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# ECB-BASIR:
# a primer on the macroeconomic implications of the Covid-19 pandemic

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## Abstract

This paper studies the macroeconomic consequences of the COVID-19 pandemic and makes a first step in adapting the central bank modelling apparatus to the new economic landscape. We augment the ECB-BASE model with the predictive dynamics of the SIR model in order to assess the interplay between epidemiological fundamentals, containment policies and the macroeconomy. Containment policies considerably reduce the share of infected and deceased people, but generate a sharp decline in economic activity. Barring the materialization of amplification risks, the induced recession may remain broadly V-shaped under targeted confinement policies. By comparison, a ”laissez-faire” approach to the pandemic emergency can even inflict in some cases higher long-term economic costs. Nevertheless, the depth of the recession and the speed of the recovery (if at all) crucially depend on the magnitude and persistence of the supply-side retrenchment, as well as on the risk of macro-financial feedback loops.

*Key words: Epidemic, modelling, COVID-19, ECB-BASE*
*JEL Classification: E1, E3, I1*

## Non-technical summary

The macroeconomic fallout of the COVID-19 pandemic is likely to shatter the productive sector, households' behaviour and the financial system through a variety of channels. As such, the unprecedented nature of the COVID-19 crisis constitutes a formidable challenge for macroeconomic models that are regularly used in the monetary policy preparation process. This paper assesses the economic consequences of the COVID-19 pandemic emergency, taking a first step to adapt the central bank modelling apparatus to the new economic landscape. In doing so, we augment the ECB-BASE model of Angelini et al. (2019), a large-scale semi-structural model for the euro area, with the predictive dynamics from a SIR model. This enables to assess the interplay between the epidemiological fundamentals of COVID-19, containment policies and the macroeconomy. To our knowledge, this paper is one of the first attempts to enhance the main policy models used in central banks with pandemic features.

The combined model, ECB-BASIR, can shed some light on the trade-offs faced by governments in addressing the public health situation while limiting the economic fallout of the pandemic. More specifically, the epidemiological module generates shocks to agents' ability to work, consume and invest, which we refer to as "pandemic wedges". These then propagate through the macroeconomic linkages of the model. With the objective of formulating realistic macroeconomic scenarios for the COVID-19 pandemic emergency in the euro area, we contemplate various settings for containment policies and consider several macroeconomic amplification channels.

The first policy we consider assumes that no specific policy measure "Laissez-faire" is undertaken to fight the pandemic: as the public health situation dramatically deteriorates, the long-term economic costs of this policy may become very significant when the fatality rate is expected to be high. Then we analyse various containment measures which we split in two stages. In the first stage of the pandemic, we assume that confinement measures are imposed on the whole population, in line with what most countries did in the first half of 2020. After the first wave of restrictions, three variants are considered. In the absence of additional intervention, a second wave of infection is bound to occur. This second wave can nonetheless be avoided with containment measures that can either be imposed on the total population or targeted to a specific part of the population.

While containment measures reduce the number of deceased people by a factor of six compared with the "Laissez-faire" scenario, they carry along much larger economic costs in the first quarters of the pandemic emergency. The targeted confinement scenario is the closest we get to a V-shaped recession, but the endogenous propagation mechanism of the model still points at pervasive economic slack. Compared with the targeted confinement scenario, the absence of further containment measures triggers a second wave of the virus but leaves limited additional scars to the macroeconomic

allocation. Conversely, the generalized confinement policy would lead to a much more dramatic outcome, generating an L-shaped recession.

Finally, unravelling the macroeconomic consequences of the pandemic emergency may require accounting for real-financial amplification risks as well as eventual hysteresis effects which could put a break on the recovery from the COVID-19 crisis: we augment our pandemic scenarios with some lasting labour market disruptions, an uncertainty shock, and adverse financial market dynamics. Altogether, our simulations build the case for stabilization policies to step in so that amplification risks do not materialise, and appropriate support to "re-boot" the economy is provided as soon as the drag from the pandemic wedges fades away.

# 1 Introduction

The outbreak of the COVID-19 pandemic emergency together with the related containment and "smart" social distancing measures are likely to shatter the productive sector, households' behaviour and the financial system through a variety of channels. The unprecedented nature of the COVID-19 pandemic shock constitutes a formidable challenge for the macroeconomic models that are regularly used in the monetary policy preparation process. This paper assesses the economic consequences of the COVID-19 pandemic, taking a first step to adapt the central bank modelling apparatus to the new economic landscape.

In doing so, we augment the ECB-BASE model Angelini et al. (2019), a large-scale semi-structural model for the euro area, with the predictive dynamics of a SIR model. This enables to assess the interplay between the epidemiological fundamentals of the COVID-19, containment policies and the macroeconomy. Our work is to our knowledge the first attempt to enhance the main policy models used in central banks with pandemic fundamentals, but it also builds on recent papers trying to integrate epidemiological and economic models like in Alvare et al. (2020), Bodenstein et al. (2020) and Eichenbaum et al. (2020).

Amongst the many papers circulating right now,[1] there are those that extend the canonical epidemiology model introduced by Kermack and McKendrick (1927). In particular, Eichenbaum et al. (2020) study the equilibrium interactions between economic decisions and epidemic dynamics. Their analysis is based on U.S. data and involves a Dynamic Stochastic General Equilibrium (DSGE) modelling framework. According to their main findings, people's decision to cut back on consumption and work reduces the severity of the epidemic but aggravates the size of the recession. The competitive equilibrium is not socially Pareto optimal because people infected with the virus do not fully internalize the effect of their consumption and work decisions on the spread of the virus. In their benchmark model, the optimal containment policy increases the severity of the recession but saves roughly half a million lives. Moreover, Bodenstein et al. (2020) assess the economic costs related to drastic public health measures, namely social distancing or lockdowns. They combine a calibrated epidemiological model with a two-sector model featuring a set of industries that produce core inputs used by all the other industries, capturing key characteristics of the U.S. Input-Output Tables. They also find that social distancing measures can reduce costs, especially if skewed towards

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[1] The Centre for Economic Policy Research (CEPR), launched a new journal, Covid Economics: Vetted and Real-Time Papers which is updated every 48 hours with new publications.

non-core industries and occupations with tasks that can be performed from home. A simplified variation of the SIR model presented by Atkeson (2020) is taken by Alvare et al. (2020) to assess optimal lockdown policy using micro data to calibrate the key model parameters. They find that the optimal policy varies over time as a function of both the fraction of infected and susceptible in the population, and that the intensity of the lockdown depends on the level of the fatality rate.

The ECB-BASIR can shed some light on the trade-offs faced by governments in addressing the public health situation while limiting the economic fallout of the pandemic. The granularity of our epidemiological module enables to account for people in quarantine by using a variant of the SIR model, the SI(Q)R (see, Tiwari (2020)). This gives the flexibility to analyse different containment measures, either forcing lockdowns, keeping infected people in quarantine or tracking down those that have recovered. We find that containment policies come at significant economic costs, but if implemented efficiently and at an early stage, they can avoid the spread of the virus and yield economic benefits. Our large semi-structural macroeconometric model allows us to not only construct a benchmark scenario but also explore a set of macroeconomic contingencies, including for example supply disruptions, uncertainty effects or macro-financial feedback loops.

More specifically, in the ECB-BASIR model the epidemiological module generates shocks to agents' ability to work, consume and invest, which we refer to as "pandemic wedges". These then propagate through the macroeconomic linkages of the model. With the ultimate objective of formulating realistic macroeconomic scenarios for the COVID-19 pandemic emergency in the euro area, we contemplate various settings for containment policies and consider several macroeconomic amplification channels.

The first policy we consider assumes that no specific measure is undertaken to fight the virus. Under this "Laissez-faire" approach, real GDP drops in the second quarter of the pandemic emergency by about 1.5%, recovering somewhat in the third quarter but remains persistently below the baseline by 0.5% over a three-year horizon. Indeed, after the second quarter the share of infected people approaches zero, and the economy starts recovering from the slump while the death toll of the disease exerts a permanent drag on economic activity. Interestingly, prices increase initially and the disinflationary effects remain muted over the simulation horizon due to supply-side factors weighting on labour force and potential output. Overall, while the public health situation dramatically deteriorates in this scenario, the long-term economic costs might become significant as well, notably when the expected fatality rate from the disease is high.

We then turn to the analysis of various containment measures and assess their effectiveness in mitigating the spread of the virus as well as their impact on the economy. We split the containment measures in two stages. In the first stage of the pandemic, we assume that confinement measures are imposed on the whole population, in line with what most countries did in the first half of 2020. After the first wave of restrictions, three variants are considered. In the absence of additional intervention, a second wave of infections is bound to occur. This second wave can nonetheless be avoided with containment measures that can either be imposed on the total population or targeted to a specific part of the population.

While containment measures reduce the number of deceased people by a factor of six compared with the "Laissez-faire" scenario, they carry along much larger economic costs in the first quarters of the pandemic emergency. The pandemic wedges for consumption, investment and employment fall by around 12 to 15% after two quarters, which is seven times bigger than under "Laissez-faire". The targeted confinement scenario is the closest we get to a V-shaped recession, with real GDP plunging to -10% by 2020Q2, bouncing back to -2% in 2020Q3 and reaching levels close to the baseline by the end of the three-year horizon. But the endogenous propagation mechanism of the model points at pervasive slack in the economy, leaving inflation 0.5 p.p. below baseline over the simulation.

Compared with the targeted confinement scenario, the absence of further containment measures triggers a second wave of the virus but leaves limited additional scars to the macroeconomic allocation. This notwithstanding, output, consumption and investment would remain around 1% lower from the beginning of 2021 onwards. Conversely, imposing the generalized confinement policy throughout would lead to a much more dramatic outcome: the economy would not be able to recover, generating an L-shaped recession, with 10% lower GDP even at the end of the three-year horizon.

Unravelling the macroeconomic consequences of the pandemic emergency may also require accounting for real-financial amplification risks as well as eventual hysteresis effects which could put a break on the recovery from the COVID-19 crisis. More specifically, we complement our pandemic scenarios with some lasting labour market disruptions, an uncertainty shock, and pro-cyclical financial market deterioration.

Altogether, our simulations build the case for stabilization policies to step in so that amplification risks do not materialise and appropriate support to "re-boot" economic activity is provided as soon as the drag from the pandemic wedges fades away.

The remainder of this paper is organized as follows. Section 2 describes the epidemiological module and its integration into the ECB-BASE model. Subsequently, Section 3 discusses the calibration of the pandemic wedges. Section 4 articulates the macroeconomic simulations of selected containment policies. Section 5 considers the implications of major amplification risks whereas Section 6 summarizes and concludes.

# 2 ECB-BASIR

ECB-BASIR is an extension of the ECB-BASE model Angelini et al. (2019) to address the specific features of the COVID-19 crisis through the lens of a satellite SIR model. In what follows we describe the main elements and characteristics of this epidemiological module and how it is connected to the decision variables of the ECB-BASE model.

