A Macroeconomic Model of Healthcare Saturation, Inequality and the Output–Pandemia Trade-off

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Published online: 14 November 2022
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Abstract
COVID-19 became a global health emergency because it threatened the collapse of health systems as demand for health goods and services and their relative prices surged. Governments responded with lockdowns and transfers. Empirical evidence shows that lockdowns and healthcare saturation contribute to explain the cross-country variation in GDP drops even after controlling for COVID-19 cases and mortality. We explain this output–pandemia trade-off as resulting from a shock to subsistence health demand that increases with capital utilization and economic activity in a model with entrepreneurs and workers. The health system saturates as the gap between supply and subsistence narrows, which worsens consumption and income inequality. An externality distorts utilization, because firms do not internalize that lower utilization reduces healthcare saturation. Lockdowns and transfers to workers are the optimal policy response. Quantitatively, strict lockdowns and large transfers yield sizable welfare gains because they neutralize the utilization externality and prevent a sharp rise in inequality. Welfare and output costs vary in response to small parameter changes or deviations from optimal policies. Weak lockdowns coupled with weak transfers programs are the worst alternative and yet are in line with what several emerging and least developed countries implemented.

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JEL Classification E60 · H0 · I18

1 Introduction

A distinguishing feature of the COVID-19 pandemic is that, unlike other viral illnesses that are either more lethal (e.g., Ebola, MERS) or just as contagious but less severe (e.g., Influenza, H1N1), it caused a large, sudden surge in demand for health goods and services (e.g., human and material resources for prolonged hospitalizations, medical and cleaning supplies, etc.). Thus, in addition to its infection and mortality rates, a key challenge posed by COVID-19 has been the threat of catastrophic collapse of health systems worldwide. The severe strain on health systems is evidenced by the suspension of regular hospital services to concentrate on COVID treatment and by the sharp increases in occupancy of hospital beds, particularly ICU beds, in demand for medical specialists and nurses, and in usage of critical equipment such as respiratory ventilators. As a result, excess mortality rates rose significantly above those explained by COVID illness itself.

Governments around the world responded to the stress on health systems by imposing severe lockdowns that required all non-essential businesses to close and households to obey strict stay-at-home orders. These lockdowns resulted in the largest quarterly declines in GDP in history in many countries during the second quarter of 2020, with a median of $-10.6\%$ relative to the second quarter of 2019 in a sample with 48 countries (see Sect. 3 for details). A full eighteen months after the initial COVID outbreak, and despite the availability of vaccines in many countries, the pandemic still continued to push hospitals to the brink of collapse.

The unprecedented economic costs of the lockdowns, on the one hand, and their effectiveness at preventing the collapse of health systems, on the other hand, pose a critical public policy trade-off: What is the socially optimal severity of a lockdown that balances the need to contain a pandemic like COVID-19 against its large economic costs? Related to this are other central questions: How does the pandemic affect income and consumption inequality? What is the optimal size of transfers for workers to offset the adverse effects of the lockdown? How does heterogeneity in economic development and health-system strength affect the output–pandemia trade-off?

This paper answers these questions by proposing a model that deviates from the widely used approach of integrating the susceptible–infected–recovered (SIR) model of epidemiology into dynamic macroeconomic models. Instead, we propose a framework that focuses on the severe scarcity problem caused by the pandemic and gives a central role to the saturation of health systems and the shortages of health goods. This approach is motivated by the key observation that COVID-19 put health systems at the risk of collapse despite its low mortality rate and large share

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1 According to the CDC, the median length of hospitalizations for surviving patients in the USA as of October 2020 was 10–13 days. Severe shortages of medical staff, ventilators, N95 masks, disinfectants, and various other health-related products were reported worldwide since the initial outbreak in January 2020.
of asymptomatic infections. By November 2021, worldwide estimates showed that for each confirmed COVID case there were in fact ten asymptomatic ones: the case fatality rate (CFR) exceeds the infection fatality rate (IFR) by a factor of 10 (at 2.02 and 0.23%, respectively). This low IFR is a central feature of COVID-19 that questions the emphasis of the SIR models on the mortality rate as opposed to the risk of saturation of health systems. Indeed, the collapse of healthcare systems resulted in excess weekly deaths as a percent of expected deaths as high as 154% in Spain, 108 in the United Kingdom, 90 in Italy, and 45 in the United States. In Mexico City excess mortality reached 300% in the March-May 2020 period.

The paper starts with an empirical examination of cross-country data on COVID-19 and its impact on economic activity. We first discuss the capacity constraints facing medical systems in the treatment of COVID-19 patients. We then show that as healthcare systems hit capacity constraints, the prices of medical goods and services spiked, particularly those that were necessary for protection against COVID-19, and governments imposed lockdowns that in turn had a negative impact on economic activity. Then, we conduct an empirical analysis showing that a non-trivial share of cross-country differences in observed output declines caused by the pandemic is explained by variables that proxy for the severity of lockdowns, resource shortages and pre-COVID-19 health system strength, even after controlling for standard SIR measures such as COVID-19 case rates and fatalities.

We next provide a macroeconomic model of the pandemia, featuring two types of agents, a representative firm, and a government. The agents are entrepreneurs, who collect wages and capital income from the health and non-health sectors, and workers, who collect only wage income. All agents have the same utility function over non-health and health goods and services with the subsistence demand for health goods and services as in Stone–Geary preferences. Firms decide on capital utilization and labor demand to produce non-health goods and maximize profits. The supply of health goods is fixed over time. The government uses lump-sum transfers to re-distribute resources across agents. The pandemia is modelled as a large, temporary shock to the subsistence demand for health goods and services that is larger at higher capital utilization. The degree of saturation of the health sector is represented by the gap between the available supply of health goods and services and their

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2 The CFR is the ratio of confirmed fatalities to confirmed cases worldwide reported by Johns Hopkins University as of Nov. 5, 2021. The IFR is from WHO research by Ioannidis (2021) and corresponds to the median of 74 estimates from 61 studies for 33 countries.

3 Ioannidis (2021) explains the relevance of the low IFR as follows: “The infection fatality rate, the probability of dying for a person who is infected, is one of the most important features of the COVID-19 pandemic... Some stringent interventions that potentially also result in more noticeable collateral harms may be considered appropriate, if the infection fatality rate is high. Conversely, the same measures may fall short of acceptable risk–benefit thresholds, if the infection fatality rate is low...Early data from China suggested a 3.4% case fatality rate and that asymptomatic infections were uncommon, thus the case fatality rate and infection fatality rate would be about the same”.

4 See [https://ourworldindata.org/excess-mortality-covid](https://ourworldindata.org/excess-mortality-covid) and [https://www.washingtonpost.com/world/the_americas/mexico-city-coronavirus-excess-death-toll/2020/07/02/2baaab3e-bbbb-11ea-80b9-40ec9a701dc_story.html](https://www.washingtonpost.com/world/the_americas/mexico-city-coronavirus-excess-death-toll/2020/07/02/2baaab3e-bbbb-11ea-80b9-40ec9a701dc_story.html).
subsistence level, and the catastrophic (i.e., nonlinear) nature of a health-system collapse is captured by the Inada condition of Stone–Geary preferences.

In the decentralized competitive equilibrium, in which the government does not intervene during the pandemic, aggregate allocations remain unchanged during the pandemic and are independent of agent heterogeneity, but the relative price of health-to-non-health goods surges and causes redistribution of consumption and income from workers to entrepreneurs. This is the result of a “utilization externality”: firms do not internalize the link between utilization and health-system-saturation when choosing capital utilization. Hence, when the pandemic hits utilization is unchanged. Consequently, the pandemic brings the health system closer to saturation and leads to a surge in the price of health goods. This worsens income and consumption inequality across agents, since the relative income of workers falls more and their consumption moves closer and faster to their subsistence levels.

We then consider the social planner’s optimal allocations, which differ from the competitive equilibrium allocations in two important dimensions. First, the planner internalizes the utilization externality and finds it socially optimal to reduce utilization during a pandemic, because the social marginal cost of utilization is higher than the private cost. Lower utilization relaxes saturation of the health system, but it also reduces demand for factors of production, output and factor payments in the non-health sector. This creates the output–pandemia trade-off. Second, the planner also redistributes from entrepreneurs to workers to neutralize the pandemia-induced increase in inequality in relative excess consumption (or relative marginal utilities) of entrepreneurs vis-a-vis workers. The planner’s optimal utilization rate and shadow relative price of health goods are unaffected by agent heterogeneity and inequality, but the optimal redistribution does depend on heterogeneity. The planner’s allocations can be decentralized as a competitive equilibrium by simultaneously imposing an optimal lockdown (i.e., a binding constraint on utilization) and increasing transfers to workers.

We finally explore the model’s quantitative implications using a calibration to US data. Key to this calibration are the subsistence demand for health in normal times (i.e., without a pandemic) and the elasticity of this subsistence demand with respect to utilization in a pandemic. For the former, we conduct a linear expenditure system estimation with US health-sector data. For the latter, we set the baseline elasticity at 0.09 to generate an output drop in the planner’s problem equal to the drop in US non-health GDP in the second quarter of 2020. Compared to the competitive equilibrium with no government intervention, the planner neutralizes the utilization externality and the large rise in consumption and income inequality caused by the pandemia by implementing a lockdown equivalent to a 15.2% cut in utilization and an increase in transfers to workers of 10.9% of GDP. Assuming that the pandemia lasts four quarters, these optimal policies yield a utilitarian social welfare gain of 0.82% (in terms of a compensating variation in consumption constant across time and agents that equalizes social welfare with and without the policy intervention).

A policy implementing the lockdown alone (without increasing transfers) yields a welfare gain of 0.49%, which represents a loss of 0.33% relative to the optimal policy regime. This indicates that the adverse effects of the pandemia on inequality are large. Although inequality in the lockdown-only case is much lower than in the
no-intervention case, it is still substantially higher than in the planner’s social optimum. The ratio of excess consumption of entrepreneurs to workers rises threefold in the lockdown-only case and fivefold in the no-intervention case during the pandemic. This is because the relative price of health goods surges by 101% in the lockdown-only case and by 158% in the no-intervention case. Furthermore, the entrepreneur’s capital income from the health sector rises much more in the no-intervention case than the lockdown-only case.

Inequality and distributional effects also make the model more plausible. In a representative-agent version of the model, the social planner gains only by removing the utilization externality. As a result, it requires much larger elasticities of subsistence health demand to utilized capital (of at least 0.13) to generate non-trivial welfare gains. These elasticities, however, imply output drops much larger than observed in the data.

The output–pandemia trade-off is nonlinear in the sense that the optimal size of the lockdown is increasing and convex in the elasticity of subsistence health demand to utilized capital. Hence, small errors in measuring the elasticity result in non-trivial differences in the size of optimal lockdown and transfer policies and their effects on aggregate variables and inequality.

We quantify the implications of deviating from the optimal lockdown and transfer policies and find that they result in sizable welfare costs relative to the optimal policies. Policy intervention to respond to the pandemic, however, is generally preferable to no intervention. Moreover, transfers and lockdowns are substitutable to a degree and using either tool with sufficient strength gets reasonably close to the gains attained by the optimal policies. The reason is that either large transfers or a strict lockdown weakens significantly the strong adverse effects of the pandemic on inequality. For the same reason, however, combining weak lockdowns with small transfers programs is the worst policy choice. Unfortunately, this seems to be what occurred in emerging and least developed countries, which on average responded to COVID-19 with weaker lockdowns and smaller fiscal interventions than advanced economies. Using the data from Sect. 3 and from the IMF’s Fiscal Monitor, we found that income per capita has a correlation with COVID lockdown effectiveness of roughly − 0.2 but its correlation with COVID-related transfers is 0.5. Through September 2020, advanced economies increased transfers by nearly 10 percentage points of GDP on average while the increases in emerging and least developed countries averaged 4.4 and 3 percentage points, respectively.

