effects of a 300 SD Adverse Labor Supply Shock to the US Economy (x-axis: time in quarters; y-axis: deviations from trend normalized at 0 in %)

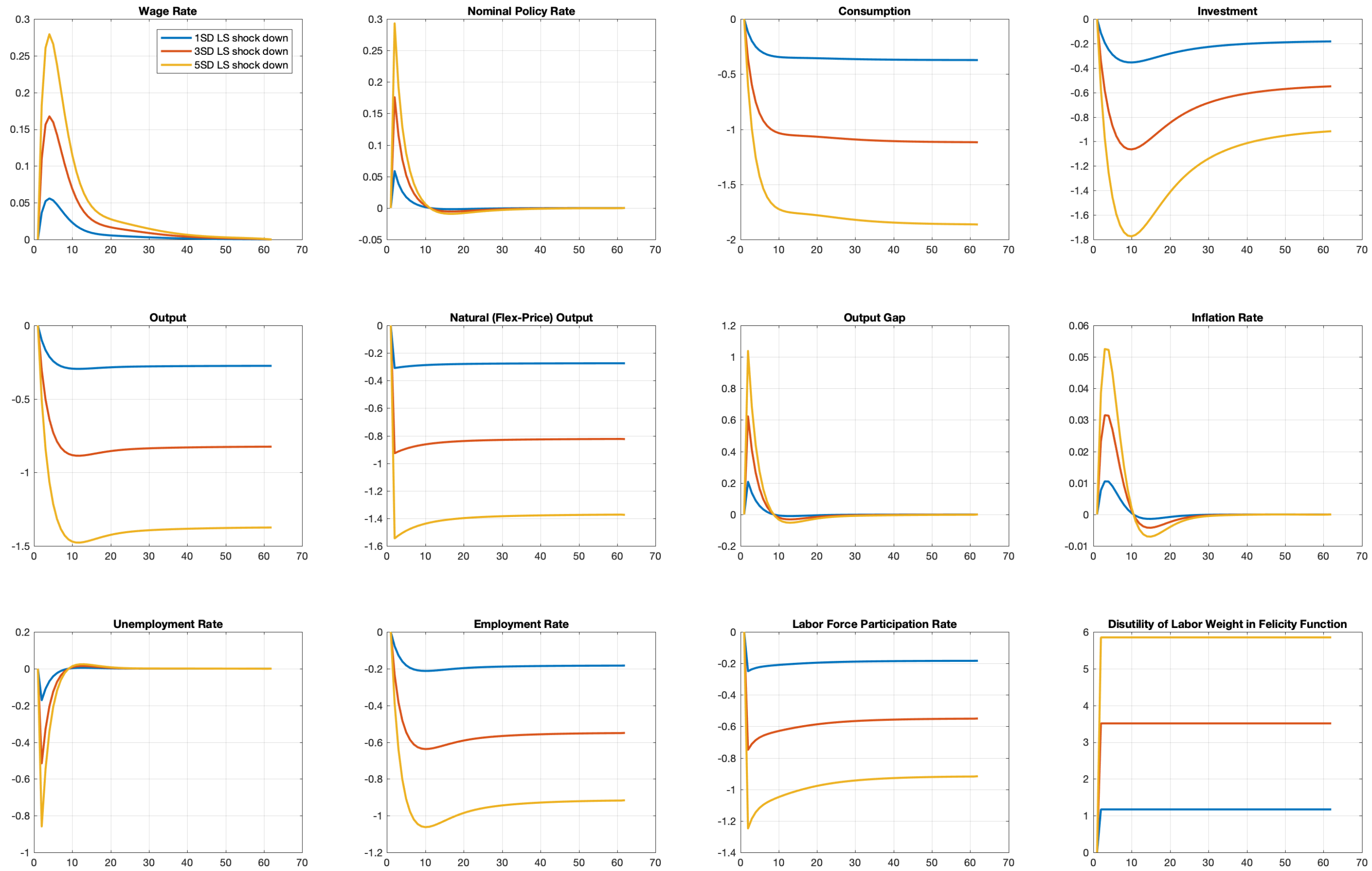

Figure 4: "Permanent Loss", US Benchmark – 3 Scenarios. Simulated Effects of a 1, 3 and 5 SD Adverse Labor Supply Shock to the US Economy (x-axis: time in quarters; y-axis: deviations from trend normalized at 0 in %)