## 2.1 The Susceptible-Infectious-Recovered (SIR) model

The SIR model we start from is the compartmental model by Kermack and McKendrick (1927) (see, Kermack and McKendrick (1927)). This mathematical model divides the population into three compartments to predict how a disease can spread: S, the number of susceptible; I, the number of infectious, and R the number of recovered or deceased (or immune) individuals. We go one step further and use a variant of the SIR model that includes also the share of quarantined, Q. The SI(Q)R variant (see, Tiwari (2020)) can flexibly account for different types of containment policies.

These S, I, Q, R compartments of the population vary over time according to the following daily dynamic system.

$$s_t = s_{t-1} - \beta s_{t-1} i_{t-1} (1 + \tilde{c}_t)(1 + \tilde{n}_t)(1 - \lambda_t) \tag{1}$$

$$i_t = i_{t-1} + \beta s_{t-1} i_{t-1} (1 + \tilde{c}_t)(1 + \tilde{n}_t)(1 - \lambda_t) - (\mu^r + \mu^d) i_{t-1} - \delta_t i_{t-1} \tag{2}$$

$$r_t = r_{t-1} + \mu^r i_{t-1} + \zeta^r q_{t-1} \tag{3}$$

$$d_t = d_{t-1} + \mu^d i_{t-1} + \zeta^d q_{t-1} \tag{4}$$

$$q_t = q_{t-1} + \delta_t i_{t-1} - (\zeta^r + \zeta^d) q_{t-1} \tag{5}$$

where $s_t$ is the share of susceptible population at risk of infection, $i_t$ is the share of infected population with or without symptoms, $r_t$ is the share of recovered population, $d_t$ is the share of population that died due to the infection and $q_t$ is the share of the infected population in quarantine.

The rate at which the infection occurs is defined by $\beta = \kappa\gamma$ where $\kappa$ is the rate of contacts with another person and $\gamma$ is the proportion of contacts which result in an infection. We set $\gamma = 0.079$, implying that 8 percent of all contacts are infectious[2] while $\kappa$ is calibrated so that the total number of infected people without measrues reaches 60% of the total population, consistent with the forecast presented by Angela Merkel, March 11, 2020.[3] We assume that, infected people either recover at a rate $\mu^r = 0.07114296$ or die with a death rate $\mu^d = 0.00025704$. The sum of the two parameters $\mu^r + \mu^d = 0.0714$ implies that the outcome of discovering the disease is on average known after 21 days,[4] while the calibrated death rate implies a fatality rate of 0.37%, somewhat on the lower end of the estimates but consistent with the evidence collected for Germany.[5] The rate at which new cases are detected from the infected and put into quarantine is expressed by $\delta_t$ and in the baseline calibration is set to $\delta_t = 0 \; \forall \; t$. $\zeta^r$ and $\zeta^d$ are the recovery and fatality rates for quarantined persons and are set to the same values as the recovery and fatality rates for infected.

We include a specific parameter, $\lambda_t$, to capture in a reduced-form way a wide range of policies to the effective infection rate. When the entire population is locked down or the number of contacts are reduced the risk of getting the disease is lower. Note that $\delta_t$ is also a time-varying parameter which we use to proxy certain types of containment policies.

Two terms in equations (1) and (2), $(1 + \tilde{c}_t)(1 + \tilde{n}_t)$ have been added to the standard SIR model, introducing a dependence between consumption and labour decisions (in the macroeconomic allocation) and the spread of the disease as in Eichenbaum et al. (2020). The term, $(1+\tilde{c}_t)$, captures the fact that during activities related to consumption contacts between people are inevitable therefore enhancing the probability of people getting infected. In fact, the exact specification assumes that when agents consume more than in the baseline case ($\tilde{c}_t>0$), these agents have $(1+\tilde{c}_t)$ more contacts, thereby increasing the spreading of the disease. The same reasoning applies to labour decisions and the term $(1 + \tilde{n}_t)$. Altogether, this specification opens a channel from the macroeconomic model

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[2] See, Qifang Bi et al. Epidemiology and Transmission of COVID-19 in Shenzhen China: Analysis of 391 cases and 1,286 of their close contacts and at: `https://www.medrxiv.org/content/10.1101/2020.03.03.20028423v3.full.pdf`.

[3] See, "Merkel gives Germans a hard truth about the Corona virus", New York Times, March 11, 2020.

[4] It can take several weeks to fully recover from the illness caused by the novel corona-virus, Dr. Mike Ryan, executive director of the World Health Organization's Health Emergencies Program, said during a briefing in Geneva March 9 2020, that: "It takes anything up to six weeks to recover from this disease. People who suffer very severe illness can take months to recover from the illness."

[5] `https://www.faz.net/aktuell/gesellschaft/gesundheit/coronavirus/neue-corona-symptome-entdeckt-virologe-hendrik-streeck-zum-virus-16681450.html`.

to the epidemiological module through the sensitivity of the spread of the disease to ”economic interactions” among people.

## 2.2 Integrating the SI(Q)R module into the ECB-BASE

ECB-BASE is a large-scale, estimated, semi-structural model for the euro area featuring optimizing agents subject to generalised adjustment costs. The model comprises a demand, supply and financial blocks. In what follows we focus on the decision problems affected by the inclusion of the SI(Q)R model: this covers consumption, investment and labour market blocks. Variables denoted with lower case letters are expressed in log while upper case letters apply to variables in level. Besides, the time increment in the macroeconomic model is quarterly. For the sake of exposition, we use the same time subscript $t$ as in the previous section but in practice, the integration of the daily SI(Q)R module to the quarterly ECB-BASE model gives rise to a mixed-frequency modelling framework.[6]

### 2.2.1 Consumption

The consumption behaviour in ECB-BASE is determined by two kinds of households, optimizing households and hand to mouth consumers. The first group maximizes their consumption based on their lifetime resource constraint, the second on the changes of their current income. The target of consumption depends on expected permanent labour income, transfer and property incomes, financial and housing wealth:

$$c_t^* = \eta_0 + \eta_T eyh_t^T + \eta_P eyh_t^P + \eta_D hw_t^D + \eta_L eyh_t^L \tag{6}$$

where, $eyh^L$, $eyh^T$, $eyh^P$ are labour, transfer and property incomes and $hw^D$ is housing wealth of households.

Let us denote $c_t^u$ the consumption of agents not subject to constraints stemming from infections

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[6] Numerically we integrate the SI(Q)R model in the ECB-BASE by solving for a fixed point, where SI(Q)R variables enter as quarterly averages, while ECB-BASE variables that enter SI(Q)R are fixed in all days over the specific quarter.

or lockdown. The short run dynamic behaviour for $c_t^u$ is given by,

$$\Delta c_t^u = (1-\theta)\left(a_0\left(c_{t-1}^* - c_{t-1}\right) + \sum_{i=1}^{m-1} a_i \Delta c_{t-i}^u + \beta_1 x_t + \mathbb{E}_{t-1}\sum_{j=0}^{\infty} d_j \Delta c_{t+j}^*\right) + \theta\Delta(yh_t^L + yh_t^T) + \epsilon_t^C \tag{7}$$

where $\theta$ is the share of rule-of-thumb consumers, $a_0$ is the coefficient on the deviation of consumption from its target and $a_i$ gives the weights on the backward looking terms. The term $\mathbb{E}_{t-1}\sum_{j=0}^{\infty} d_j \Delta c_{t+j}^*$ represents the expectations of future targets.

Aggregate consumption $C_t$ can be derived in the following way based on different shares of agents:

$$C_t = (1 - i_t - l_t - d_t)C_t^u + i_t\alpha_C^I C_t^u + l_t\alpha_C^L C_t^u \tag{8}$$

where $(1 - i_t - l_t - d_t)$ is a share of agents not affected by the virus, $i_t$ is the share of infected agents, $l_t$ is the share of locked down agents, and $d_t$ is the share of deceased people. $l_t$ can comprise more agents than the quarantine ones depending on confinement measures as exposed in section 4.2.

Parameters $\alpha_C^I$ and $\alpha_C^L$ determine how much lower consumption of infected and locked down agents is compared to unconstrained agents.

### 2.2.2 Labour market

In the ECB-BASE model, total employees is the key equation of the labour market block. Firms decide on an optimal target of employment which is reached gradually

$$n_t^* = mc + log(1-\alpha) + y_t - w_t \tag{9}$$

where $mc$ is the log of the Lagrange multiplier on the technology constraint, $\alpha$ is the geometric weight on physical capital in the production function, $w_t$ is real compensation of employees and $y_t$ is real GDP.

As for the consumption block, let us denote $n_t^u$ the unconstrained (log-)labour whose dynamic behaviour is given by,

$$\Delta n_t^u = a_0^n \left(n_{t-1}^* - n_{t-1}^u\right) + a_1^n \Delta n_{t-1}^u + \mathbb{E}_{t-1} \sum_{j=0}^{\infty} d_j \Delta n_{t+j}^* + e^n \tag{10}$$

Aggregating across agent epidemiological types, the total labour input in the productive process is

$$N_t = (1 - i_t - l_t - d_t) N_t^u + i_t \alpha_N^I N_t^u + l_t \alpha_N^L N_t^u \tag{11}$$

As before, we introduce $\alpha_N^I$ and $\alpha_N^L$ to capture the constraints on the productive match between firms and employees related to infected and locked down agents.

Total population and working age population specified in the ECB-BASE model are also adapted to take into account the fatalities due to the disease. Total population $P^b$ and working age population $WP^b$ are adjusted as follows:

$$P_t = P_t^b (1 - d_t) \tag{12}$$

$$WP_t = WP_t^b (1 - d_t) \tag{13}$$

Following the specification of the ECB-BASE model, the equation for the unconstrained labour force participation rate, $lfp_t^u$, is given by as

$$lfp_t^u = -0.5 * (lfp_{t-1}^u - lfp_{t-1}^T) - \beta(u_{t-1} - u_{t-1}^T) + \Delta\, lfp_t^T \tag{14}$$

where, $lfp_t^u$ is the labour force participation rate, $lfp_t^T$ is the trend labour force participation rate, $u_t$ is the unemployment rate and $u_t^T$ is the trend unemployment rate.

Again, aggregating across epidemiological types gives the total labour force:

$$LF_t = (1 - i_t - l_t - d_t) LF_t^u + i_t \alpha_{LF}^I LF_t^u + l_t \alpha_{LF}^L LF_t^u \tag{15}$$

where $\alpha_{LF}^I$ and $\alpha_{LF}^L$ map the constraints on the supply of labour from infected and locked down agents.

### 2.2.3 Investment

In the ECB-BASE, business investment is derived from a standard optimization problem where firms maximise their profits subject to a capital accumulation equation.[7].

The target for business investment is based on the following,

$$IB^*_t = \left(G^{K^*}_{t+1} + \delta\right)\frac{S^K_t Y_t}{UC_t} \tag{18}$$

where $IB^*$ denotes the target for business investment and $G^{K^\star}_{t+1}$ is the growth rate of the (target) capital stock, which is approximated by the real GDP growth.