As a robustness check of our model, we study an extension of it where we allow for heterogeneous impacts of the pandemic on the rise of the subsistence demand of agents in the economy. Entrepreneurs are less affected by the saturation of the healthcare system, capturing the idea that one group of agents experiences smaller health risks. Our findings show that milder impacts on the subsistence demand of this type of agents lead to weaker lockdowns, increases in transfers, and rises in inequality. We also explore varying the fraction of agents that are subject to the weaker impact on their subsistence demand. Our results show that even in extreme cases like when the subsistence demand of 50% of the population is unaffected by the pandemic, lockdowns and transfers are still sizable, with cuts in utilization of 4% and increases in transfers of 8 percentage points of GDP.
The model and the quantitative findings have important implications for the analysis of cross-country or cross-region responses to COVID-19. The model predicts that the pandemia has been more damaging for countries with higher wealth inequality and/or weaker pre-pandemia conditions in characteristics such as quality or capacity of health systems, income per capita, etc. Weaker pre-pandemia conditions can be thought of as implying higher elasticities of subsistence health demand to utilized capital which the model associates with larger optimal lockdowns and output drops. The relative size of the health sector also reflects cross-country differences in health systems. For a given elasticity, the model predicts larger effects of pandemias in countries with smaller health sectors or smaller shares of non-health expenditures.

The rest of the paper is organized as follows. Section 2 places our paper in the context of the growing macro literature on the pandemia. Section 3 provides empirical evidence on the relevance of healthcare saturation and important empirical regularities of the macro effects of the COVID-19 pandemia. Section 4 describes the model. Section 5 presents the quantitative results of the calibrated model. Section 6 provides some conclusions.

2 Literature Review

Our paper is related to the growing COVID-19 macro-literature. Most of this literature emphasizes the probabilistic dynamics of contagion, infection, and death (or recovery) from the disease itself, by incorporating them into macro-models using the canonical SIR/SEIR models from epidemiology. The contribution of our work is the focus on resource scarcity and the saturation of the health sector as the drivers of the output–pandemia trade-off and its distributional implications. This is in parallel with the public health literature on pandemias, in which a branch focusing on resource scarcity and saturation of hospitals (e.g., Ajao et al. 2015; Halpern and Tan 2020) coexists with the SIR/SEIR epidemiology branch (see the survey by Britton 2010).

In SIR/SEIR-based models, decentralized equilibria are inefficient because the planner internalizes the disease dynamics and the social welfare function depends negatively (positively) on the death (recovery) rates. In contrast, in the model proposed here social welfare is a standard aggregation of individual preferences, and the adverse implications of a pandemia for efficiency and inequality result from the surge in subsistence demand for health that it causes, which is larger at higher utilization and affects workers more severely than entrepreneurs. Moreover, this framework also accounts for large increases in the relative price of health goods during a pandemia.

Alvarez et al. (2020), Atkeson (2020) and Eichenbaum et al. (2020) initiated the literature on quantitative SIR-based macro-models. In these models, the pandemia affects macroeconomic outcomes through demand and supply effects. Infections and mortality increase with consumption and hours worked. Sick workers become less productive or work less and consume less, and consumption and labor have feedback effects on infections. In addition, contagion causes externalities as agents do
not internalize how their individual actions affect the SIR dynamics. Lockdowns improve efficiency by tackling this externality. Alvarez et al. (2020), Favero et al. (2020) and Jones et al. (2020) introduce also a congestion externality by modeling the COVID-19 fatality rate as an increasing function of total infections above a constant rate. This externality is similar to the utilization externality resulting from the adverse effect of utilization on the health subsistence demand in our model, but it differs in that in the SIR models congestion increases fatalities, which the planner is assumed to dislike. Hence, although both models predict that lockdowns are desirable because of health-system congestion, the mechanism driving the result is different. In particular, in our setup lockdowns are desirable because the pandemia brings all agents closer to their subsistence level of health regardless of whether they are infected and of the COVID-19 fatality rate, and redistribution is desirable because this effect hits workers more severely than entrepreneurs. Moreover, COVID’s very low IFR (estimated at 0.23%) weakens mechanisms of SIR models that rely on a high fatality rate but it is much less relevant for healthcare-saturation driven models like ours.

The macro-SIR/SEIR framework has also been used in models with agent and sectoral heterogeneity, as in the studies by Acemoglu et al. (2020), Baqee et al. (2020), Bodenstein et al. (2020), Azzimonti et al. (2020), Glover et al. (2020), Guerrieri et al. (2020), Hur (2020), Kaplan et al. (2020), Krueger et al. (2020) and Rampini (2020). These studies suggest that lockdowns should be targeted differentially across sectors, with their severity depending on how contact-intensive sectors are, the composition of workers in the sector (age, susceptibility, health), how essential and easy to substitute are the goods produced by the sector, and how connected agents are in a production network. In most of these articles, agent and/or sectoral heterogeneity drive the policies due to their effect on aggregate outcomes and on the dynamics of infection, recovery and death rates.

SIR models with wealth and income inequality have also been used to study the optimal redistributive policy during a pandemia. Glover et al. (2020) find that the optimal policy involves redistribution from agents that continue working towards those who cannot or who lost their jobs. Bloom et al. (2020) argue that lockdowns and transfers should consider dimensions of income and wealth inequality, because low-income or low-wealth workers typically are more affected by lockdowns since their occupations are less suitable for teleworking (see also Galasso 2020, Mongey et al. 2020 and Palomino et al. 2020). Thus, economies with a larger fraction of low-wealth agents require milder lockdowns and/or larger transfers. Chetty et al. (2020) examine heterogeneous effects on consumption. Using high-frequency data, they find that COVID-19 has had negative effects on consumption, with lower-income agents being affected disproportionately.

The SIR framework has also been used in open economy models. Arellano et al. (2020) embed SIR dynamics into an Eaton–Gersovitz sovereign default model. The sovereign cares about the fatality rate and imposes lockdowns in order to mitigate the magnitude of the health crisis. Since lockdowns depress output, the sovereign has the incentive to borrow abroad to smooth consumption, but this increases default risk and hence limits the planner’s ability to impose aggressive lockdowns as its borrowing capacity is restricted, costing additional lives. Cakmakli et al. (2020) study
a multi-sector model with sectoral supply and demand shocks that vary with infections depending on lockdowns. The openness of the economy matters via external demand shocks and input-output linkages.

There are other influential macro-models of COVID-19 that do not use the SIR setup and consider the role of financial frictions on firms. Gourinchas et al. (2020) study effects on small and medium enterprises using a model in which the virus causes labor supply constraints that vary by sector and also causes sectoral and aggregate demand shocks and business failures. They find that firm bailouts are better than labor subsidies for reducing bankruptcies and saving jobs and that targeted bailouts have sizable benefits at lower GDP costs. Céspedes et al. (2020) and Fornaro and Wolf (2020) show that financial frictions combined with a negative productivity shock during the pandemic can produce equilibria with long-lasting crises and slow recoveries. Elenev et al. (2020) study a setup in which firms can go bankrupt due to the pandemic and study how bailouts can help save firms that are experiencing financial distress. Faria e Castro (2020) models the pandemic as a shutdown of the contact-intensive services sector (caused by a utility shock) that is transmitted to other sectors in the economy, while Guerrieri et al. (2020) model it as a shock on the labor supply of a productive sector that requires physical interactions (a fraction of workers becomes unable to work in this sector). In turn, reduced consumption of goods from this sector reduces the households’ health. These studies find that transfer payments to workers in sectors affected by the pandemic are socially optimal.

3 Empirical Evidence

In this section, we review the empirical evidence on COVID-19 that motivates the theoretical model and will inform our calibration to data. First, to rationalize our choice of a model that emphasizes the nonlinearity of healthcare saturation, we present evidence on the capacity constraints for COVID-19 treatment. Second, we provide evidence on the spike in prices of critical medical services and equipment that will play a central role in the dynamics following the outbreak of the pandemia. Third we provide international evidence on the severity and duration of lockdowns. Fourth, we use a cross-country analysis to show that measures of healthcare capacity and severity of lockdowns are significant determinants of the output collapse during the pandemia, even after controlling for the SIR variables of COVID transmission. We find that the effects of the non-SIR variables are stronger.

3.1 Resource Shortages and Capacity Constraints for COVID-19

Many diseases, some more deadly and some more contagious than COVID-19, have broken out at various times across the globe. What was it about COVID-19 that resulted in a global health emergency and an unprecedented freeze on economic activity?

Well before the start of the COVID pandemic in the winter of 2020, Ajao et al. (2015) assessed the capacity of the US healthcare system to respond to increased
demand for ventilation therapy due to a hypothetical influenza pandemic under three levels of health-system stress: (1) conventional capacity (usual and normal patient care); (2) contingency capacity (minor adaptation of treatment approaches) and (3) crisis capacity (fundamental, systematic change in which standards of care are significantly altered to allow treatment of a greater number of patients). Their study identified four key components necessary to provide ventilation therapy:

1. Supplies, such as ventilators, ancillary supplies, and equipment.
2. Space, namely hospital beds equipped for ventilation and critical care.
3. Staff, consisting of specialized medical personnel to manage patients on ventilators.
4. Systems, namely accessible, exercised plans to rapidly increase ventilation therapy capacity.

Hence, the provision of ventilation therapy is akin to a Leontief technology that requires complementary inputs in relatively fixed proportions. As a result, hitting a constraint on one input limits the ability to provide ventilation therapy. Taking as given the estimated number of ventilators available in 2010 and assuming that they would not be the constraining factor, Ajao et al. (2015) showed that at the peak of the hypothetical influenza pandemic in the USA, the constraining factor for ventilation therapy in scenarios (1) and (3) would be the number of physicians and respiratory therapists, not the number of beds.5

Halpern and Tan (2020) provide a similar assessment of US capacity for treating COVID-19 patients under current conditions. Based on surveys of US hospitals, they conclude that the critical factor is staffing. “At forecasted crisis levels, we estimate that the projected shortages of intensivists, critical care APPs, critical care nurses, pharmacists, and respiratory therapists trained in mechanical ventilation would limit the care of critically ill ventilated patients” (p. 1). “Moreover, even in the 50% of acute care hospitals with intensivists, the intensivist team may be overstretched as new ICU sites are created or experienced ICU staff become ill” (p. 8). Indeed, as late as December 2021, almost two years into the pandemia, one in five US hospitals reported being stretched to their limits, with intensive care units reportedly operating at 95% capacity.6

As medical systems approach saturation limits due to COVID-19, hospitals respond by reallocating physical and human resources normally dedicated to other uses to treat COVID patients. This shift in access to medical care caused a sharp increase in mortality, as measured by the standard excess mortality P-Score, due not just to COVID-19 but to other non-COVID-19 illnesses. We collect cross-country data for P-Scores computed using the number of total deaths, COVID- and non-COVID-related, at a weekly frequency minus the average of deaths over the

5 Because of the shortage of respiratory therapists in the crisis scenario, the study projects that 28,000 beds would be unused.
6 See https://www.nytimes.com/interactive/2020/us/covid-hospitals-near-you.html for more details.
2015–2019 period and divided by the same 2015–2019 average. Table 1 shows the highest weekly P-Scores for the January–June, 2020 period in 35 countries. The mean (median) reached 42.9 (23.8)%, but in several cases it exceeded 50% (Belgium, Chile, Italy, Netherlands, Mexico, Peru, Spain, Turkey and the U.K.). Since P-scores combine COVID and non-COVID fatalities, they are a noisy measure of fatalities not caused directly by the disease, but in the analysis of cross-country output drops conducted below we will control for COVID fatalities to identify the effect of non-COVID excess mortality.