The short-run dynamics for the unconstrained (log-)business investment, $ib^u_t$ is given by the following equation:

$$\Delta ib^u_t = \left(1-\theta^{ib}\right)\left(a^{ib}_0\left(ib^*_{t-1} - ib^u_{t-1}\right) + \sum_{k=1}^{m-1} a^{ib}_k \Delta ib_{t-k} + \mathbb{E}_{t-1}\sum_{j=0}^{\infty} d^{ib}_j \Delta ib^*_{t+j}\right) + \theta^{ib}\Delta y_{t-1} + \epsilon^{ib}_t \tag{19}$$

The aggregate business investment across epidemiological types is then

$$IB_t = (1 - i_t - l_t - d_t)IB^u_t + i_t\alpha^I_{IB}IB^u_t + l_t\alpha^L_{IB}IB^u_t \tag{20}$$

where $\alpha^L_{IB}$ and $\alpha^I_{IB}$ incorporate the constraints on investment stemming from locked down and infected agents, similar to what was done for consumption decisions.

The same adaptation and calibration strategy is applied to the residential investment block.

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[7] Residential investment is modelled along an analogous specification. The target for residential investment can be expressed as a function of output, relative prices and pure user costs of housing capital (user costs excluding relative house prices):

$$IH^\star_t = Y_t(UC^H_{-RP^H_t})^{\beta^{ih}_1}(RP^H_t)^{\beta^{ih}_2} \tag{16}$$

where a clear distinction between relative house prices and user costs of housing capital is made to allow the examination of different elasticities of investment to the two respective components.

For the empirical estimation, priors associated with the implied Cobb-Douglass elasticities are set to $\beta^{ih}_1 = -1$ and $\beta^{ih}_2 = 1$. The empirical specification of (16) then takes the following log-linear form:

$$ih^*_t = \beta^{ih}_0 + y_t + \beta^{ih}_1 uc^H_t + \beta^{ih}_2 rp^H_t + \gamma^{ih}T \tag{17}$$

where $ih^*_t$ is the log of the target for residential investment, $\beta^{ih}_0$ is a constant, coefficients $\beta_1$ and $\beta_2$ are Cobb-Douglass implied elasticities, and $\gamma^{ih}$ accounts for the effect of a linear time trend $T$.

### 2.3 Productive efficiency

Potential output in the ECB-BASE model is derived from a Cobb-Douglas production function approach which bundles physical capital and labour. As explained previously, the capital stock and the labour supply are affected by the SI(Q)R module, which then feeds into potential output. Beyond this, the trend labor productivity component $A_t^*$ includes some dependence to the epidemiological shares as follows,

$$A_t^* = A_t^{*u}(1 - i_t - l_t) + \alpha_A^I i_t A_t^{*u} + \alpha_A^L l_t A_t^{*u} \tag{21}$$

where $A_t^{*u}$ refers to the unconstrained trend labor productivity, whereas $\alpha_A^L$ and $\alpha_A^I$ account for the lower labour productivity of locked down and infected agents.

## 3 Calibration of the pandemic wedges

Compared with the ECB-BASE model, there are three main categories of new parameters which need to be calibrated: i) calibration of parameters specific to the SI(Q)R module which has been discussed in section 2.1 and follows the standard values available in the epidemiological literature, such that the share of people getting infected without any intervention stabilizes at 60%; ii) calibration of parameters related to infected people which directly link the SI(Q)R variables to the ECB-BASE through "the pandemic wedges" in consumption, investment, labour market and productivity blocks; iii) parameters related to public health and lockdown policies which reflect an additional economic wedge created by interventions aimed at containing the spread of the disease. A total wedge on the economy can then be perceived as a combination of the wedge due to infected population and the wedge created by lockdown measures. Parameters associated with both type of wedges are reported in Table 1.

We start by discussing parameters related to the wedge created on the economy by infected population. One of the most important statistics for this calibration is the number of infected people that show no symptoms. However, the estimated share of people testing positive for SARS-CoV-2 that are asymptomatic varies considerably between different studies ranging from a minimum of 5% to a maximum of 80%.[8] Therefore, we consider three possible values, 60% in the baseline scenario, 80% for the mild scenario and 40% for the severe scenario.[9] Accordingly, in the baseline

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[8] See, https://www.cebm.net/covid-19/covid-19-what-proportion-are-asymptomatic.

[9] Same calibration as in Eichenbaum et al. (2020).

calibration we assume $\alpha_C^I = 0.6$, which follows from the fact that 60% of infected people do not show symptoms of infection. For example, this implies that the asymptomatic agents have the same consumption level as unconstrained agents, while those infected with symptoms do not consume at all. We apply a homogeneous treatment to the investment decisions and labour demand and set the same value for $\alpha_{IB}^I$ and $\alpha_N^I$. We assume that due to the infected population, the production side of the economy is decreased by the same degree through wedges imposed on total factor productivity and labour supply ($\alpha_A^I = 0.6$ and $\alpha_{LF}^I = 0.6$).

In addition to modelling the pandemic wedges due to actual infection, it is essential to reasonably account for the specific impact of lockdown measures. To appropriately calibrate the shock linking containment measures to reduced consumption, investment and labour demand, we rely on the range of recent studies related to the euro area countries. For example, an INSEE (2020) study suggests that the confinement measures in France could be directly associated with roughly 35% lower household consumption in March. Moreover, the business activity for non-essential market-based sectors in France, subject to shutdown measures, was on average 42% lower than would otherwise be (see Table 1 in INSEE (2020)). A loss of business activity close to 40% due to containment measures is also confirmed for Germany in the study by Dorn et al. (2020). Given that these results suggest roughly 40% respective drops in household consumption and business activity, we calibrate accordingly the lockdown-related wedges for demand variables (consumption, investment and labour demand), i.e. $\alpha_C^L$, $\alpha_I^L$, $\alpha_N^L$ are in the baseline set to 0.6. To calibrate the wedge on labour supply due to lockdown measures, we rely on Coibion et al. (2020) who in their early study for the U.S. labour market show that roughly half of the employment wedge could be translated into a wedge on the labour force participation rate, which would in our case imply that $\alpha_{LF}^L = 0.8$. Similarly, in line with Bodenstein et al. (2020) we assume that half of the impact of the lockdown measured on output is translated into the production side of the economy which would in our case imply a calibration of $\alpha_A^L = 0.8$.

## 4 Macroeconomic propagation of the pandemic wedges under different containment policies

In this section, we evaluate the macroeconomic implications of the pandemic wedges on agents' ability to work, consume and invest. With the objective of formulating a realistic macroeconomic

Table 1: The calibration of BASIR wedges

| | | Calibrations | | |
|---|---|---|---|---|
| | | MILD | BASELINE | SEVERE |
| Consumption | $\alpha_C^I$ | 0.8 | 0.6 | 0.4 |
| | $\alpha_C^L$ | 0.8 | 0.6 | 0.4 |
| Investment | $\alpha_I^I$ | 0.8 | 0.6 | 0.4 |
| | $\alpha_I^L$ | 0.8 | 0.6 | 0.4 |
| Labour | $\alpha_N^I$ | 0.8 | 0.6 | 0.4 |
| | $\alpha_N^L$ | 0.8 | 0.6 | 0.4 |
| Labour force | $\alpha_{LF}^I$ | 0.7 | 0.6 | 0.5 |
| | $\alpha_{LF}^L$ | 0.9 | 0.8 | 0.7 |
| Productivity | $\alpha_A^I$ | 0.7 | 0.6 | 0.5 |
| | $\alpha_A^L$ | 0.9 | 0.8 | 0.7 |

scenario for the COVID-19 pandemic emergency in the euro area, we contemplate various settings for containment policies and run a sensitivity analysis on the calibration of our pandemic wedges.

The policy interventions we consider are, i) "laissez-faire" policy without containment measures, ii) generalized confinement policy for the first half of 2020 without containment measures thereafter, iii) generalized confinement policy for the first half of 2020 followed by targeted confinement through testing, detection and quarantine, iv) generalized confinement policy for the first half of 2020 followed by subsequent generalized confinement interventions.

Additional macroeconomic channels stemming from supply distortions, uncertainty and financial amplification will be considered later on, in the next section. A fully-fledged counterfactual scenario (in absence of macroeconomic stabilisation policies) is then presented at the end of Section 5.

In all the simulations, the international environment is kept unchanged. The global implications of the COVID-19 crisis regarding trade, commodity prices and financing conditions are beyond the scope of this paper.

## 4.1 “Laissez-faire”

The fundamental shock of the pandemic is 0.01% of infected population at the beginning of the first quarter of 2020.[10]

The first policy we consider assumes that no specific policy measure is undertaken to fight the pandemic (which we reference thereafter as the “Laissez-faire” policy). Accordingly, the health policy parameters are set to $\delta_t = 0$ and $\lambda_t = 0 \; \forall \; t$.

Figure 1 presents the simulation results of the SI(Q)R module under different policies. As explained in section 2.1 our calibration implies that 60% of the population gets infected in the absence of any policy response (see blue line in Figure 1). The share of infected population starts to grow immediately after the initial shock and reaches its peak at the beginning of the second quarter of 2020. However, even on days with the highest infection rates, the share of infected population is still below 10%.

Based on the evidence collected so far, 60% of the infected people do not show any symptoms and 40% of those infected will not consume, invest nor work. Although the infected share of the population never exceeds 10%, the economic recession in the first half of 2020 is still to a large extent driven by the infected population. The pandemic wedges in this scenario are shown in Figure 2 (solid black line): in partial equilibrium, the dynamic of the infection would lead to almost a 2% cumulative decline in consumption, investment and labour by the second quarter of 2020, reverting back to the baseline thereafter.

Moreover, the large death toll caused by the unconstrained pandemic leads to a sizeable permanent long-term loss for the economy. In the baseline calibration with an assumed 0.37% fatality rate, 0.22% of the population dies, leading to a permanent drop in the labour force and potential output.[11]

The solid line in Figure 3 presents the macroeconomic propagation of the scenario. The simulations are run assuming constant financial spreads as well as unchanged monetary and fiscal policy. Real GDP drops in the second quarter by about 1.5%, recovering somewhat in the third quarter

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[10] Exact number of initially infected only changes the timing of the pandemic, while all qualitative and quantitative effects are invariant to the initial share of infected.

[11] We assume the fatality rate is uniformly distributed in the population. Therefore the effect on the labour force can be seen as an upper bound limit, as evidence suggests the COVID-19 disease is riskier for the older part of the population who are in fact already out of the labour force.

but remaining persistently below the baseline by 0.5% over a three-year horizon. Indeed, after the second quarter, the share of infected people approaches zero and the economy starts recovering from the slump but the death toll of the pandemic emergency exerts a permanent drag on economic activity. Interestingly, prices increase initially and the disinflationary effects remain muted over the simulation horizon, driven by supply factors as labour force and potential output are impaired. The slack in the labour market turns out to be marginal with wage inflation returning to baseline by end-2021.

Figure 3 also displays a sensitivity analysis on the fatality rate. The adverse long-term effects are even more evident in the case with a higher fatality rate. When the fatality rate is assumed to be 3.7% (dotted line), we can observe a more L-shaped recession and the economy permanently loses 3% of its output. Overall, while the public health situation dramatically deteriorates under the "Laissez-faire" policy, the long-term economic costs might be significant as well, notably when the fatality rate from the disease is elevated.

## 4.2 Macroeconomic outcomes under containment measures

The counterfactual "Laissez-faire" scenario is a useful benchmark but has been presented mainly for illustrative purposes as in all countries exposed to the COVID-19 pandemic, containment measures have been put in place.

Accordingly, we now turn to the analysis of various containment measures and assess their effectiveness in mitigating the spread of the virus as well as their impact on the economy. We split the containment measures in two stages. In the first stage of the pandemic, we assume that confinement measures are imposed on the whole population, in line with what most countries did in the first half of 2020. After the first wave of restrictions, three variants are considered. In the absence of additional intervention, a second wave of infections is bound to occur. This second wave can nonetheless be avoided with containment measures that can either be imposed on the total population or can be targeted to a specific part of the population.

In the following, we start by explaining how the alternative containment policies are modelled and then describe their macroeconomic implications.

**Non pharmaceutical interventions** Non-pharmaceutical interventions (NPI) are methods to reduce an epidemic spread without requiring pharmaceutical treatments. In our setup we have two main measures, the first option is to quarantine infected people. This is the case when $\delta_t > 0$ in the SI(Q)R module of section 2.1.

Beyond the quarantine policy, the second option is to lock down all or part of the population: such containment measures are first mapped into the epidemiological block by setting $\lambda_t > 0$ which is parametrically equivalent to a lower contact rate ($\kappa$) and as a consequence infection rate ($\beta$). Then, in order to capture confinement measures, we postulate the following formulation for the share of locked down agents, $l_t$:

$$l_t = q_t + \lambda_t(\omega^s s_{t-1} + \omega^i i_{t-1} + \omega^r r_{t-1}) \tag{22}$$

Locked down people comprise the quarantined group, $q_t$, as well as a weighted share of the other compartments of the population, scaled by the parameter $\lambda_t$. The weighting scheme $(\omega^s, \omega^i, \omega^r)$ enables to vary the efficiency of the confinement measures. For example, governments may lock down only the susceptible people as recovered people have gained immunity and therefore locking down this part of the population is reducing the productive capacity of the economy without any gains in containing the spread of the virus.

In all scenarios, we assume the same containment measures in the first stage of the pandemic emergency: a confinement of 1/3 of the whole population in the second half of the first quarter of 2020 and 2/3 of the population in the first half of the second quarter of 2020. This implies $\lambda_t = 0.33$ for $t = 1.5$ and $\lambda_t = 0.66$ for $t = 2$, and we use $\omega^s = 1$, $\omega^i = 0.6$ and $\omega^r = 1$ in equation (22).[12] In a generalized confinement, the government does not test, detect or quarantine infected people, so that $\delta_t = 0$ at all times.

After this first stage policy response for the first half of 2020 we study three subsequent policies:

1. No additional containment measures: $\delta_t = 0$ and $\lambda_t = 0 \; \forall \; t \geqslant 2$;
2. Targeted confinement: the second scenario is the most efficient NPI in terms of economic consequences. It assumes that the government is able to test, detect and quarantine 30% of infected people: $\delta_t = 0.3$ and $\lambda_t = 0 \; \forall \; t \geqslant 2$;

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[12] $\omega^i = 0.6$ since we assume that 40% of infected have symptoms and stay at home even without specific containment measure.

3. Generalized confinement: in the last scenario we assume confinement measures for the whole population, without testing, detection or quarantine (i.e. $\delta_t = 0$ at all times). This policy is formalised in equation (22) with $\omega^s = 1$, $\omega^i = 0.6$ and $\omega^r = 1$, as in the first stage of the policy response to the pandemic.[13] Moreover, we set $\lambda_t$ such that the basic reproduction number ($R_0$) in all periods after the first stage policy response is equal to one.[14] The basic reproduction number is defined as:
$$R_0 = \frac{\beta(1+\tilde{c}_t)(1+\tilde{n}_t)(1-\lambda_t)}{(\mu^r + \mu^d)} \tag{23}$$
where $\beta(1+\tilde{c}_t)(1+\tilde{n}_t)(1-\lambda_t)$ is the effective infection rate and $(\mu^r + \mu^d)$ is the recovery rate. Intuitively, the basic reproduction number tells us the expected number of cases directly generated by one case in a population. When $R_0 > 1$ the virus is spreading, $R_0 < 1$ the spread of the virus is receding. The containment policy is then constructed such that $R_{0t} = 1 \; \forall t \geqslant 2$, which is a policy followed in some countries.[15]

**Epidemiological implications** We first focus on the epidemiological implications of the various containment measures which are displayed in Figure 1. As mentioned previously, the blue lines represent the "Laissez-faire" scenario. The other lines show the outcome corresponding to the alternative containment policies: no additional containment measures (dashed), targeted confinement (solid black line) and generalized confinement (black dotted line).

First, let us recall that all three cases have the same dynamics in the first quarter of 2020 and in the first half of the second quarter, given the symmetric policy response in the first stage of the pandemic. The bottom right panel shows the share of locked down people in the population: around 1/3 in days 45-90 and 2/3 in days 90-134. Comparing with the "Laissez-faire" simulation, all three containment scenarios dramatically reduce the spread of the virus over this period: instead of almost 60% of the population getting infected until the third quarter, this share drops to only around 10%.[16]

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[13] We have also studied an alternative where only the susceptible part of the population is confined. In terms of equation (22) this implies $\omega^s = 1$, $\omega^i = 0.6$ and $\omega^r = 0$. In practice this assumes that we manage to identify the part of the population that has recovered and has gained immunity. Interestingly, in our calibration there is not much difference in economic outcomes between locking down the total population or only the susceptible part. The reason is that lockdown measures in our calibration are efficient in curbing the total number of infected people and therefore the share of recovered people of the population is small.

[14] Technically we set $\lambda_t$ such that $R_0$ is equal to 1 in all periods considered.

[15] https://www.nytimes.com/2020/05/12/world/europe/germany-coronavirus-r-number.html.

[16] We did not consider the constraints of health systems. As observed in countries with overwhelmed health system due to high number of patient, fatality rate can become higher when hospitals are overwhelmed, which would imply even higher impact of containment measures on total number of deceased.

After the first stage of containment measures, the rebound of economic activity with higher consumption and employment, combined with residual share of infected people may lead to the reemergence of the virus. This is what happens in the absence of additional containment measures (see dashed black lines in Figure 1): the virus reemerges with full speed and in the autumn the share of the infected people starts to increase rapidly and a second wave reaches its peak during the winter.

One option to avoid such a second wave is to start efficiently quarantining the infected people. In our calibration we are able to prevent the second wave of infections by quarantining around 30% of infected people (see black line in Figure 1).

The other option to avoid a second wave is to contain the spread of the virus by a generalized confinement in order to keep the basic reproduction number $R_0$ equal to one. As can be seen in the lower right panel in Figure 1 (see dotted black line), this implies that around 20% of the population is locked down (i.e. $\lambda_t = 0.22$).

**Macroeconomic implications** Turning to macroeconomic outcomes, Figure 2 displays the pandemic wedges associated with the various policies. While containment measures reduce the number of deceased people by a factor of six compared with the "Laissez-faire" scenario, they carry along much larger economic costs in the first half of 2020. The pandemic wedges for consumption, investment and employment fall by around 12 to 15% after two quarters, which is seven times bigger than under "Laissez-faire".

For the second half of 2020, the targeted confinement policy proves extremely efficient from an economic perspective (see black lines in Figure 2): the share of quarantined people is small in the total population and therefore locking down such a small part of the population does not involve large economic costs. Consequently, the pandemic wedges becomes broadly neutral as of the third quarter of 2020. In the absence of further containment measures (see dashed black lines in Figure 2), the public health outcomes are severely affected by a second wave but the implied pandemic wedges are modest in comparison with their levels in the first half of 2020: indeed, the second wave pandemic wedges resemble the ones in the "Laissez-faire" allocation with a somewhat smaller peak as the initial share of susceptible people has been reduced during the first stage of the pandemic. By contrast, the generalized confinement policy leads to sizeable and persistent pandemic wedges (see dotted black lines in Figure 2). This inefficient policy relies on locking down a significant share of the population for the entire simulation horizon and generates negative wedges for consumption, investment and employment by around 7% from the third quarter of 2020 onwards.

Simulating the pandemic wedges, Figure 4 shows the macroeconomic outcomes for the three containment policies. The simulations are run assuming constant financial spreads as well as unchanged monetary and fiscal policy. Starting with the targeted confinement policy (see thick red lines), real activity drops dramatically in the first and second quarter with GDP being 10% lower than in the baseline but bounces back to -2% in the third quarter of 2020, gradually reverting back to baseline thereafter. Large supply shock due to the first stage containment measures prevent inflation from falling in the first quarters of the simulation. However through the second half of 2020, inflation drops persistently below baseline by around 0.5 p.p. following lower demand. Unemployment increases 7 percentage points, generating further downward pressure on nominal wage inflation which decreases for 2 p.p. in 2020 before gradually returning its baseline level by end-2022.

Altogether, the targeted confinement scenario is the closest we get to a V-shaped recession, with real GDP reaching levels close to the baseline by the end of the three-year horizon. Nonetheless, the macroeconomic performance in this scenario is worse than the partial equilibrium perspective from the pandemic wedges would have suggested. Figure .1 in the appendix compares the pandemic wedges with their general equilibrium propagation in the model. While the pandemic wedges becomes neutral by the third quarter of 2020, consumption remains 2% below baseline on average after the third quarter of 2020 and the rebound of investment is even less pronounced. This illustrates the endogenous propagation mechanism of the model which predicts pervasive slack in the economy and hints at the need for stabilization policies to support the ”re-boot” of economy activity as soon as the drag from the pandemic wedges fades away.

Compared with the targeted confinement scenario, the second wave of the virus in the absence of further containment measures leaves limited additional scars to the macroeconomic allocation. This notwithstanding, output, consumption and investment would remain around 1% lower from the beginning of 2021 onwards (see dashed lines in Figure 4). Conversely, the generalized confinement policy would lead to a much more dramatic outcome: the economy would not be able to recover, generating an L-shaped recession, with GDP 10% lower even at the end of a 3 year period (see dotted lines in Figure 4). In this case, the macroeconomic dynamics of the scenario would largely undershoot its corresponding pandemic wedges with no signs of normalisation towards the baseline over the three-year horizon of the simulation. In particular, inflation is still in free fall by end-2022, reaching -2 p.p. below is baseline level.

### 4.3 Sensitivity analysis on the calibration of the pandemic wedges

Figure 5 presents some sensitivity analysis with respect to the calibration of pandemic wedges and their sensitivity to the shares of infected and locked down agents in the population. More specifically, we consider tighter calibrations of $\alpha^I$ and $\alpha^L$ parameters characterized by column *severe* in Table 1 and alternative looser calibration characterised by column *mild*. We focus on the policy scenario assuming a generalized confinement during the first phase of the pandemic, followed by targeted confinement measures quarantining infected only in order to prevent a second wave of the virus: this scenario actually becomes the benchmark hereafter.