### 3.2 Rising Prices of PPE and Medical Equipment

A second feature of the saturation of the healthcare system was the severe shortages of medical equipment and cleaning supplies that resulted in sharp price hikes. In the USA, spikes in prices for cleaning supplies, toilet paper and medical masks prompted consumer groups to complain of price gouging. A Google search of images of “COVID price gouging” (as of mid-December 2021) yields pictures of 8 oz. bottles of hand sanitizer priced at $50 and Clorox wipes at over $40 per container. The US PIRG consumer watchdog association reported inflation rates of COVID-19-related goods ranging from 200% for thermometers to 1300% for antibacterial handwipes. These goods disappeared from store shelves where they were priced at regular prices, resulting in massive, prolonged stockouts of key items in retail chains. The prices of these goods facing severe shortages are mismeasured in aggregate price indexes, because these indexes rely on surveys of posted retail prices even for out-of-stock goods (e.g., on August 18, 2020, the posted but out-of-stock price for Clorox disinfecting wipes 75ct was $6.59 on the CVS website, but they were available on eBay for $29 plus $11.67 shipping; Lysol disinfectant spray 19oz was $5.97 at Home Depot but out of stock, while on eBay it was available for $12.50 plus $17.50 shipping).

Table 2 shows evidence of the large price hikes caused by COVID-related shortages of essential health goods and services. The median price increase for transactions of thirteen key goods, including N95 masks, ventilators, thermometers and disinfectants, reached 259% from March to April, 2020. Table also shows inflation rates for aggregate price indexes. Health-service prices rose at annualized rates ranging from 3.1 to 4.7% in the second quarter of 2020, while the price index for private good-producing industries fell − 16.1%. Hence, prices of health services relative to those for goods-producing industries rose between 19.2 and 20.8%, and for the specific health goods listed in the table, the median relative price hike exceeded 275%.

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7 The source was https://ourworldindata.org/excess-mortality-covid and some country-specific sources.
8 Health services at this level of aggregation include some for which prices fell as a result of suspension of elective treatments, routine medical, dental and optical appointments.
9 Price hikes along with shortages had an impact on the profitability of firms in health-related sectors. Figure 11 in “Appendix 1” presents cumulative stock returns for these firms. We compare their returns with the ones of the S &P and with the ones in the services industry (most affected by the pandemia). Stock returns in the health sector were much larger than those of the S &P and services. For more details see “Appendix 1”.

3.3 Duration and Severity of Lockdowns

As medical systems reached capacity, governments imposed lockdowns to slow the transmission of the disease and allow hospitals time to adjust their ability to treat COVID patients. Figure 1 illustrates the severity and duration of the lockdowns implemented in a group of sixteen advanced and emerging economies. The data correspond to the Government Response Stringency Index constructed as part of the Oxford COVID-19 Government Response Tracker (OxCGRT). This index combines information from nine indicators on a scale from 0 to 100 (with 100 for the...
strictest). In countries where policies varied within the country, the index corresponds to the strictest area.

The figure shows that strict lockdowns were implemented in all countries by mid-March, 2020. In most cases, the index peaked around 75–80%, except in Sweden, well-known for its less restrictive stance. Even in Sweden, however, the stringency index reached nearly 65%. Moreover, lockdowns persisted through the end of 2021. Their severity fluctuated somewhat and in several cases declined (in some like France and New Zealand quite sharply), but as of December 2021 all countries still maintained significant restrictions on economic activity relative to the

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**Table 2** Price changes of key health goods and services during the COVID-19 pandemic

| Item                        | Price change (%) | Source          |
|-----------------------------|------------------|-----------------|
| N95 masks                   | 1513             | SHOPP           |
| 3M N95 masks                | 6136             | SHOPP           |
| Hand sanitizer              | 215              | SHOPP           |
| Isolation gowns             | 2000             | SHOPP           |
| Face shields                | 900              | SHOPP           |
| Soap                        | 184              | SHOPP           |
| Ventilators                 | 80               | NY State        |
| Clorox disinfecting wipes   | 660              | US PCW          |
| Anti-viral facial tissues   | 254              | US PCW          |
| Bleach cleaner              | 238              | US PCW          |
| Thermometers                | 200              | US PCW          |
| Face masks                  | 259              | US PCW          |
| Anti-bacterial hand wipes   | 1294             | US PCW          |

*Aggregate price indexes (Q2:2020 v. Q1:2020 annualized)*

| Item                        | Price change (%) | Source |
|-----------------------------|------------------|--------|
| Physicians’ services        | 4.68             | BLS    |
| Medical care services       | 4.40             | BLS    |
| Hospital services           | 3.14             | BLS    |
| Health care and social assistance | 3.60 | BEA    |
| Private goods-producing industries | −16.10 | BEA    |

Personal protective equipment price changes are for April 2020 relative to pre COVID-19 levels (not annualized) reported by the Society for Healthcare Organization Procurement Professionals (SHOPP). Price changes (not annualized) for items reported by the US PCW (US PIRG Consumer Watchdog) correspond to the difference between the price listed in Amazon and the lowest price listed by other platforms during August 2020. BLS and BEA price indexes correspond to percent changes between 1st and 2nd quarter of 2020, annualized. Private goods-producing industries are: agriculture, forestry, fishing, and hunting; mining; construction; and manufacturing

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11 The index considers measures of school, workplace and public transportation closures, cancellation of public events, restrictions of gatherings, stay-at-home requirements, and restrictions on domestic and international travel.
Even in Sweden, the stringency index fell from its peak but it remained close to 25%.

### 3.4 Output Response

The strict lockdowns caused deep recessions, in many cases the largest recorded declines in quarterly GDP. Figure 2 shows year-on-year drops in GDP in the second quarter of 2020 for 48 advanced and emerging economies.\(^{12}\) The mean (median) drop was a staggering \(-11.5 \text{ (} -10.6\text{)}\)\%.

How much of the output declines was due to healthcare system saturation? To answer this question, we test for the relative importance of lockdowns, COVID case and mortality rates, and measures of the stress on healthcare systems in explaining cross-country differences in the magnitude of the decline in GDP.

The severity of lockdowns can be gauged with de jure or de facto measures. For the former, we use again the Oxford Stringency Index, and for the latter we use the components of the Google COVID-19 Community Mobility Reports that track movement to and from retail, recreational and work places. Mobility is reported as percent change relative to a pre-COVID baseline (the median for the 5-week period.

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\(^{12}\) Most of the data are from ourworldindata.org, fred.stlouisfed.org, and www.focus-economics.com. For China and Hong Kong, the figure shows the GDP drop in the first quarter, because these countries entered the pandemic earlier.
This indicator is useful because it captures the actual mobility of the population while the stringency index captures legal restrictions.

Unconditional scatter diagrams of both de jure and de facto lockdown severity indicators show a clear relationship with the quarterly GDP drops (see Fig. 3). Output drops were larger in countries with stricter lockdowns, whether measured by a higher stringency index or lower mobility. These scatter diagrams only tell part of the story; however, because other variables are likely to jointly affect economic activity and lockdowns, and we are interested in particular in determining whether variables that proxy for resource shortages and capacity constraints (i.e., health system saturation) play a role. To identify those effects, we conduct a regression analysis in a cross-section of 35 countries.

The dependent variable is the contraction in GDP, as measured by the fall in the second quarter of 2020 relative to the same quarter in 2019. The independent variables include: the stringency index and community mobility changes described above, two variables to capture the infection and mortality rates of COVID-19 itself (COVID cases for November, 2020 and cumulative COVID deaths through the end of November), and four variables as proxies for health system resources and capacity limits. The latter include a proxy for the non-COVID excess mortality rate (defined as the residual from regressing the excess mortality P-scores on COVID deaths), hospital beds, the log of 2019 GDP per capita, and the UNDP’s human development index (HDI) that combines life expectancy, educational attainment and gross national income per capita. COVID cases and fatalities and hospital beds are in units per one-million inhabitants and the rest of the variables are in percent. The data are available for 48 countries for most variables, but excess mortality P-scores are only available for 35, which sets the sample size of the regressions. The variables are expressed in deviations from their means and the regressions are estimated using MM robust least squares. The coefficients for all variables but hospital beds and COVID cases and deaths are elasticities, since the data are all in percent, and hence they are comparable. Coefficients for hospital beds, COVID cases and deaths are comparable, because the data for each are per one-million inhabitants.

The results are reported in Table 3. Column (1) shows the results with the highest overall significance ($R^2 = 99.2$) and explanatory power (robust $R^2_w = 0.81$), and the lowest deviance coefficient (0.036). The regressors include the stringency index, non-COVID excess mortality, (log of) GDP per capita, hospital beds and COVID cases. Using together a measure of lockdown severity, proxies for resource shortages and health system capacity, and COVID cases is important to avoid possible omitted variable bias (e.g., lockdown severity is likely to depend on COVID cases and deaths). Simultaneity bias is addressed by using lockdown severity and COVID variables with data up to November 2020, which makes them less likely to

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13 For both the Stringency Index and Community Mobility, we use 30-day averages as of the end of November, which were obtained from the components of Bloomberg’s Covid Resilience Index, see [https://www.bloomberg.com/news/articles/2020-11-24/inside-bloomberg-s-covid-resilience-ranking](https://www.bloomberg.com/news/articles/2020-11-24/inside-bloomberg-s-covid-resilience-ranking).

14 Leverage plots, influence statistics and histograms indicated outliers in Q2:2020 GDP and in several of the regressors.
be determined jointly with Q2:2020 GDP. All of the regression coefficients are significant at the 95% level or higher (hospital beds marginally) and have the expected signs. The regression explains roughly 81% of the cross-country variation in Q2:2020 GDP drops. In addition, an important result for the argument of this paper is that lockdown severity and the variables that proxy for health system resources and capacity are all significant, even after controlling for COVID infections.\textsuperscript{15} Non-COVID excess mortality has the largest elasticity. A 100-basis-points increase in this variable reduces quarterly GDP growth by 1.12 basis points, compared with 0.9 for a 100-basis points rise in the stringency index and 0.65 for a cut in GDP per capita of the same magnitude. Moreover, hospital beds have a significantly larger effect on quarterly GDP than COVID cases. Adding one bed per one-thousand people improves GDP by roughly 58 basis points, whereas an extra COVID case per one-thousand inhabitants reduces GDP growth by 35 basis points.

Columns (2)–(8) explore the robustness of the above results to potentially important modifications. Column (2) shows that adding cumulative COVID deaths is not useful. The coefficient for this variable is not significant, the rest of the coefficients change slightly, and the explanatory power, significance and deviance statistics of the regression are slightly weaker. The coefficients on stringency and beds are

\textsuperscript{15} Healthcare system capacity is likely to be correlated with income per capita. To explore this issue, we estimated regressions including the interaction between these two terms. The interaction coefficients were not statistically significant by a wide margin, with \(p\) values well below 20%.
estimated with less precision (they are marginally significant at the 90% confidence level). Column (3) shows that replacing cases for November 2020 with cumulative COVID deaths throughout end November worsens the results. The regression explains about 10 percentage points less of the cross-country variation in GDP drops and has sharply lower $R^2_n$ and higher deviance than Columns (1) and (2). Beds are no longer significant. Columns (4) and (6) show that replacing the stringency index with community mobility makes little difference. Both are statistically significant (with opposite signs because higher mobility implies a weaker lockdown), and the other coefficients are similar to those in Columns (3) and (5), respectively. Column (5) shows that removing hospital beds also weakens the results, with sharply lower $R^2_n$ and $R^2_w$ and higher deviance. Column (7) compared with Column (5) shows that using either GDP per capita or HDI yields similar results. Finally, Column (8) shows that removing hospital beds from Column (1) yields slightly weaker results. The coefficient on the stringency index rises from $-0.095$ to $-0.128$, suggesting the possibility of omitted variable bias as lockdown severity may depend on hospital capacity.