Figure 5 shows that the macroeconomic impact of the benchmark scenario turns out to be broadly homothetic across the alternative parameter sets. In the severe calibration (see dashed line in Figure 5), the peak drop in GDP level is roughly 5 p.p. larger than in the baseline calibration (see solid line in Figure 5). The corresponding inflation drop for the severe relative to the baseline calibration is 0.4 p.p. with slightly delayed trough reached one year and a half after the initial shock. The mild calibration appears as a symmetric case in comparison with the baseline calibration, attenuating the GDP drop by around 5 p.p. at the trough and limiting the disinflationary pressures by around 0.3 p.p. in mid-2021. At the end of the simulation horizon (fourth quarter 2022) the broad normalisation of economic aggregates in the benchmark scenario towards their baseline values is still somewhat preserved across the various calibration strategies.

The calibration of the supply-side pandemic wedges matters particularly for the short-term inflationary response to the crisis scenario. Figure 6 shows different simulations of the benchmark scenario where we alternate the *severe* and *mild* calibration for the labour force and productivity wedges, while keeping the calibration of the demand wedges at its baseline values in Table 1. The dashed lines show that the benchmark pandemic scenario can actually produce inflationary pressures in the first periods of the simulation under the *severe* calibration of the supply-side wedges. By contrast, the *mild* calibration of supply-side wedges results in an immediate deflationary response with the trough reached at -0.7p.p. relative to the no-Covid baseline.

# 5 Macroeconomic amplification channels

This section considers additional macroeconomic amplification channels which were not activated in our simulation simulations up to now but could fit the narrative of the shock related to the COVID-19 crisis. As demonstrated previously, the health situation and confinement measures can lead to strong retrenchment in households' consumption and labour supply, as well as cuts in firms' capital expenditures and labour demand through V-shaped type of shocks which we called "pandemic wedges". But unravelling the macroeconomic consequences of the pandemic emergency may also require to account for real-financial amplification risks as well as eventual hysteresis which could put a break on the recovery from the COVID-19 crisis. More specifically, we revisit the benchmark scenario assuming some lasting labour market disruptions, an uncertainty shock, and pro-cyclical financial market deterioration.

As mentioned previously, for the subsequent simulations, we treat the international environment as exogenous and assume unchanged monetary and fiscal policy.

## 5.1 Persistent supply-side disruption

Post-recessionary periods in the past have often been connected to labour market hysteresis. The early evidence from the US labour market suggests that the COVID-19 crisis is no exception. Namely, the survey based data analysed by Coibion et al. (2020) show that the reduction in the US employment in April was predominantly reflected in reduced labour supply and to a relatively lesser extent in unemployment. While early retirement has been exposed as the main driver behind the atypical correlation between employment and unemployment, other factors like health risk and higher share of homemakers due to reduced child care and services may impose a persistent impact on labour force participation. Specifically, the empirical results for the panel of OECD countries, studied in Duval et al. (2010), point towards peak response of labour force participation being on average attained 5 years after initial downturn shock. To account for labour force hysteresis we assume a persistent 0.6 p.p. drop in trend labour force participation rate, which would match an average computed decrease after 2 years in severe downturn episodes documented in Duval et al. (2010).

Moreover, following the discussion of Ball (2009), the hysteresis is also allowed to be reflected in the trend unemployment rate. Namely, findings of Ball (2009) show that, especially in crisis episodes, large aggregate demand shocks can be central to explaining the dynamics of long-term unemployment. Accordingly, we assume that 20% of the change in unemployment spills over to the change in trend unemployment over the course of the simulation horizon.

Finally, following Bodenstein et al. (2020), the permanent supply-side disruption is completed by adding a 1% persistent drop in trend labour productivity. This implies that part of the loss in productivity may become lasting as containment measures trigger pervasive dysfunctions in the goods market supply chain, thereby hampering the productive efficiency of the economy. These effects may also come from spontaneous social-distancing and other precautionary measures that workers and firms may engage in even after the phasing-out of the official preventive and lockdown measures.

Impulse responses incorporating permanent supply-side disruptions are depicted by dashed lines in Figure 7. Compared to the benchmark scenario (depicted by solid lines), a permanent supply disruption is passed to a persistently lower potential output. On the nominal side, lower potential output elevates the inflation response through less negative output gap. On the real side, however, output remains roughly 2% below the no-Covid benchmark due to permanently lower consumption and depressed investment activity.

## 5.2 Uncertainty and financial amplification

This paper essentially attempts to predict future macro outcome related to severe economic shock. Adrian et al. (2019) show that while a well defined macroeconomic modelling structure can provide a solid basis for median GDP forecasts, it is commonly not sufficient to capture the tail events related to severe downturns. To appropriately capture vulnerability of macro forecast, Adrian et al. (2019) propose the use of financial condition indicators which tend to offer a reliable signal of uncertainty shock to the economy. The hypothesis was for the euro area confirmed by Figueres and Jarociński (2020) who as a preferred measure of financial conditions and uncertainty put forward the Composite Indicator of Systemic Stress (CISS) designed by Kremer et al. (2012).

Therefore, to account for the uncertainty channel we calibrate an additional exogenous shock by projecting the proposed uncertainty indicator, CISS, on the residuals of expected investment, consumption and employment.[17] In addition, to account for the asymmetry in relation between

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[17] Residuals are obtained from VAR models that are used to construct expected values of the future target values

CISS and the expected demand components related to extreme negative conditions, we estimate regressions for the 25th quantile of each respective variable.[18] The estimation results are available in Table .1. Given the maximum elasticities observed for each respective expected target in Table .1 and the peak observed value for CISS in March 2020 of 0.6, the calibration of an uncertainty shock would coincide with roughly 3.7% drop in expected investment quarterly growth, 0.5% drop in expected consumption growth and 0.6% drop in expected employment growth.

In addition to macroeconomic uncertainty, we also consider real-financial amplification mechanism. Namely, the magnitude of the economic shock from the COVID-19 crisis is likely to give rise to strong pro-cyclical effects through the financial sector. Macroeconomic downturns and declining financial asset prices are eroding the net worth of households and firms, spurring a sharp rise in credit risk and actual defaults, which in turn deteriorates lending conditions for firms and consumers. To account for the real-financial linkages we first assume an initial financial shock in 2020Q1-Q2 calibrated using the latest data on the corporate bond rate, spread on NFC lending rate, and cost of financing to be increased.[19] Beyond the initial shock on financing conditions, the financial block within the ECB-BASIR is allowed to respond endogenously to the unfolding economic consequences of the scenario.

Against this background, the dotted lines in Figure 7 depict the amplification related to uncertainty and financial propagation on top of the one already implied by persistent labour supply effects. In the model, financial amplification leads to a strong rise in external finance premium by 150 bps. Together with the macroeconomic uncertainty shock, these amplification factors are predominantly transmitted through lower investment. Compared with the benchmark scenario, the investment response is roughly 15% lower in 2021 and 2022. By the end of the forecast horizon, the huge negative impact on investment largely explains the 5% lower GDP, 3 p.p. higher unemployment and almost 1 p.p. lower inflation rate than in the benchmark scenario.

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of the variable of interest, $\mathbb{E}_{t-1}\sum_{j=0}^{\infty} d_j \Delta i^*_{t+j}\ for\ i = c, n, i$. For more details see Section 2.2.

[18] The estimation sample related to expected target investment spans period from 2000Q4 to 2014Q4, while estimation period for expected consumption and employment is longer and it spans period from 2000Q4 to 20184. Period 2015Q1 to 2018Q4 is exempted for the case of investment due to volatile investment dynamics attributable to specific data issues in official national accounts statistics.

[19] Specifically, we assume spread on NFC lending to be increased by 72b.p. in the first quarter and 114b.p. in the second quarter, while corporate bond rates and cost of equity are assumed to increase by 24b.p. in the first quarter and 75b.p. in the second quarter.

## 6 Conclusion

We augment a semi-structural macro model, the ECB-BASE, with an epidemiological model including quarantine elements to assess economic effects and lockdown policies. The link with the epidemiological model is via demand and supply. Our simulations show that different confinement measures, forcing lockdowns, keeping the infected in quarantine or tracking down those that have recovered yield different effects on the economy. Moreover non-targeted containment policies stop the spread of the virus, but have large economic costs. Economic outcomes following no containment policies are less severe, but permanent. Targeted containment policies, especially discovering and quarantining infected people, have huge epidemiological and economic benefits.

Finally, with this model we examine additional amplification channels via uncertainty, adverse financial conditions and supply disruptions all of which lead to a more severe recession and also severely hamper the recovery.

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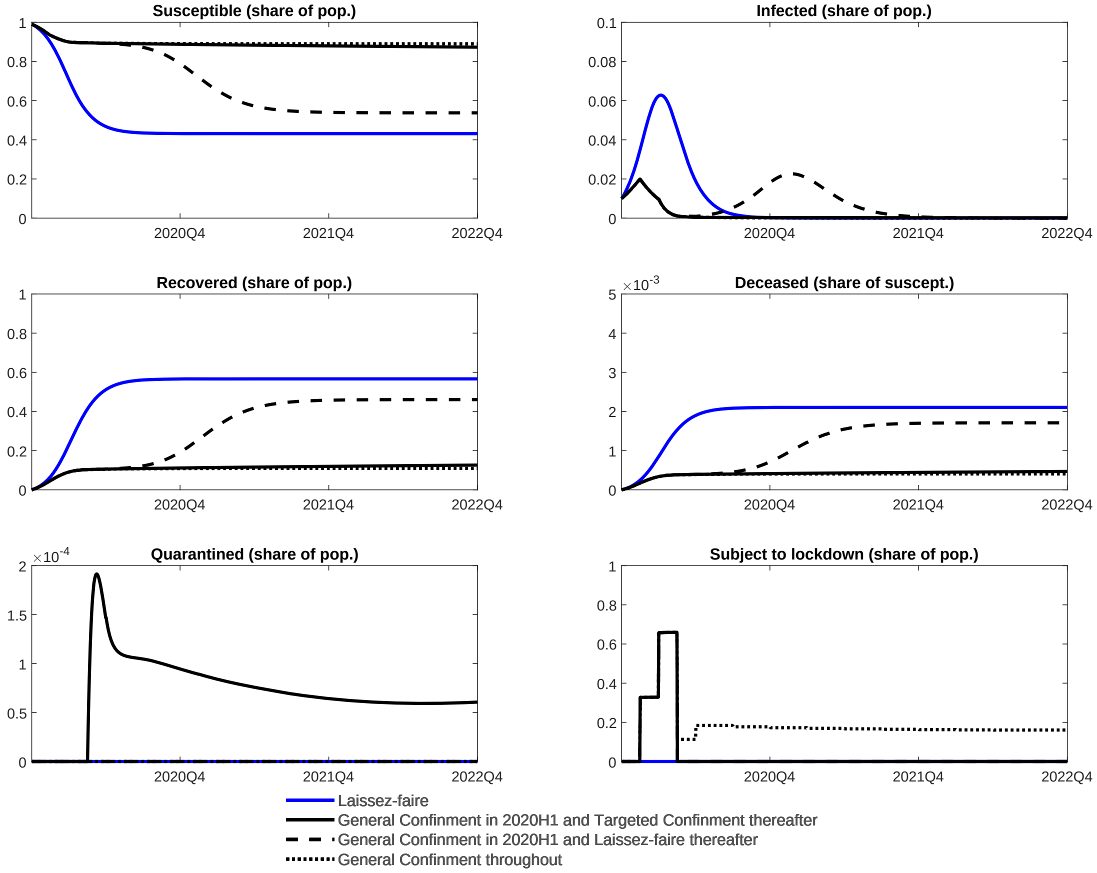
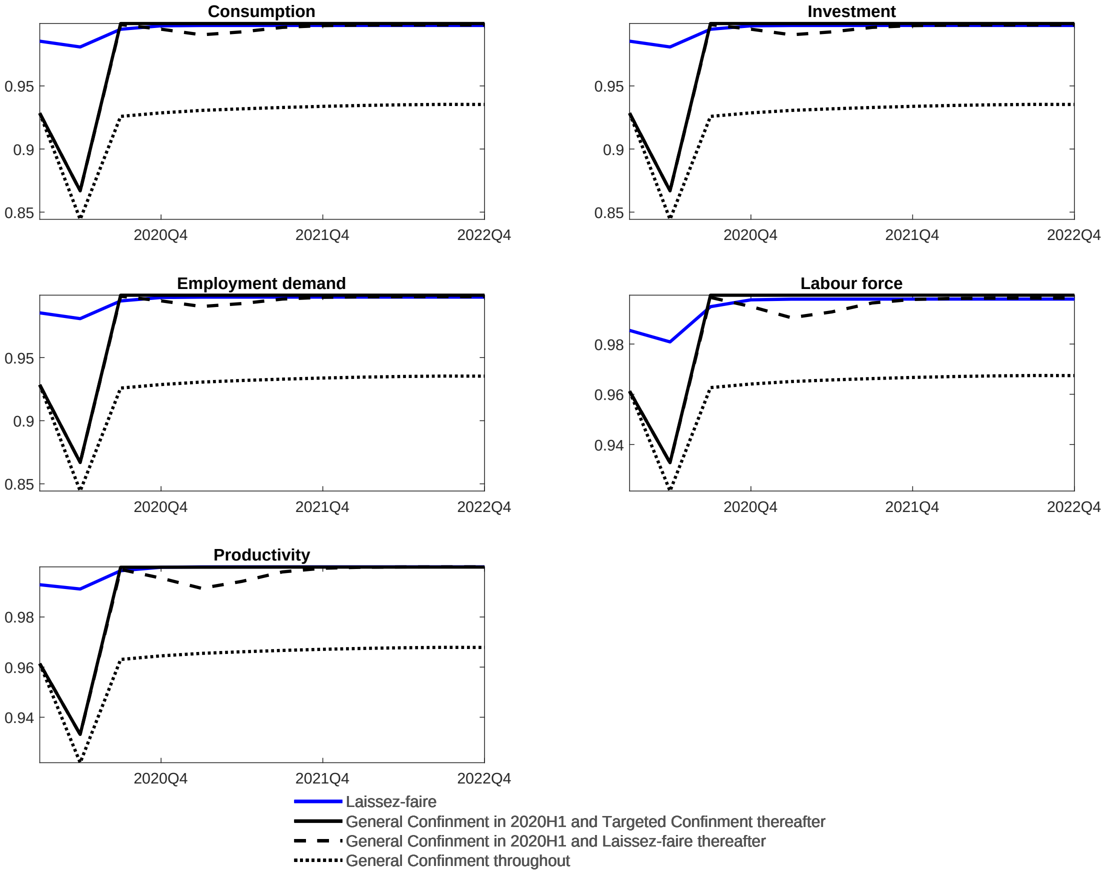
Figure 1: SI(Q)R block variables under baseline specifications - no containment vs containment



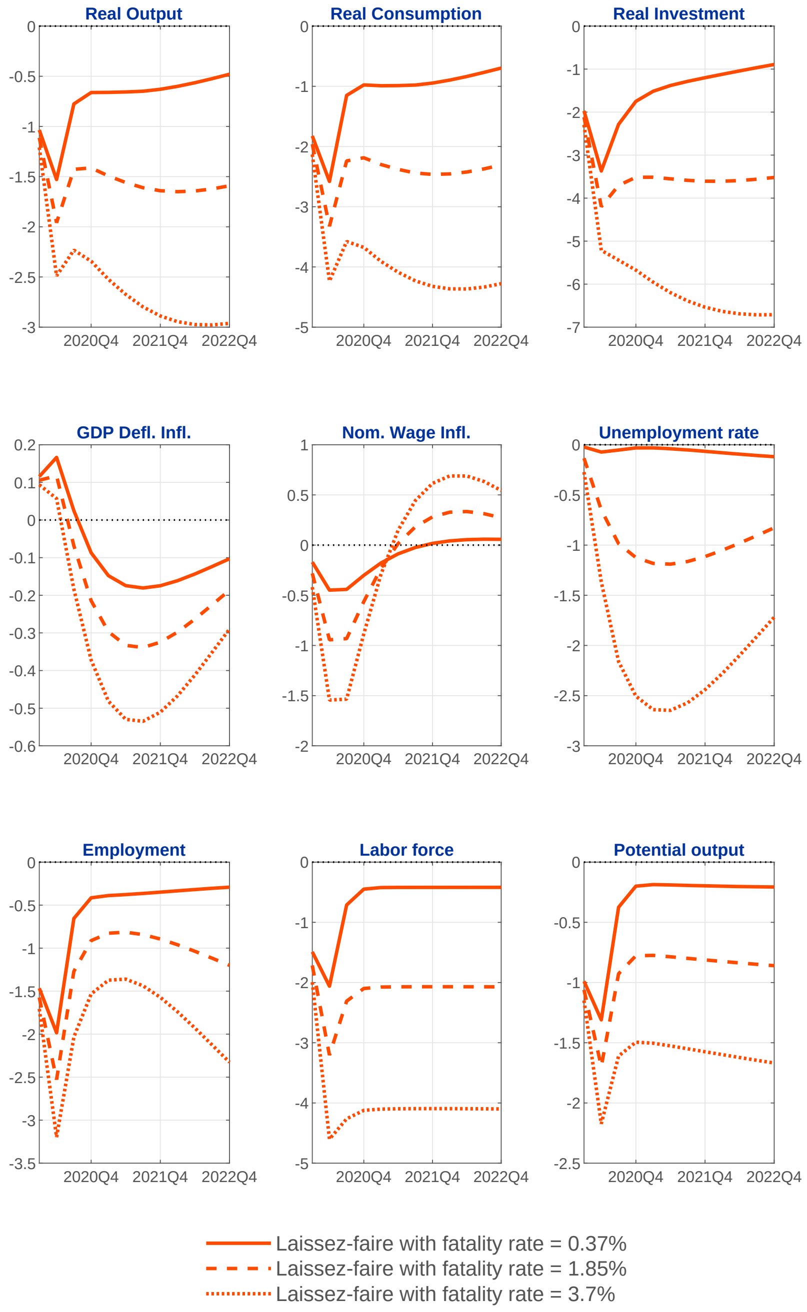
Note: The figure shows SI(Q)R variables related to the baseline calibration. The blue solid line represents realizations of the virus block under "Laissez-faire". The black solid line correspond to generalized confinement policy for 20H1 followed by targeted confinement through testing, detection and quarantine. The dashed line represents realizations in case of generalized confinement policy for 20H1 without containment measures thereafter. The dotted black line depicts the case of generalized confinement policy for 20H1 followed by subsequent generalized confinement interventions.

Figure 2: Pandemic wedges under the baseline parameter calibration



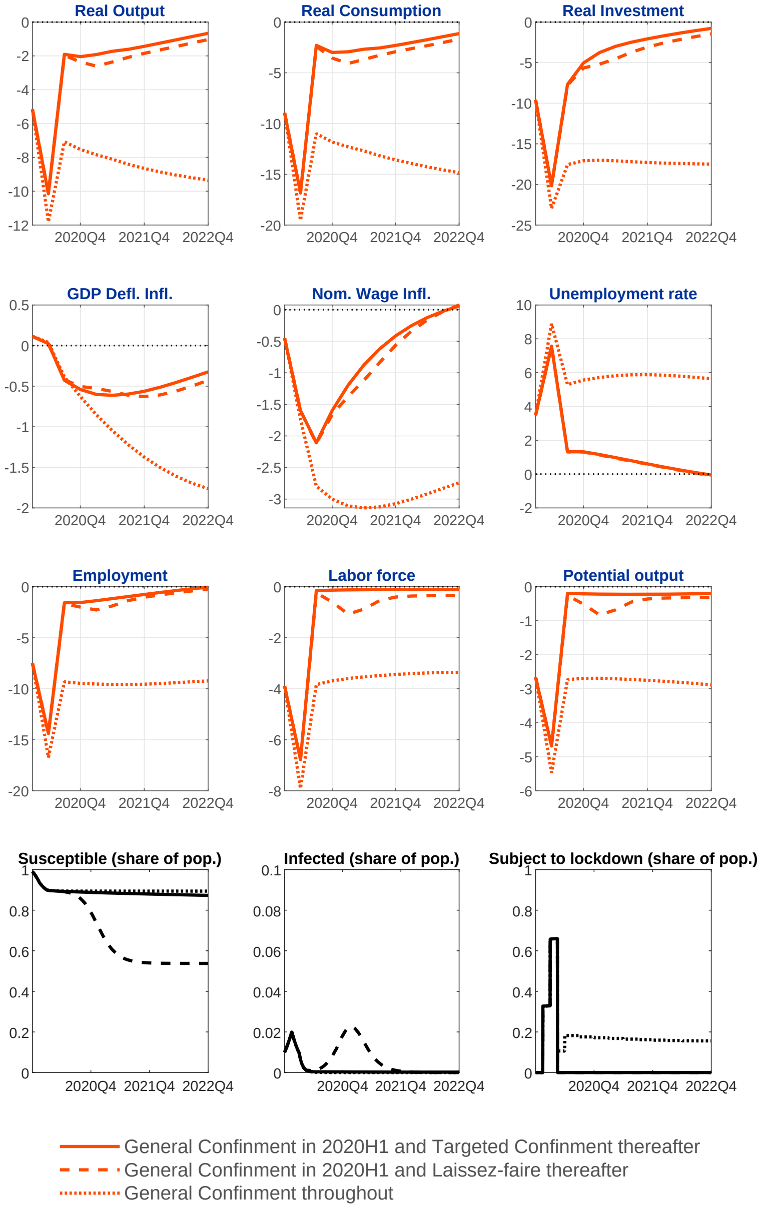
Note: The figure shows ad-hoc adjustment factors or pandemic wedges imposed on endogenous responses of selected variables in line with the baseline parameter calibration set in Table 1. The blue solid line represents pandemic wedges under "Laissez-faire" policy response. The black solid line pandemic wedges under generalized confinement policy for 20H1 followed by targeted confinement through testing, detection and quarantine. The dashed line represents pandemic wedges under generalized confinement policy for 20H1 and without containment measures thereafter. The dotted black line depicts the case of generalized confinement policy for 20H1 followed by subsequent generalized confinement interventions.