In summary, Table 3 yields three key results: (a) non-SIR variables, particularly the proxies for differences in health system resources and capacity, are important determinants of the depth of the recessions caused by COVID-19, even after controlling for the direct effects of COVID transmission; (b) variables driving SIR dynamics also play a role, since the coefficients on COVID cases and/or deaths are statistically significant; and (c) the effects of non-SIR variables are stronger.

4 A Model of the Output–Pandemia Trade-off

Our empirical findings suggest that healthcare saturation is key to the policy trade-off between slowing COVID transmission and the large economic costs of lockdowns. With this in mind, we propose a model in which the pandemia arrives as a large, transitory shock to the subsistence level of demand for health goods and

![Fig. 3 Lockdown severity and 2020:Q2 output declines. Notes See footnotes to Figs. 1 and 2 for sources of stringency index and GDP. Community mobility was retrieved from https://www.bloomberg.com/news/articles/2020-11-24/inside-bloomberg-s-covid-resilience-ranking on 11/29/2020]
| Regressors          | (1)          | (2)          | (3)          | (4)          | (5)          | (6)          | (7)          | (8)          |
|---------------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
| Dependent variable: year-on-year quarterly GDP growth as of Q2:2020 |
| Stringency         | −0.095       | −0.084       | −0.110       | −0.115       | −0.116       | −0.128       |              |              |
|                     | (0.048)      | (0.109)      | (0.073)      | (0.058)      | (0.010)      |              |              |              |
| Mobility            |              |              |              | 0.186        |              | 0.168        |              |              |
|                     |              |              |              | (0.025)      |              | (0.044)      |              |              |
| Non-COVID excess    | −0.112       | −0.108       | −0.081       | −0.095       | −0.084       | −0.090       | −0.089       | −0.116       |
|                     | (0.000)      | (0.004)      | (0.000)      | (0.002)      | (0.001)      | (0.002)      | (0.002)      | (0.000)      |
| Mobility            |              |              |              |              |              |              |              |              |
| Non-COVID excess    |              |              |              |              |              |              |              |              |
| Mobility            |              |              |              |              |              |              |              |              |
| ln(GDP pc)          | 0.065        | 0.063        | 0.047        | 0.052        | 0.050        | 0.051        | 0.071        |              |
|                     | (0.000)      | (0.000)      | (0.001)      | (0.000)      | (0.000)      | (0.000)      | (0.000)      |              |
| Human dev. index    |              |              |              |              |              |              |              | 0.361        |
|                     |              |              |              |              |              |              |              | (0.000)      |
| Hospital beds       | 5.801        | 5.262        | 1.649        | 2.766        |              |              |              |              |
|                     | (0.053)      | (0.100)      | (0.644)      | (0.410)      |              |              |              |              |
| Covid cases         | −3.51E−04    | −3.11E−04    |              |              |              | −2.98E−04    |              |              |
|                     | (0.001)      | (0.013)      |              |              |              | (0.005)      |              |              |
| Covid deaths        | −1.49E−05    | −6.00E−05    | −3.85E−05    | −6.06E−05    | −5.15E−05    | −5.84E−05    |              |              |
|                     | (0.557)      | (0.020)      | (0.144)      | (0.017)      | (0.050)      | (0.024)      |              |              |
| # Observations      | 35           | 35           | 35           | 35           | 35           | 35           | 35           | 35           |
| $R^2_w$             | 0.812        | 0.809        | 0.711        | 0.770        | 0.713        | 0.711        | 0.702        | 0.780        |
| Adjusted $R^2_w$    | 0.812        | 0.809        | 0.711        | 0.770        | 0.713        | 0.711        | 0.702        | 0.780        |
| $R^2_n$             | 99.151       | 93.737       | 55.515       | 69.026       | 56.655       | 61.942       | 54.073       | 82.747       |
| Deviance            | 0.0363       | 0.037        | 0.0461       | 0.042        | 0.046        | 0.047        | 0.048        | 0.042        |
### Table 3 Cross-country regressions for output collapse in Q2:2020

All regressions were estimated using robust MM least squares. The variables are deviations from their respective country means in the common sample. Numbers in parenthesis are *p* values. *Stringency* is the Oxford stringency index divided by 100. *Mobility* is Google’s community mobility indicator. Both stringency and mobility are 30-day averages over a period ending in late November 2020. *Non-COVID excess mortality* is the residual of regressing the excess mortality P-scores in Table 1 on the cumulative deaths due to COVID-19 as of end November 2020. *Human dev. index* is the 2019 UNDP’s human development index, which combines GNI per capita, life expectancy at birth, and mean years of schooling of adults older than 25. *Ln(GDP pc)* is the natural log of GDP per capita in 2019. *Hospital beds* are per 1 million inhabitants. *Covid cases* are the one-month COVID cases per 1 million population for the month ending in late November 2020. *COVID deaths* are cumulative deaths due to COVID-19 per 1 million inhabitants through late November 2020. *Q2:2020 GDP* data are from the sources reported in the note to Fig. 2. Data on stringency, mobility, human development index, COVID cases and COVID deaths were retrieved from https://www.bloomberg.com/news/articles/2020-11-24/inside-bloomberg-s-covid-resilience-ranking on 11/29/2020. 2019 real GDP and hospital beds are from World Bank Open Data and population data are from IMF World Economic Outlook. Hospital beds data are based on WHO figures and is for the most recent year available, which is in the 2010–2015 range for most countries.
services ($\bar{h}_t$) in a Stone–Geary utility function, with the size of the shock directly related to the utilization rate ($m_t$) of the capital stock ($K$).

The value of $\bar{h}_t$ is given by:

$$\bar{h}_t = h^* + z_t f(m_tK),$$

where $h^*$ is the “normal” subsistence demand for $h$ goods, $z_t$ is a binary variable which equals 0 in normal times and 1 when there is a pandemia, and $f(\cdot)$ is a monotonically increasing function. A pandemia lasts $j$ periods, so that $z_t = 1$ for $t = 0, \ldots, j$ and $z_t = 0$ for $t > j$, and is a fully unanticipated, non-recurrent shock.\(^{16}\)

In addition, the supply of health goods $H$ is assumed to be fixed, which is reasonable since the shock is unanticipated and key parts of the provision of health goods and services rely on forms of capital that are difficult to adjust in the short run (e.g., hospitals, equipment, specialists, etc.).\(^{17}\)

We start by analyzing the model’s decentralized competitive equilibrium, in which the government does not intervene during the pandemia. We then examine the social planner’s problem and highlight the output–pandemia trade-off: Because the social marginal cost of utilization is higher than the private marginal cost during the pandemia, the planner reduces utilization and output. In addition, since the pandemia worsens income and consumption inequality, the planner redistributes across agents. We next show that the planner’s allocations can be decentralized with an optimal policy that includes lockdown and transfers. Lastly, we analyze social and private welfare gains under the optimal policy.

### 4.1 Model Structure

The model economy has two types of households, a representative firm and a government.

#### 4.1.1 Households

There are two types of households, which together add up to a unit mass of agents. A fraction $\gamma_1$ are type-1 agents (entrepreneurs) who own all the wealth, both the capital stock used to produce non-health goods and the stock of health goods and services. A fraction $\gamma_2 \equiv 1 - \gamma_1$ are type-2 agents (workers) who only collect labor income.

All agents have identical preferences of the following form:

\(^{16}\) The pandemic could also be modeled as a stochastic, non-insurable disaster shock, but modeling it as an unanticipated shock is a reasonable approximation to how COVID-19 arrived. Still, modeling it as a disaster shock is worthwhile, because it would alter precautionary saving behavior and incentivize the accumulation of buffer stocks of health goods.

\(^{17}\) There is some room for increasing capacity by shifting hospital resources, contemplated in pandemic protocols in the conventional, contingency and crisis stages described earlier. But as Ajao et al. (2015) showed, the effectiveness of these adjustments is hampered by the shortages in critical inputs such as respiratory therapists, ICU staff, etc.
\[ \max_{\{c_i^i, h_i^i\}} \sum_{t=0}^{\infty} \beta^t \left( a \ln \left( c_i^i - \frac{(l_i^i)^\omega}{\omega} \right) + (1 - a) \ln \left( h_i^i - \bar{h}_t \right) \right), \quad \text{for } i = 1, 2. \]  

\( c_i^i \) and \( h_i^i \) are consumption of non-health and health goods, respectively, and \( l_i^i \) is labor supply. The utility function is time-separable, with discount factor \( \beta \) and period utility given by a Stone–Geary utility function of consumption of \( h \) and \( c \). The argument for utility of non-health consumption is of the Greenwood–Hercowitz–Huffman form (i.e., the subsistence level is determined by the disutility of labor, which removes the wealth effect on labor supply by making the marginal rate of substitution between \( l_i^i \) and \( c_i^i \) independent of the latter).\(^{18}\) The parameter \( a \) is the share of expenditure on non-health goods in excess of the disutility of labor relative to income net of the disutility of labor and subsistence expenditure on health goods. Similarly, \((1 - a)\) is the share of excess health expenditure above its subsistence level relative to the same net income measure.

The entrepreneurs’ budget constraint is:

\[ c_1^1 + p_h^1 h_1^1 = w_1 l_1^1 + \pi_1 + p_h^1 h - \tau_1. \]  

(3)

Non-health goods are the numeraire, so \( p_h^1 \) is the relative price of health goods, and \( w_i \) is the wage rate, all in units of non-health goods. Type-1 agents own the endowment of health goods, with an amount \( h \) for each type-1 agent, and they also collect the profits paid by firms producing non-health goods and pay lump-sum taxes, with amounts \( \pi_i \) and \( \tau_i \) for each type-1 agent, respectively, both in units of non-health goods.

The workers’ budget constraint is:

\[ c_2^2 + p_h^2 h_2^2 = w_2 l_2^2 + \tau_2. \]  

(4)

Workers collect income from wages, \( w_i l_i^2 \), and from government transfers in the amount \( \tau_i \), per agent.

Simplifying the first-order conditions of type-\( i \) agents’ problem yields two optimality conditions:

\[ \frac{1 - a}{a} \frac{c_i^i - \frac{(l_i^i)^\omega}{\omega}}{h_i^i - \bar{h}_t} = p_h^i, \]  

(5)

\[ (l_i^i)^{\omega-1} = w_i. \]  

(6)

Condition (5) equates the marginal rate of substitution between non-health and health consumption to the relative price. Condition (6) equates the marginal disutility of labor supply to the real wage.

18 This assumption is essential for the result that aggregate allocations and the optimal lockdown are independent of agent heterogeneity, inequality and optimal transfers.
4.1.2 Firms

The representative firm’s optimization problem is:

\[
\max_{m_t, L_t} \Pi_t = (m_t K)^{1-a} L_t^a - w_t L_t - \frac{m_t^*}{\chi_1} - K,
\]

subject to the technological constraint on utilization,

\[
m_t \leq \bar{m},
\]

where \( L_t \) is aggregate labor demand and \( \bar{m} \) is the technologically feasible maximum rate of utilization, which is assumed to be non-binding. Since the capital stock is constant, utilization costs \( \left( \frac{m_t^*}{\chi_1} K \right) \) can be seen as the standard cost associated with faster depreciation at higher utilization or as a rental cost that increases with utilization.