Figure 3: Forecast with no containment measures and various fatality rates



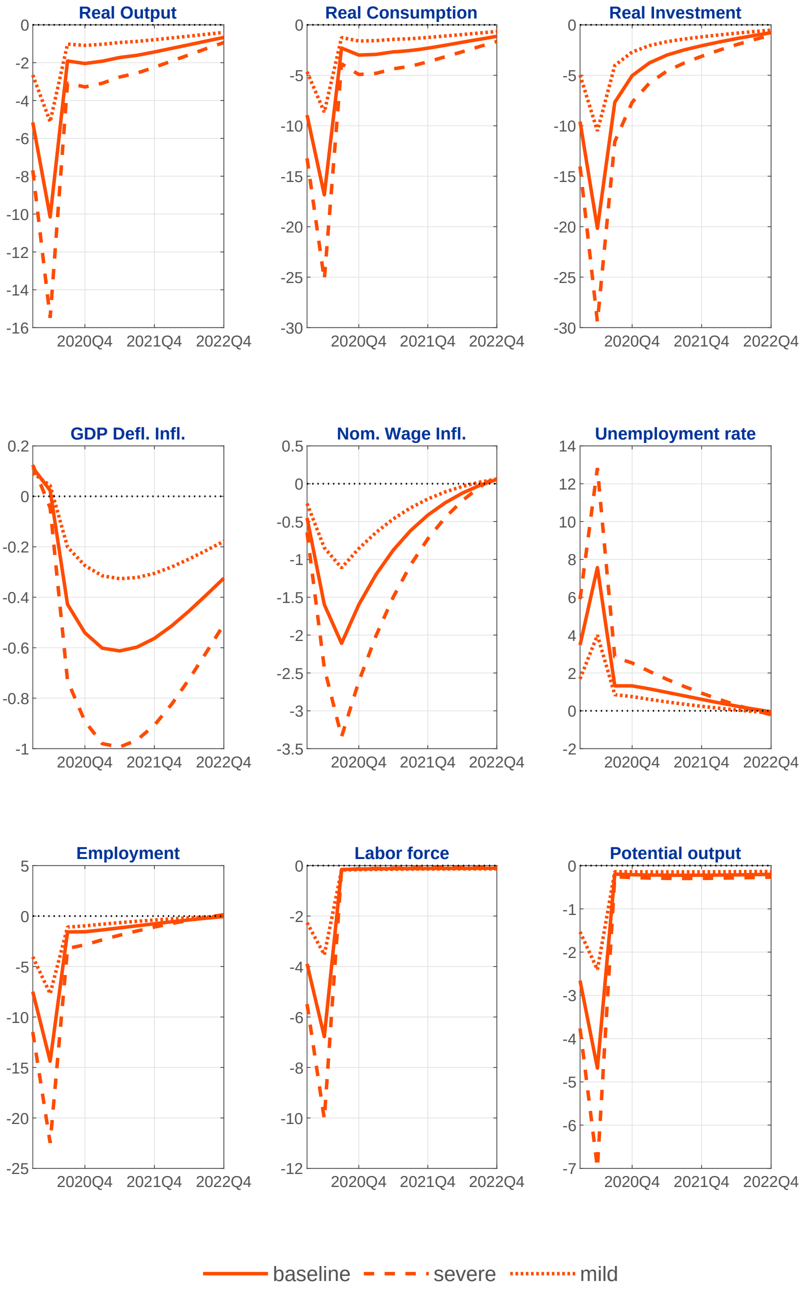
Note: The figure shows simulation outcomes in deviation from baseline. Red solid lines correspond to ”Laissez-faire” scenario with no containment measures and fatality rate equal to 0.37%. The dashed and dotted lines represent counterfactuals with fatality rates of 1.85% and 3.7% respectively. Real variables are expressed as percentage deviations from the baseline levels. Price and wage inflation rates are annualized and expressed as percentage point deviations from the baseline. Unemployment rate and lending rates are expressed as percentage point deviations from baseline.

Figure 4: ECB_BASIR forecast with containment measures and various response policies



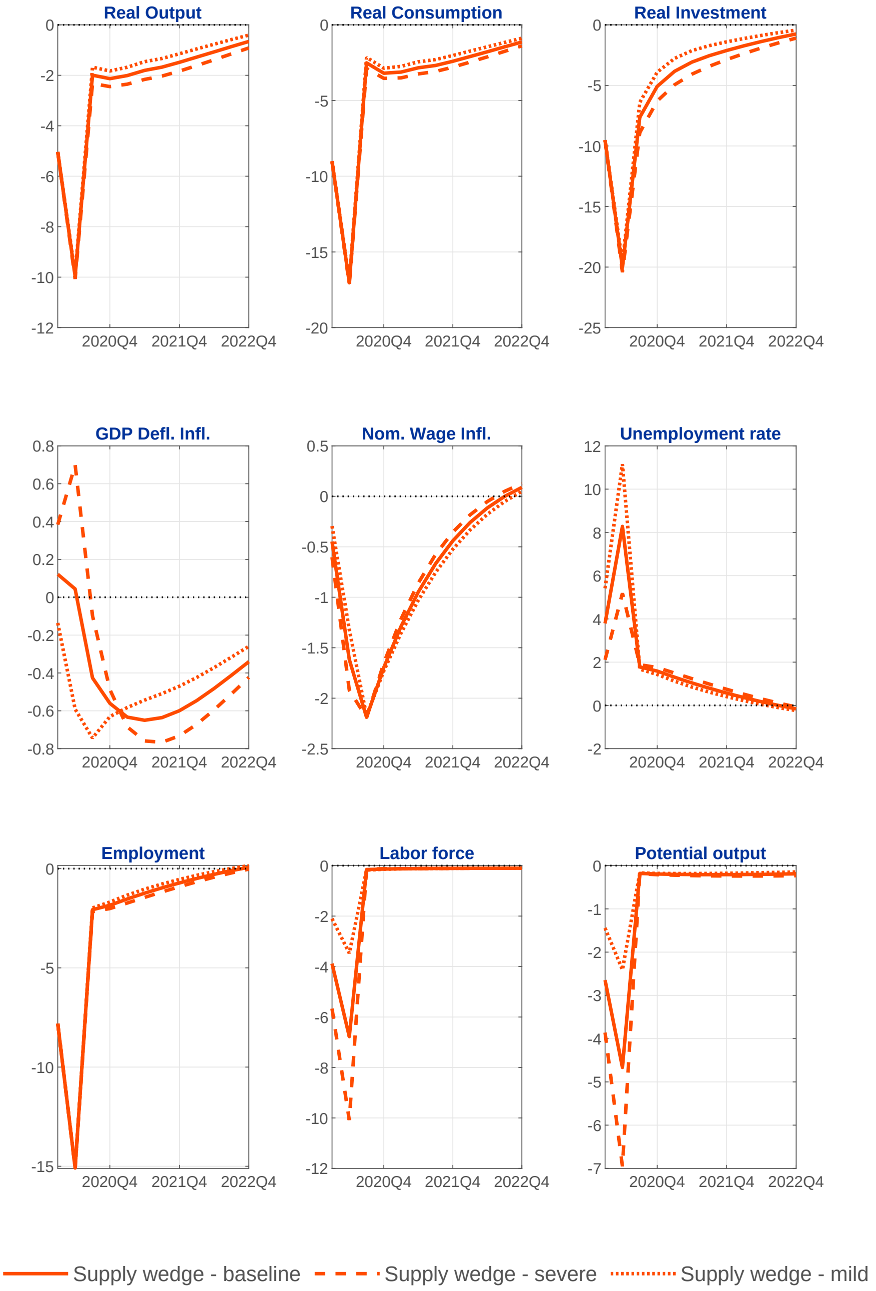
Note: The figure shows simulation outcomes in deviation from baseline. The solid line shows the case where initial confinement policy is followed by efficient policy targeted at infected people in subsequent waves. The dashed line corresponds to the scenario with containment measures in 2020H1 followed by a passive policy thereafter. The dotted line represents a case of confinement followed by confinement of all susceptible in order to keep spread of disease at 1 in subsequent waves. Real variables are expressed as percentage deviations from the baseline levels. Price and wage inflation rates are annualized and expressed as percentage point deviations from baseline. Unemployment rate and lending rates are expressed as percentage point deviations from baseline.

Figure 5: ECB_BASIR forecast sensitivity to alternative lockdown calibration



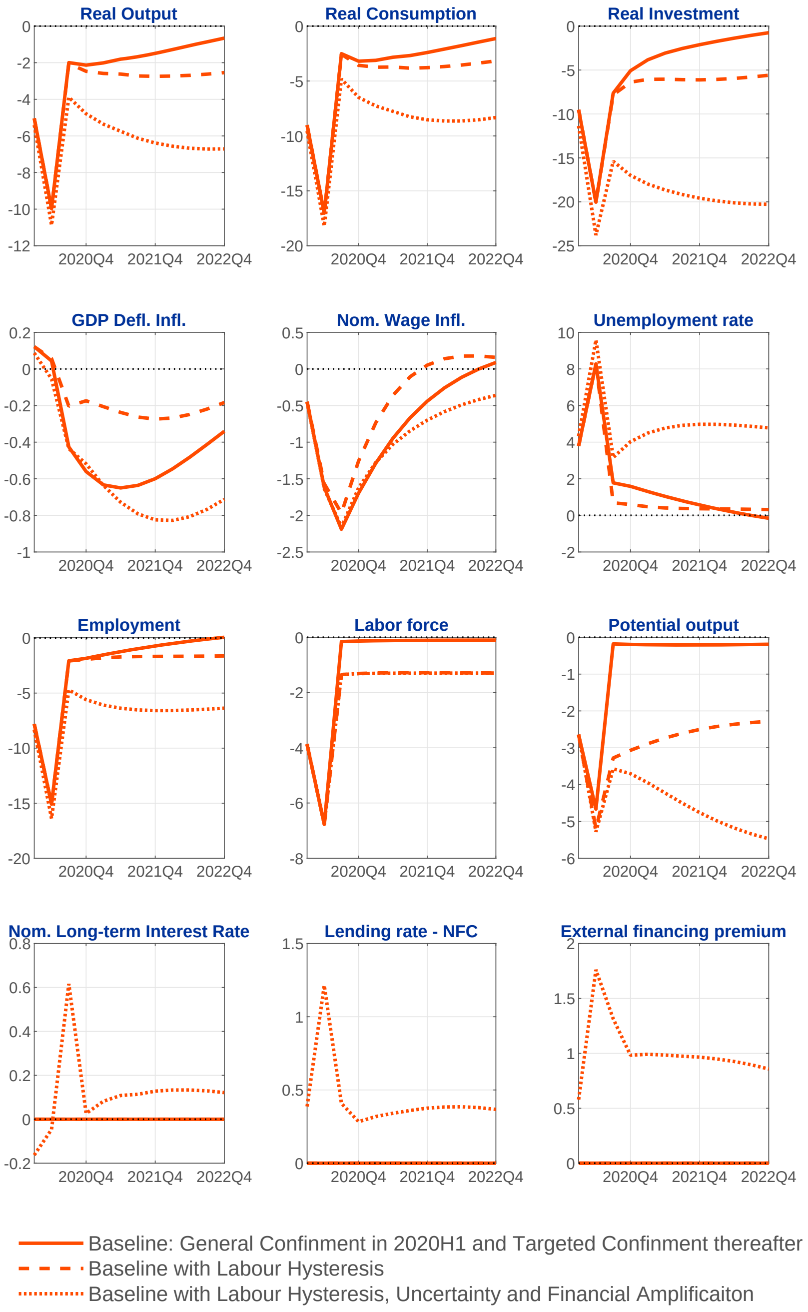
Note: The figure shows simulation outcomes in deviation from baseline. The solid line shows the case where initial confinement policy is followed by efficient policy targeted at infected people in subsequent waves with baseline calibration of $\alpha$ parameters proposed in Table 1. The dashed line report counterfactual related to severe $\alpha$ calibration presented in Table 1. The dotted line represents the scenario with mild $\alpha$ calibration in Table 1. Real variables are expressed as percentage deviations from the baseline levels. Price and wage inflation rates are annualized and expressed as percentage point deviations from baseline. Unemployment rate and lending rates are expressed as percentage point deviations from baseline.