The first-order conditions of the above problem yield standard marginal-productivity conditions for labor demand and the utilization rate:

\[
(1 - a)(m_t K)^{-a} L_t^a = \chi_0 m_t^{1-a} -^1 - w_t L_t - \frac{m_t^*}{\chi_1} \]

\[
\alpha(m_t K)^{1-a} L_t^{1-a} = w_t.
\]

The marginal products of utilization and labor equal their marginal costs. For the former, the cost is determined by the firm’s utilization choice and for the latter the cost is the market wage rate.

4.1.3 Government Budget Constraint

The fiscal structure abstracts from public debt so that transfers to type-2 agents are paid by lump-sum taxes paid by type-1 agents and the government’s budget is balanced each period. The government budget constraint is given by:

\[
T_t = TR_t,
\]

where \( T_t \) denotes aggregate tax revenue and \( TR_t \) denotes total transfer payments. In this subsection, we keep lump-sum taxes and transfers constant over the pandemic and post-pandemic periods. In the next subsection, we study the optimal government policy in response to the pandemia.

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19 In an early version of this paper, we considered financing the transfers with Ricardian debt and studied government debt prices and debt dynamics during and post the pandemia. Since the debt is Ricardian and taxes are non-distortionary, the effects of the pandemics on allocations and welfare remain unchanged. For details, see Mendoza et al. (2021).
4.1.4 Decentralized Competitive Equilibrium with and Without Pandemia

The decentralized competitive equilibrium (DCE) is defined by sequences of individual allocations \(\{c^1_t, c^2_t, h^1_t, h^2_t, l^1_t, l^2_t\}_{t=0}^{\infty}\), aggregate allocations \(\{m_t, L_t, C_t, \Pi_t\}_{t=0}^{\infty}\), and prices \(\{p^h_t, w_t\}_{t=0}^{\infty}\) such that (a) the optimality conditions of type-1 and type-2 agents hold, (b) the optimality conditions of the representative firm hold, (c) the following market-clearing conditions:

\[
\gamma_1 l^1_t + \gamma_2 l^2_t = L_t, \tag{12}
\]

\[
\gamma_1 h^1_t + \gamma_2 h^2_t = H, \tag{13}
\]

and (d) the following aggregation conditions hold: \(\gamma_1 t_i = T_t, \gamma_2 t_r = TR_t, \gamma_1 h = H, \gamma_1 \pi_t = \Pi_t, \) and \(\gamma_1 c^1_t + \gamma_2 c^2_t = C_t.\)

The budget constraints of the agents, the definition of profits and the above market-clearing and aggregation conditions yield the following resource constraint:

\[
C_t = (m_tK)^{1-a}L^a_t - \frac{m_t^{\tau_t}}{\lambda_t}K. \tag{14}
\]

**Characterization of the Competitive Equilibrium** Since the only shock to the economy is the unanticipated, temporary hike in \(\bar{h}_t\) during the pandemic, and since there are no endogenous mechanisms to induce dynamics, the DCE separates into pandemic (P) and no-pandemic (NP) phases, and within each prices and allocations are constant. The DCE has a closed-form solution. We highlight two important features of the decentralized competitive equilibrium: (1) the aggregate DCE allocations are unaffected by both the pandemic and agent heterogeneity and (2) the pandemic increases consumption and income inequality across entrepreneurs and workers.

(1) Aggregate Allocations Since preferences are identical, labor is homogeneous, and all agents are paid the same wage, condition (6) implies that all agents offer the same labor supply, which must equal labor demand at equilibrium: \(l^1_t = l^2_t = L_t.\) Therefore, using the labor demand and supply conditions we obtain:

\[
L_t^{a-1} = \alpha(m_tK)^{1-a}L_t^{a-1}. \tag{15}
\]

This condition together with the firm’s optimality condition for utilization yields the following expression for the labor allocation as a function of the utilization rate:

\[
L_t = \left(\frac{\chi_0 a K}{1 - \alpha}\right)^{\frac{1}{\alpha}}\frac{\mu_t}{m_t^{-\alpha}}. \tag{16}
\]

Using the above result, the DCE factor allocations follow from conditions (9) and (10):

\[
m_t = m^* = \left(\frac{\chi_0 a - \alpha(1 - \alpha)^{a-\alpha} K^{\alpha(1-a)}}{x_t^{a-\omega - \omega - x_t^a}}\right)^{\frac{1}{1-a}}. \tag{17}
\]
Given the above, it is straightforward to obtain the DCE solutions for output, profits, wages and aggregate consumption using other optimality conditions and the resource constraint:

\[ L_t = l^1_t = l^2_t = L^* = \left( x_0^{\alpha-1} x_1^{\alpha-1} (1-\alpha)^{1-\alpha} K^{(1-\alpha)(x_1-1)} \right)^{\frac{1}{x_1^{(\alpha+\omega)\omega-\omega x_1}}} \]  

(18)

The above results for aggregate DCE allocations, profits and wages display two important properties: First, they are independent of heterogeneity and inequality in wealth, income and consumption, as is evident by the fact that \( u_1 \) and \( u_2 \) do not enter in the results. Second, they are the same in the P and NP phases (i.e., for \( t = 0, \ldots, j \) and for \( t > j \)).

2) Individual Allocations In contrast to the aggregate allocations, individual consumption allocations of health and non-health goods and the relative price of those goods differ in the P and NP phases in the DCE. The equilibrium prices are:

\[ p^*_{hP} = 1-a \frac{C^* - (L^*)^\omega}{H - h^* - f(m^*K)} \quad \text{for} \ t = 0, \ldots, j, \]  

(23)

\[ p^*_{hNP} = 1-a \frac{C^* - (L^*)^\omega}{H - h^*} \quad \text{for} \ t > j. \]  

(24)

Prices are higher during the pandemia because of the direct effect on demand for health goods and services due to higher \( \bar{h}_t \). In turn, this rise in \( p^*_{hP} \) worsens income inequality because it increases the value of the endowment of health goods owned by type-1 agents.

The solutions of the consumption allocations across agents are straightforward applications of the linear expenditure system implied by the Stone–Geary preferences. In particular, using condition (5) together with the budget constraints of the agents and the above results for aggregate variables, we obtain these solutions for the individual consumption allocations:

\[ c^*_1(p^*_h, \bar{h}_t) = a \left[ \pi^* + p^*_h \bar{h}_t - \pi_t + (L^*)^\omega - p^*_h \bar{h}_t - \frac{(L^*)^\omega}{\omega} \right] + \frac{(L^*)^\omega}{\omega}, \]  

(25)
Dividing Eq. (25) by (26), or (27) by (28), yields:

$$c_t^2(p_t^{\ast h}, \bar{h}_t) = a \left[ \tau_t + (L^*)^o - p_t^{\ast h} \bar{h}_t - \frac{(L^*)^o}{\omega} \right] + \frac{(L^*)^o}{\omega}, \quad (26)$$

$$h_t^1(p_t^{\ast h}, \bar{h}_t) = \frac{1 - a}{p_t^{\ast h}} \left[ \pi^* + p_t^{\ast h} \bar{h} - \tau_t + (L^*)^o - p_t^{\ast h} \bar{h}_t - \frac{(L^*)^o}{\omega} \right] + \bar{h}_t, \quad (27)$$

$$h_t^2(p_t^{\ast h}, \bar{h}_t) = \frac{1 - a}{p_t^{\ast h}} \left[ \tau_t + (L^*)^o - p_t^{\ast h} \bar{h}_t - \frac{(L^*)^o}{\omega} \right] + \bar{h}_t. \quad (28)$$

Expressing individual consumption allocations as functions of \((p_t^{\ast h}, \bar{h}_t)\) is useful because these are the only two variables that cause the allocations to differ in the P and NP phases. Both \(\bar{h}_t\) and \(p_t^{\ast h}\) are higher in the P phase, affecting individual consumption allocations as explained below.

Recall that for the DCE we assume that transfers are unchanged in the pandemia. Equation (26) implies that \(c^{2P} < c^{2NP}\), because \(p_t^{\ast h} \bar{h}_t\) rises during the pandemia and the rest of the variables that determine non-health consumption of type-2 agents are unaffected by the pandemia. The intuition is that type-2 agents need to redirect some of their income to pay for the subsistence level of health, which increased both in quantity and in price. Since aggregate consumption is unchanged, it must be that \(c^{1P} > c^{1NP}\). For these agents, the rise in the value of the endowment of health goods exceeds the increase in the cost of the subsistence level of health. Hence, during a pandemia, non-health consumption of type-1 (type-2) agents rises (falls). The same applies to excess consumption of health and non-health goods relative to the disutility of labor. It rises for type-1 agents and falls for type-2 agents.

The responses of health consumption differ from those of non-health consumption. In particular, \(h_t^2\) rises but \(h_t^1\) falls. The direct effect of higher \(\bar{h}_t\) on demand for health goods is the same for both agents, but the income effect of higher \(p_t^{\ast h}\) reducing the real value of income is stronger for entrepreneurs as the value of profits from the non-health sector in units of health goods falls. Excess health consumption (i.e., net of \(\bar{h}_t\)) falls for both agents, however, because even for type-2 agents the adverse income effects of higher prices imply that the increase in \(\bar{h}_t\) exceeds that in \(h_t^2\). Overall, type-2 agents suffer more with the pandemia, because they always consume less of all goods than type-1 agents and the pandemia causes their excess consumption of both health and non-health goods to fall, while for type-1 agents excess consumption of non-health goods rises.

Finally, to characterize the effects of the pandemia on consumption inequality, it is useful to focus on the ratio of excess consumption of type-1 to type-2 agents denoted by \(\Omega_t^*\). Dividing Eq. (25) by (26), or (27) by (28), yields:

$$\Omega_t^* = \frac{\pi^* + p_t^{\ast h} \bar{h} - \tau_t + (L^*)^o - p_t^{\ast h} \bar{h}_t - \frac{(L^*)^o}{\omega}}{\tau_t + (L^*)^o - p_t^{\ast h} \bar{h}_t - \frac{(L^*)^o}{\omega}}. \quad (29)$$

Across the two types of agents in the DCE, this ratio is the same for non-health consumption or for health consumption, and the ratio itself satisfies \(\Omega_t^* > 1\). This is clearly true for the DCE without transfers, and when transfers are present it holds
because we assume that \( \tau_t < \pi^* + p_t^* h \) (i.e., per-capita transfers never exceed the non-wage income of type-1 agents). Moreover, the ratio is constant at different levels with and without pandemia, and satisfies \( \Omega^{*P} > \Omega^{*NP} \) so that consumption inequality worsens temporarily with a pandemia.

Since both agents supply the same labor, collect the same wages, and have the same \( \bar{h} \), the movements in \( \Omega^* \) also capture the changes in income inequality due to the pandemia. Type-1 agents own the firms and the endowment of \( H \), so their income includes, in addition to wages, the profits from non-health goods production and the sales of health goods. The adverse effect of the pandemia on income inequality occurs because the hike in the relative price of health goods induces regressive income redistribution as the income from sales of those goods that type-1 agents collect rises.

### 4.2 Social Planner’s Problem

The social planner solves the following optimization problem:

\[
\max_{\{c^i_t, l^i_t, h^i_t, m_t\}} \sum_{i=1,2} \left\{ \phi_i \gamma_i \sum_{t=0}^{\infty} \beta^t \left[ a \ln \left( c^i_t - \frac{(h^i_t)^\omega}{\omega} \right) + (1 - a) \ln \left( h^i_t - \bar{h}_t \right) \right] \right\},
\]

subject to resource constraints on labor, health goods, and non-health goods, the technological constraint on utilization, and the subsistence demand for health:

\[
\begin{align*}
\gamma_1 l^1_t + \gamma_2 l^2_t &= L_t, \\
\gamma_1 h^1_t + \gamma_2 h^2_t &= H, \\
\gamma_1 c^1_t + \gamma_2 c^2_t &= C_t = (m_t K)^{1-a} L_t^a - \frac{m_t \chi_t}{\chi_1} K, \\
m_t \leq \bar{m}, \quad \bar{h}_t &= h^* + z_t f(m_t K).
\end{align*}
\]

As in the DCE, \( \bar{m} \) is assumed to be non-binding. The social welfare function is standard, with weight \( \phi_i \) on type-\( i \) agents, and the ratio of these weights is denoted \( \Omega^{SP} \equiv \phi_1 / \phi_2 \). We set \( \Omega^{SP} = \Omega^{*NP} \) so that the planner takes existing pre-COVID inequality as given and focuses on addressing only the additional inequality that COVID creates.\(^{20}\)

### 4.2.1 Socially Optimal Allocations

The social planner’s equilibrium (SPE) can be characterized as the set of allocations that satisfy the constraints of the planner’s problem and the following optimality conditions:

\(^{20}\) For discussions on the implications of alternative social weights, see Mendoza et al. (2021).
The planner sets allocations at two different constant levels for the P and NP phases. As we show below, aggregate allocations are lower in the P phase. The conditions in (31) show that the planner aligns with the DCE in that it allocates the same labor supply to both agents, and the total labor allocation equates the marginal disutility of labor with the marginal product of labor.

Conditions (32)–(34) are essential to this paper’s argument. Condition (32) determines the planner’s optimal utilization choice and it drives the planner’s incentive to lockdown the economy. It differs from its counterpart – Eq. (9) in the DCE – in that, during a pandemic, the social marginal cost of utilization in the right-hand side of (32) exceeds its private counterpart by the amount

\[ p_h = sp_{st} \equiv \frac{1}{a C_t - \frac{1}{2} \omega} \]

\[ \frac{m_t}{K} \]

where \( p_h \), \( sp \) is the social price of health goods. Hence, utilization is inefficiently chosen in the DCE during a pandemic, because firms do not internalize the marginal social cost of utilization. This cost exceeds the private one because of the marginal social value of lowering utilization to relax the degree of saturation of the health system by hampering the increase in \( h_t \) due to the pandemic. As a result, the planner reduces utilization and this reduces labor demand, output, profits and wages, giving rise to the output–pandemia trade-off.

The SPE does not have a closed-form solution because of the nonlinear nature of condition (32). Using this condition together with (31) and the feasibility condition on non-health goods, the optimal utilization rate (i.e., the optimal lockdown) can be represented as the solution to the following nonlinear equation in \( m_t \):

\[
(1 - \alpha) \left( \frac{L_t}{m_tK} \right)^a = \chi_0 m_t^{\chi_t - 1} + \frac{1 - a}{a} \left( \frac{C_t - \frac{1}{\omega}}{H - \bar{h}_t} \right) z f'(m_tK),
\]

\[
\frac{h_t^1 - \bar{h}_t}{\bar{h}_t^2 - \bar{h}_t} = \Omega_{sp},
\]

\[
\frac{c_t^1 - \left( \frac{c_t^1}{\omega} \right)}{c_t^2 - \left( \frac{c_t^2}{\omega} \right)} = \Omega_{sp}.
\]

\[
(1 - \alpha) \left( \frac{a(m_tK)^{1-a}}{m_tK} \right)^{-a} - \chi_0 m_t^{\chi_t - 1} = \frac{1 - a}{a} \left( \frac{m_t}{K} \right)^{1-a} \left( \frac{a(m_tK)^{1-a}}{m_tK} \right)^{-a} - \chi_0 m_t^{\chi_t - 1} K - \left( \frac{a(m_tK)^{1-a}}{m_tK} \right)^{-a} \frac{1}{\omega} z f'(m_tK).
\]

\[
(31)
\]

\[
(32)
\]

\[
(33)
\]

\[
(34)
\]

\[
(35)
\]
Without pandemia, \( z_t = 0 \) and this equation collapses to the closed-form solution for utilization in the DCE, because there is no externality affecting the choice of \( m_t \). Labor, output and aggregate consumption are therefore the same as well. During the pandemia, utilization is lower because of its higher marginal social cost, but notice that it retains the property of the DCE that it is independent of individual allocations and now also of the planner’s welfare weights. As a result, the planner’s aggregate allocations for labor and production in the pandemia phase also retain this property.

The above results imply that in this model the utilization externality and the optimal lockdown do not interact with the planner’s incentives to redistribute across agents. The planner’s utilization choice depends on \( f'(m_t K) \) and \( p_t^{h, sp} \), which are determined by aggregate variables. The planner determines first aggregate utilization and non-health GDP and then allocates health and non-health GDP to keep the ratios of excess consumption across agents equal to each other and equal to \( \Omega^{sp} \). This also implies that the planner’s aggregate allocations and the utilization externality are identical in a representative-agent version of the model (i.e., for \( \gamma_1 = 1 \)).

Conditions (33) and (34) are important because they drive the planner’s incentives to redistribute resources across agents during the pandemia. The planner sets the (inverse) ratios of marginal utilities of health and non-health consumption across agents equal to the ratio of its welfare weights. The extent to which redistribution is relevant depends on the extent to which \( \Omega^{*p} > \Omega^{*NP} > 1 \) in the DCE, and since \( \Omega^{sp} = \Omega^{*NP} \), it follows that \( \Omega^{sp} > \Omega^{sp} \).

Given the above intuition for the utilization externality and the distributional incentives of the planner, we can now characterize the solution of the planner’s problem when the pandemia is present. The solution to the nonlinear equation (35) yields the planner’s optimal utilization rate \( m_t^{sp} \), and once it is known, it can be used to determine the rest of the SPE allocations: \( L_t^{sp}, c_t^{sp}, c_t^{1sp}, c_t^{2sp}, h_t^{1sp}, \) and \( h_t^{2sp} \). It is evident that there are no distributional incentives affecting the utilization choice because \( \phi, \gamma_1 \) and \( \gamma_2 \) do not enter in Eq. (35). The higher social marginal cost of utilization leads the planner to reduce \( m_t^{sp} \). Condition (31) then implies that aggregate and individual labor allocations fall, and since both labor and utilization fall, output and \( C_t \) also fall. This is again the output–pandemia trade-off: The planner internalizes that by reducing utilization it weakens the pandemia, but it also takes into account that lowering utilization has output and consumption costs.

The drops in utilization, output and consumption chosen by the planner trigger distributional incentives, because as \( C_t^{sp} \) falls, the planner wants to keep consumption ratios aligned with \( \Omega^{sp} \). Given the SPE’s aggregate allocations, the planner assigns to type-2 agents these consumption allocations:

\[
c_t^{2sp} = \frac{C_t^{sp} - \left( \frac{L_t^{sp}}{\omega} \right)^{\omega}}{1 + \gamma_1(\Omega^{sp} - 1)} + \frac{\left( \frac{L_t^{sp}}{\omega} \right)^{\omega}}{\omega},
\]  

(36)

---

21 The resource constraints and conditions (33) and (34) imply also that \( p_t^{h, sp} = \left( c_t^{i} - \phi_i^{h, sp} \right) / (h_t^{i} - \tilde{h}_t) \) for \( i = 1, 2 \).
As explained earlier, the size of $\Omega^{sp}$ determines the degree of consumption inequality that is optimal for the planner. For $\Omega^{sp} = \Omega^{*NP}$, this yields the same consumption allocations and the same inequality as in the DCE so that no redistribution is optimal without a pandemic.

4.2.2 Decentralization and Optimal Policies

The social planner’s allocations can be implemented as a competitive equilibrium by imposing a lockdown (i.e., a binding limit on utilization) and providing transfers to type-2 agents. The optimal design of these two policies is characterized below.

**Optimal Lockdown** The planner’s optimal utilization rate can be decentralized using various instruments to correct the utilization externality. Since COVID-19 arrived as a large, unexpected shock that required an urgent response to the threat of saturation of health systems, it is reasonable to consider a lockdown as the policy instrument, instead of standard policy instruments (e.g., taxes) that would have been too slow and cumbersome to implement. The optimal lockdown is obtained by implementing the following policy rule:

$$m_t \leq m_t^{sp} \quad \text{for } t = 0, \ldots, j,$$

(38)

$$m_t \leq \bar{m} \quad \text{for } t > j.$$

(39)

Since the utilization externality increases the marginal cost of utilization relative to the DCE and $\bar{m}$ is not binding in the DCE, it must be the case that $m_t^{sp} < m^* < \bar{m}$ for $t = 0, \ldots, j$. Recall also that in the DCE, $m^*$ is the optimal utilization rate with or without pandemia and that, since there is no utilization externality without pandemia, $m_t^{sp} = m^*$ for $t > j$.

In the decentralized solution, the above lockdown policy rule enters as an additional constraint that binds during the pandemic. The associated Lagrange multiplier adds to the marginal cost of utilization, so that the firm’s optimal utilization choice is $m_t = m_t^{sp}$ for $t = 0, \ldots, j$. Since labor demand falls, the wage rate falls, and if the wages bill falls enough, profits of the NH sector may rise relative to the DCE without intervention despite the cut in utilization.

**Optimal Transfers** By imposing the planner’s health and non-health consumption allocations for type-2 agents [Eqs. (36) and (37)] on these agents’ budget constraint in the DCE solution [Eq. (4)], it follows that the optimal policy rules for government transfers during the pandemia are

$$\frac{\text{TR}^{sp,P}_t}{\gamma_2} = \left[ \frac{C_t^{sp} - \frac{(L_t^{sp})^\omega}{\omega}}{1 + \gamma_1(\Omega^{sp} - 1)} + \frac{(L_t^{sp})^\omega}{\omega} + p_t^{h,sp}\left(\frac{H - \bar{h}_t}{1 + \gamma_1(\Omega^{sp} - 1)} + \bar{h}_t\right) \right] - (L_t^{sp})^\omega.$$

(40)
for \( t = 1, 2, \ldots, j \), and the optimal transfers post the pandemia are zero, i.e.,
\[
TR_{sp,NP}^{\gamma_2} = 0 \quad \text{for} \ t > j.
\]

In Eq. (40), the terms inside square brackets represent the total value of non-health and health consumption of type-2 agents, and the term \((L_{sp}^{\gamma_2})_w\) is their wage income. Hence, the optimal transfer covers the gap between the planner’s desired allocation of total consumption to type-2 agents and the wages they collect (all in units of non-health goods). Since the transfers are financed with lump-sum taxes on type-1 agents, the planner is redistributing resources from type-1 to type-2 agents.

The planner takes into account that a pandemia always worsens income inequality, even if a lockdown as tight as the optimal lockdown is implemented, because the income of type-1 agents rises relative to that of type-2 agents, since the latter only earn wages while the former collect profits and sales of \( H \) in addition to wages. The planner internalizes that the relative price of health goods rises, making health-good purchases costlier and income from selling health goods larger, and that without policy intervention the overall result of these effects would move type-2 agents closer to their subsistence levels of health and non-health goods. To correct for this, the planner uses transfers to redistribute income and consumption from type-1 to type-2 agents by more than in normal times without pandemia. If \( \Omega_{sp} = \Omega_{*NP} \), there is no redistribution in normal times \( (TR_{sp,NP}^{\Omega_{*NP}} = 0) \), but the planner still redistributes during the pandemia. Hence, the planner has incentives to intervene in the DCE so as to both reduce utilization (to tackle the utilization externality) and redistribute resources across agents (to keep the ratio of excess consumption across them equal to \( \Omega_{sp} \)).

The planner chooses \( m_{sp}^{\Omega_{sp}} \) independently of inequality but it is critical to note that the lockdown itself mitigates the increase in inequality caused by the pandemia. This is because the lockdown reduces the spike in the price of health goods that drives the regressive effect on income. As a result, the smaller increase in \( p_{t}^{h,sp} \) that the lockdown produces, reduces the size of the planner’s optimal transfers during the pandemia, as Eq. (40) shows.