Figure 6: ECB_BASIR forecast sensitivity to alternative supply wedge calibration



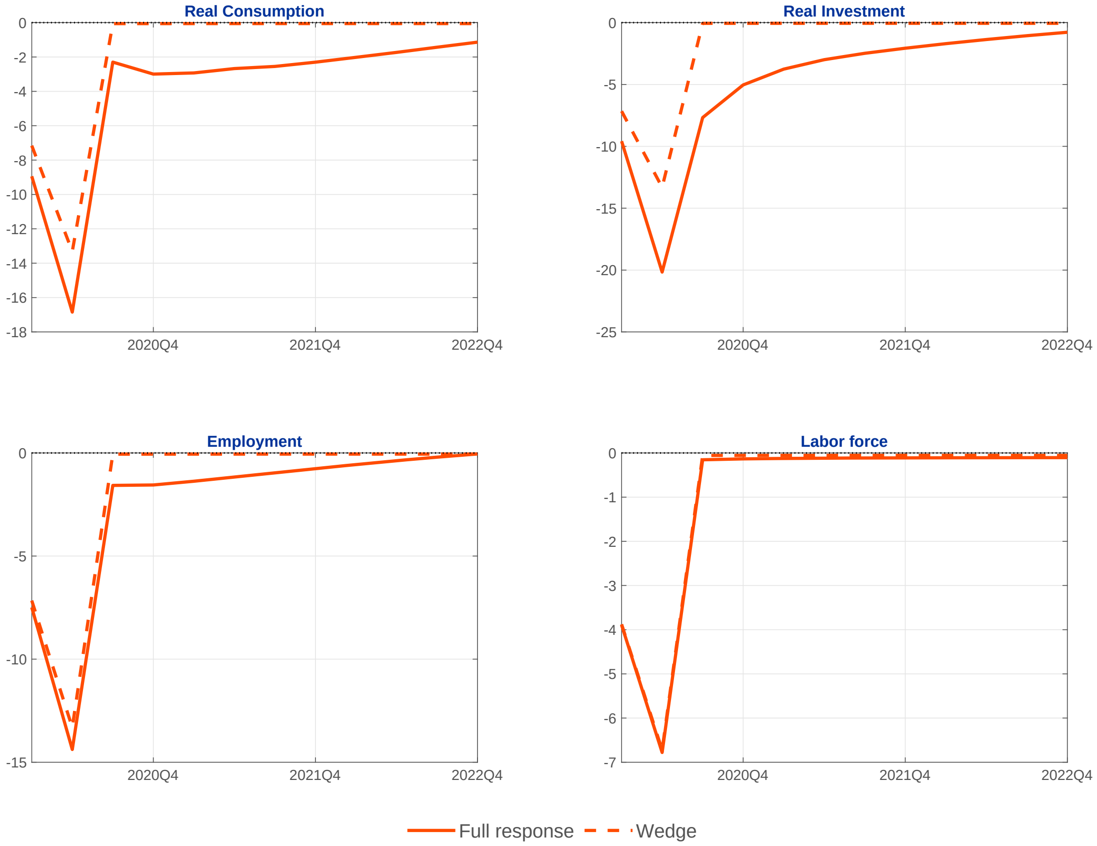
Note: The figure shows simulation outcomes in deviation from baseline. The solid line shows the case where initial confinement policy is followed by efficient policy targeted at infected people in subsequent waves with baseline calibration of $\alpha$ parameters proposed in Table 1. The dashed line report counterfactual related to severe $\alpha$ calibration related only to labour force and productivity variables in Table 1. The dotted line represents the scenario with mild $\alpha$ calibration related only to labour force and productivity variables in Table 1. Real variables are expressed as percentage deviations from the baseline levels. Price and wage inflation rates are annualized and expressed as percentage point deviations from baseline. Unemployment rate and lending rates are expressed as percentage point deviations from baseline.

Figure 7: ECB_BASIR forecast with amplifying effects



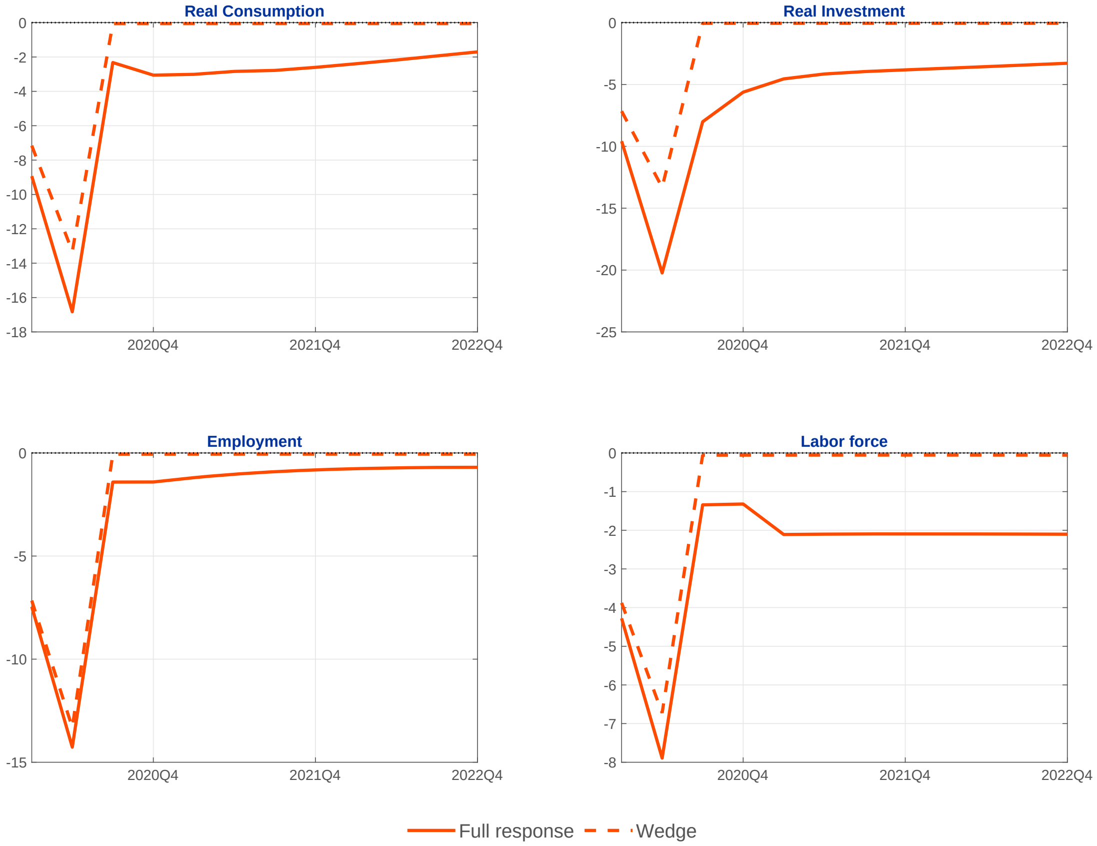
Note: The figure shows simulation outcomes in deviation from baseline. Red solid lines correspond to scenario with containment measures and efficient targeting policy in subsequent waves. The dashed line represent the counterfactual with added uncertainty shocks. The dotted line represent the counterfactual with added uncertainty and financial shocks. Real variables are expressed as percentage deviations from the baseline levels. Price and wage inflation rates are annualized and expressed as percentage point deviations from baseline. Unemployment rate and lending rates are expressed as percentage point deviations from baseline.

Figure .1: ECB_BASIR full baseline response versus pandemic wedge



Note: The figure shows simulation outcomes in deviation from baseline. Red solid lines correspond to full response of variables related to scenario with containment measures and efficient targeting policy in subsequent waves. The dashed line represent the response of variables based on corresponding pandemic wedges and with no endogenous propagation of the model.

Figure .2: ECB_BASIR full baseline response with labour hysteresis versus pandemic wedge



Note: The figure shows simulation outcomes in deviation from baseline. Red solid lines correspond to full response of variables related to scenario with containment measures and efficient targeting policy in subsequent waves and incorporated labour market hysteresis. The dashed line represent the response of variables based on corresponding pandemic wedges and with no endogenous propagation of the model.

Table .1: Estimated elasticities between CISS and expected target residuals

| | Residual of expected one-period-ahead target | | | | | |
|---|---|---|---|---|---|---|
| | Investment | | Consumption | | Employment | |
| | OLS | Q25 | OLS | Q25 | OLS | Q25 |
| $CISS_t$ | -2.98*** | -6.28*** | -0.29** | -0.86*** | -0.39*** | -0.92*** |
| $CISS_{t-1}$ | -3.30*** | -4.59*** | -0.24*** | -0.84*** | -0.49*** | -0.83*** |
| $CISS_{t-2}$ | -2.47*** | -4.42*** | -0.15** | -0.88*** | -0.48*** | -0.79*** |
| $CISS_{t-3}$ | -2.03*** | -4.42*** | -0.04** | -0.04*** | -0.46*** | -0.53*** |

Note: The table reports elasticities of respective residuals of one-period-ahead expected demand components and the CISS indicator. Demand components considered are expected investment, consumption and labour demand. The first row reports contemporaneous elasticities, while rows 2 to 4 report elasticities related to one-, two- and three-quarter lag of the CISS indicator. Columns denoted as *OLS* correspond to the ordinary least square estimation, whereas columns denoted as *Q25* correspond to estimates obtained via quantile regressions related to 25th quantile. The estimation sample spans period from 2002Q1 to 2016Q4.

*** - indicates statistical significance at 1%, ** - indicates statistical significance at 5%

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