### 4.3 Social Welfare and Private Utility Gains

In order to compare the utility that agents derive under the SPE and the DCE, define \( \Delta U_{i} = U_{i}^{SPE} - U_{i}^{DCE} \) for agents of type \( i = 1, 2 \) where \( U_{1} \) and \( U_{2} \) are the lifetime utility functions shown in (2). Because \( \Omega_{sp} = \Omega_{*NP} \), the post-pandemic allocations under the SPE and the DCE are identical. Then, denoting excess consumption levels as \( \tilde{C}_{t} \equiv C_{t} - L_{i}^{\omega}/\omega \) and \( \tilde{h}_{t} \equiv h_{t} - \bar{h}_{t} \) and using the results from the SPE and the DCE yields these expressions:

\[
\Delta U_{i} = \sum_{t=0}^{j} \beta^{t} \left[ a \ln \left( \frac{\tilde{C}_{t}^{\Omega_{sp}}}{\tilde{C}^{*}} \right) + (1 - a) \ln \left( \frac{\tilde{h}_{t}^{\Omega_{sp}}}{\tilde{h}^{*}} \right) + \ln \left( \frac{\Omega_{sp} 1 + \gamma_{1}(\Omega_{*P} - 1)}{\Omega_{*P} 1 + \gamma_{1}(\Omega_{sp} - 1)} \right) \right],
\]

(41)
Using these results, the change in social welfare, $\Delta W$, under the SPE allocations with the optimal lockdown and transfer policies relative to the unregulated DCE allocations can be expressed as:

$$\Delta W = \sum_{i=1}^{2} \phi_i \gamma_i \Delta U_i.$$  \hspace{1cm} (43)

Thus, the change in social welfare attained by the optimal policies equals the valuation of the individual lifetime utility changes valued using the social welfare function.

To obtain a cardinal measure of $\Delta W$, we follow the standard procedure of expressing welfare gains in terms of a compensating variation in consumption. In particular, we calculate the percentage increase in consumption of non-health goods common across households and time periods ($\Lambda$) that would be needed for the DCE to yield the same social welfare as under the SPE allocations:

$$\Delta U_2 = \sum_{i=0}^{j} \beta^i \left[ a \ln \left( \frac{\bar{C}_{i}^{sp}}{\bar{C}^*} \right) + (1 - a) \ln \left( \frac{\bar{H}_t^{sp}}{\bar{H}^*_t} \right) \right].$$  \hspace{1cm} (42)

Using these results, the change in social welfare, $\Delta W$, under the SPE allocations with the optimal lockdown and transfer policies relative to the unregulated DCE allocations can be expressed as:

$$\Delta W = \sum_{i=1}^{2} \phi_i \gamma_i \Delta U_i.$$  \hspace{1cm} (43)

The first two terms in the right-hand side of $\Delta U_1$ and $\Delta U_2$ [Eqs. (41)–(42)] are the same, because they represent the aggregate effects of the planner’s management of the output–pandemia trade-off by neutralizing the utilization externality. Since, as we showed earlier, the SPE’s aggregate allocations are independent of inequality, this term depends only on aggregate allocations and not on their distribution across agents. In the DCE, aggregate labor and consumption of non-health goods are constant at the same level in the P and NP phases, so that $\bar{C}^*$ is constant at all times. During the pandemia, however, aggregate excess health goods consumption ($\bar{H}_t^*$) falls because of the increase in $\bar{h}_t$ for $t = 0, \ldots, j$. The utilization externality implies that these allocations are suboptimal. Hence, during the pandemia the planner lowers the utilization rate, which reduces $\bar{C}_{i}^{sp}$ but props-up $\bar{H}_t^{sp}$. The post-pandemia phase washes out from this term, because, as explained earlier, for all $t > j$ there is no utilization externality and hence the aggregate allocations of labor, non-health output and consumption of both goods are the same in the DCE and SPE.

The third term in the right-hand side of $\Delta U_1$ and $\Delta U_2$ reflects the distributional effects during the pandemia. These distributional effects are determined by a collection of constant terms that depend on $\gamma_1$ and the marginal utility ratios of the planner.
(Ω\text{sp}) vis-a-vis those in the DCE (Ω*\text{P}). The terms for the pandemia phase reflect the result justifying increased transfers to type-2 agents, because the distribution of resources for health and non-health consumption is suboptimal and worsens during the pandemia (since Ω*\text{P} rises).

For quantitative analysis, expressions (41) and (42) provide an intuitive way of separating the social welfare gain into key components. One is the gain due to correcting the efficiency loss affecting aggregate allocations via the utilization externality. The other is the gain due to the socially optimal redistribution during a pandemia (which also depend partially on the utilization externality, since a larger externality implies more inequality in the DCE).

Evaluating ΔU_1 and ΔU_2 separately from social welfare is also helpful for assessing whether the optimal policy is Pareto efficient (i.e., ΔU_1, ΔU_2 ≥ 0). For this to be the case, the utility gain for type-1 agents from correcting the aggregate effects of the utilization externality must exceed their loss due to the redistribution in favor of type-2 agents during the pandemia. A heuristic argument suggests that, for given social welfare weights, the SPE can be Pareto efficient if γ_1 is sufficiently high. Start with some γ_1 that yields a particular Ω*\text{NP}(γ_1) and assume we set Ω\text{P} = Ω*\text{NP}(γ_1). As we increase γ_1 keeping Ω\text{P} fixed, the utility of type-1 agents rises (locally) because the cost of redistribution falls. The result is not general, however, because the redistribution costs and ΔU_1 are nonlinear functions of γ_1, but as we verify in the numerical example below, it is possible to have a parameterization such that for given Ω\text{P} there is an interval of γ_1 values such that ΔU_1, ΔU_2 ≥ 0.

5 Quantitative Analysis

In this section, we study the model’s quantitative predictions using a calibration to US data. We quantify the optimal policies (lockdowns plus transfers) and assess how effective they are in comparison with alternatives (no intervention and only lockdowns). We also study the trade-off that arises from deviating from the optimal policy and what combinations of lockdowns and transfers are good substitutes for it. Lastly, we examine results for a variant of the model in which entrepreneurs are less affected by the pandemia’s shock in subsistence demand for health goods than workers.

5.1 Calibration

Table 4 lists the calibrated parameter values. The values of all of the parameters, except those of the Stone–Geary utility and the f(mK) function, are easy to set

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22 In the [1, ∞) interval of Ω\text{P}, the utilitarian planner (Ω\text{P} = 1) has the strongest desire for reallocating resources. All the terms that include Ω\text{P} vanish from ΔU_1, ΔU_2, which implies that the second and third rows of ΔU_1 (ΔU_2) take their most negative (positive) values. In particular, comparing the second rows of the two expressions shows that the planner has the strongest desire to redistribute when the pandemia hits, relative to scenarios with Ω\text{P} > 1.
following a conventional calibration approach. The model is set to a quarterly frequency with a standard discount factor of $\beta = 0.99$. The standard value of the Frisch elasticity of labor supply is 2 in the literature, and since the Frisch elasticity in the model is $\frac{1}{\omega - 1}$, we obtain $\omega = 1.5$. The labor share in production $\alpha$ is set to 0.7 based on historical US data. We set the fraction of type-1 agents $\gamma_1$ at 0.2 because the top quintile of the US wealth distribution owned nearly 90% of the wealth in 2017 (Leiserson et al. 2019).

Utilization without pandemia is normalized to $m^* = 1$. The depreciation function takes a formulation typical of dynamic macro-models (see Mendoza et al. 2014): $\delta(m_t) = \chi_0 \frac{m_t}{\chi_1}$. Without pandemia, since $m^* = 1$, the capital depreciation rate satisfies $\delta = \frac{\chi_0}{\chi_1}$, where $\delta$ is set to a depreciation rate of 0.0164 per quarter, consistent with the calibration to US data in Mendoza et al. (2014) and D’Erasmo et al. (2016). The capital stock is set to $K = 6.04$, which is consistent with a capital-GDP ratio of 3. The value of $\chi_0$ then follows from the DCE optimality condition for capital utilization, which yields $\chi_0 = (1 - \alpha)(L(K, m)/K)^{\alpha} = 0.10$, where $L(K, m)$ is the solution to Eq. (15) for $K = 6.04$ and $m = 1$, and then, the condition that $\delta = \frac{\chi_0}{\chi_1}$ yields $\chi_1 = 6.10$.

To calibrate the Stone–Geary preferences, we normalize the endowment of health goods so that $H = 1$. Hence, $h^*$ represents the percent of the available supply of health goods that constitutes subsistence demand in normal times. The value of $h^*$ is set by estimating a standard linear-expenditure-system regression of nominal expenditures of health goods and services on nominal expenditures of non-health goods and services and the price of health goods. This regression follows from the pricing condition for the NP phase, Eq. (24), using the resource constraint for non-health goods and the market-clearing condition for health goods. The value of $h^*$ corresponds to the coefficient on $p_h$, which yields $h^* = 0.0948$ with a standard error of 0.0235 and a $p$ value of 0.0002.

The share of non-health expenditures $a$ is determined by imposing on the same pricing condition (24) the estimated value of $h^* = 0.0948$ and the average ratios of non-health to health consumption and non-health to health GDP for the period 2009–2018, which are 5.01 and 4.73, respectively. We use 2009–2018 data because they yield stable averages for these ratios, after several years in which both fell steadily. This yields $a = 0.756$.

The last item that needs to be specified is the function $f(m_tK)$ that maps utilization into subsistence health demand during a pandemia. As noted earlier, the

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23 After simplifying terms, combining these expressions yields $p_hH = \frac{1 - \alpha}{a} \left( 1 - \frac{\delta \chi_1}{\chi_1} \right) Y + h^* p_h$.

24 The regression uses data for 1960–2018. Expenditures are proxied by GDP of health and non-health goods. The price index corresponds to the GDP deflator for the health sector (obtained from the BLS). Expenditures are expressed as indexes with the same base year as the deflator. Other time series used are Total National Health Expenditures, Health Investment, Health Consumption Expenditures, obtained from the National Health Expenditure database of the Centers for Medicaid and Medicare Services (CMS), and Nominal GDP and Gross Private Domestic Investment, obtained from the BLS and BEA, respectively. The regression is estimated in second differences, because non-health expenditures are integrated of order two, reflecting the sharp growth of the health sector relative to the rest of the US economy.
function is assumed to be monotonically increasing. A concave (convex) \( f(\cdot) \) would represent an economy in which reductions in utilization are less (more) effective at reducing the stress on the health system during a pandemic. For simplicity, we assume a linear function \( f(mK) = \theta mK \), so that the elasticity of \( \bar{h} \) with respect to \( mK \) is equal to \( \theta \). We know little about \( \theta \), but given the value of \( K \), there is an upper bound \( \bar{\theta} \) at which health demand of type-2 agents equals their subsistence demand and there is no DCE solution with pandemic.\(^\text{25}\) Hence, we will study model solutions for \( \theta \in [0, \bar{\theta}) \). Moreover, within this interval, we examine detailed solutions for the value of \( \theta \) that makes the drop in US non-health GDP observed during the pandemic consistent with an optimal lockdown. Matching the decline of 8.8% in US non-health GDP in the second quarter of 2020 relative to the first quarter as part of the SPE solution requires \( \theta = 0.0918 \). The corresponding utilization rate is 0.848 and hence \( f(mK) = 0.0918 \times 0.848 \times 6.04 = 0.47 \). Thus, accounting for the observed non-health GDP drop as the result of an optimal lockdown implies a sharp increase in subsistence demand for health from 9.48 to 9.48 + 47 = 56.4 percent of the available supply.

### 5.2 Results

This subsection discusses the quantitative results. We start by comparing the DCE and SPE solutions for the baseline value of \( \theta \). Then we examine results for the full range of \( \theta \) values for which the DCE exists and quantify the effectiveness of suboptimal policies. We close with the results for the model variant in which type-1 agents are less affected by the shock to \( \bar{h}_t \).

\(^{25}\) See Mendoza et al. (2021) for a characterization of the upper bound \( \bar{\theta} \).
5.2.1 Decentralized Equilibrium and Optimal Policy

Table 5 shows a set of results for the calibration with $\theta = 0.0918$. Column (I) shows the equilibrium without pandemia, for which $DCE_{NP} = SPE_{NP}$ since $\Omega^p = \Omega^{NP}$. Column (IV) is the SPE solution for the pandemia that rationalizes the observed output drop as resulting from an optimal lockdown ($SPE_p$). Columns (II) and (III) show two other DCE solutions: Column (II) is the “no intervention” (NI) case studied in Sect. 4, in which utilization is unaffected by the pandemia ($DCE_{P,NI}$), and Column (III) is the “lockdown only” (LO) case with an ad hoc lockdown of the same size as the optimal lockdown ($DCE_{P,LO}$). Transfers are unchanged from the normal-times level in both DCE solutions. Column (I) is in levels and the rest are percent changes relative to NP levels, except $m$ and $Tr/GDP$ for which we show percentage points changes and $\Omega$ and $\bar{h}$ which are always in levels.

The aggregate allocations for $DCE_{P,LO}$ and $SPE_p$ show that the 8.8% output drop during the pandemia is associated with a cut in $m$ of 15 percentage points and declines in consumption and labor of about 6%. For the planner, the cut in $m$ is the optimal response to the utilization externality by construction (i.e., by the calibration strategy used to obtain $\theta = 0.0918$). Profits of the non-health sector actually rise slightly (1.9%), because the fall in wages reduces labor costs by more than the fall in output net of utilization costs. Subsistence health demand climbs from 0.09 to 0.56, as explained earlier, and the relative price of health goods rises 101.1%, because aggregate excess consumption of health goods falls much more than for non-health goods. Without lockdown, the results for aggregate allocations in the $DCE_{P,NI}$ differ from the NP phase only in that the relative price rises sharply, by nearly 158%. This is larger than in the LO and planner’s solutions because there is no cut in utilization moderating the spike in subsistence health demand, which climbs to 0.65 instead of 0.56.

Regarding individual allocations, recall that the planner has weights set so as to match the ratio of excess consumption across agents without pandemia ($\Omega^{p} = \Omega^{NP} = 3.46$). Hence, the planner cuts excess consumptions of each agent by the same percentage relative to the NP state ($-3.3$ and $-51.9\%$ for non-health and health goods, respectively). In levels, however, the planner reduces entrepreneurs’ consumption of both goods ($-4.9$ and $-28.3\%$ for non-health and health goods, respectively), while for workers it reduces non-health consumption by $-6.6\%$ but increases health consumption by $22.1\%$. The planner spreads the drop in the aggregate supply of non-health goods triggered by the optimal lockdown relatively evenly across agents, while the contrast of the large drop it assigns to health consumption for entrepreneurs v. the large increase for workers is in response to the planner’s strong incentive to redistribute so as to keep $\Omega^p = 3.46$. This redistribution requires an increase in the ratio of transfers to GDP of nearly 11 percentage points. Assuming the pandemia lasts four quarters, the optimal lockdown and transfers policies increase welfare by 0.82%, which is a sizable gain.

Inequality worsens sharply in the NI scenario, with $\Omega^{p,NI}$ rising to 16.5. This large increase in excess consumption inequality results from $\hat{c}$ increasing (falling) by 73.5 ($-63.6\%$) for type-1 (type-2) agents. Since labor supply and labor disutility are the same for both agents, this implies that non-health consumption
also rises sharply for type-1 agents and falls sharply for type-2 agents. Regarding excess health consumption, $\tilde{h}$ falls much less for type-1 than type-2 agents ($-32.7\%$ vs. $-85.9\%$, respectively). Hence, the pandemic moves workers closer to the subsistence demand for health at a much faster pace than entrepreneurs. Income inequality also worsens sharply as result of the large increase in the value of the endowment of health goods that type-1 agents own. Transfers are unchanged in

| Table 5 | Competitive and social planner’s equilibria for $\theta = 0.0918$ |
|---------|---------------------------------------------------------------|
| Variable | (I) | (II) | (III) | (IV) |
|          | Normal times | No intervention | Lockdown only | Social planner |
|          | (levels) | (percent changes) | (percent changes) | (percent changes) |
| $DCE_{NP} = SPE_{NP}$ | | | | |
| $DCE_{P,NI}$ | | | | |
| $DCE_{P,LO}$ | | | | |
| SPE$_P$ | | | | |
| Aggregate variables | | | | |
| $\Omega$ | 3.46 | 16.46 | 9.54 | 3.46 |
| $h$ | 0.09 | 0.65 | 0.56 | 0.56 |
| GDP$_{NH}$ | 2.01 | 0 | $-8.84$ | $-8.84$ |
| $m$ | 1 | 0 | $-15.18$ | $-15.18$ |
| $l$ | 1.26 | 0 | $-5.99$ | $-5.99$ |
| $\pi$ | 0.5 | 0 | 1.85 | 1.85 |
| $c$ | 1.91 | 0 | $-6.02$ | $-6.02$ |
| $w$ | 1.12 | 0 | $-3.04$ | $-3.04$ |
| $p^h$ | 0.35 | 157.76 | 101.1 | 101.1 |
| Individual variables | | | | |
| $c_1$ | 3.2 | 51.91 | 30.54 | $-4.93$ |
| $c_2$ | 1.59 | $-26.07$ | $-24.38$ | $-6.57$ |
| $h_1$ | 2.19 | $-6.02$ | $-4.35$ | $-28.25$ |
| $h_2$ | 0.7 | 4.71 | 3.4 | 22.08 |
| $\tilde{c}_1$ | 2.26 | 73.49 | 46.92 | $-3.3$ |
| $\tilde{c}_2$ | 0.65 | $-63.55$ | $-46.73$ | $-3.3$ |
| $\tilde{h}_1$ | 2.1 | $-32.69$ | $-26.94$ | $-51.92$ |
| $\tilde{h}_2$ | 0.61 | $-85.86$ | $-73.51$ | $-51.92$ |
| Transfers and welfare | | | | |
| $Tr/GDP$ (%) | 14.5 | $-2.74$ | $-1.00$ | 10.85 |
| Welfare Gain (%) | n.a. | n.a. | n.a. | 0.82 (0.33) |
| $\Delta U_1$ | n.a. | n.a. | n.a. | $-2.06$ ($-1.65$) |
| $\Delta U_2$ | n.a. | n.a. | n.a. | 4.08 (2.35) |

The “Normal Times” column shows the equilibrium without pandemia (DCE and SPE are identical because the calibration assumes $\Omega^{NP} = \Omega^{*NP}$). Allocations and prices in the No Intervention and Lockdown Only scenarios are reported as percent changes relative to Normal Times, except $h$ and $\Omega$ are shown in levels and $m$ and $Tr/GDP$ are differences in percentage points relative to their normal-times values. Welfare gains, $\Delta U^1$ and $\Delta U^2$ are as defined in the text. Welfare gains assume the pandemic lasts four quarters and are relative to the No Intervention scenario with values in parenthesis relative to the Lockdown Only scenario.
levels from the NP state, but since the value of GDP rises with \( p^h \), transfers as a share of GDP fall by \(-2.7\) percentage points.

The LO equilibrium with the ad hoc lockdown (Column (III)) performs better than the NI case but it is still inferior to the optimal policy scenario. The ad hoc lockdown yields the same aggregate allocations and prices as for the planner. Importantly, it also moderates the adverse effects of the pandemia on inequality. The ratio of excess consumptions rises to \( \Omega^p_{\text{LO}} = 9.5 \), instead of 16.5 in the NI case, and this is possible because both \( \bar{h} \) and \( p^h \) increase less. The latter implies that income inequality also worsens less in the LO than the NI case.\(^{26}\) The implied weaker valuation effect also implies that transfers (which are constant at the NP level) fall less as a share of GDP, by 1 percentage point instead of 2.7. The SPE yields a welfare gain of 0.33% relative to this LO case, and since the gain relative to the NI case was 0.82, it follows that the lockdown alone yields a welfare gain of about 50 basis points and the transfers add 32. Thus, roughly 3/5ths of the total welfare gain produced by the optimal policies is due to the lockdown. Keep in mind, however, that the lockdown has effects both on aggregate efficiency (by tackling the utilization externality) and on inequality (by moderating the hikes in \( \bar{h} \) and \( p^h \)). Thus, the ad hoc lockdown does help mitigate the adverse inequality effects of the pandemia but not nearly enough as is socially optimal.\(^{27}\)

To close this analysis, we show that the SPE\(_p\) scenario in Table 5 is not a Pareto improvement, because it reduces the welfare of type-1 agents, but that if there were a slightly larger share of these agents, the resulting optimal policy is a Pareto improvement. These findings follow from Fig. 4, which shows the changes in \( \Delta U_1 < 0 \) and \( \Delta U_2 > 0 \) that result under the SPE solution relative to the no-intervention DCE solution as the fraction of type-1 agents rises. For each value of \( \gamma_1 \), we solve the SPE and DCE solutions keeping social welfare weights and \( \theta \) at the levels used in Table 5 (i.e., \( \Omega^p = 3.46 \) and \( \theta = 0.0918 \)). At the calibrated value of \( \gamma_1 = 0.2 \), the SPE yields \( \Delta U_1 < 0 \) and \( \Delta U_2 > 0 \) (i.e., type-2 agents are better off in the SPE but type-1 agents are not). However, for slightly higher \( \gamma_1 \) in the shaded area of the figure, both agents are better off under the SPE. Thus, given social welfare weights, the SPE can be Pareto efficient if \( \gamma_1 \) is sufficiently high so as to reduce the per-agent cost of redistribution for type-1 enough to make them better off but also not too high so that redistribution is insufficient to make type-2 agents better off. The per-agent cost of redistribution for type-1 agents falls with \( \gamma_1 \) because there are more agents of this type to share the cost and the SPE allocates less consumption of health and non-health goods to type-2 agents as \( \gamma_1 \) rises [see Eqs. (36)–(37)].

\(^{26}\) Note that wage income falls by the same amount for both agents, since they supply the same labor at the same wage, and that the small increase in profits worsens income inequality but it is dwarfed by the effect of the smaller hike in \( p^h \).

\(^{27}\) Lockdowns may have positive and negative impacts on inequality via other channels such as their effects on the labor market. The predictions of our model abstract from these other effects.
5.2.2 The Role of $\theta$ in Optimal Policy

We turn now to examine the full spectrum of solutions for the interval of $\theta$ values that support competitive equilibria. As noted earlier, this is possible for $\theta \in [0, \bar{\theta})$ where $\bar{\theta}$ is the upper bound at which health consumption of workers hits the subsistence level. Under the calibration to US data, the DCE with no lockdown yields $\bar{\theta} = 0.1069$.

Figure 5 shows utilization and non-health GDP. The blue curves show the SPE solutions, the black lines show the DCE under the NI case (for which aggregate allocations are invariant in $\theta$), and the red lines show the LO solutions for the DCE with an ad hoc lockdown of the same size as the optimal lockdown that matches the drop in US non-health GDP. The black and red dots denote the solutions shown in Table 5. By construction, the red dots must be at the intersection of the blue curves with the red lines (i.e., an ad hoc lockdown of the same size as the optimal lockdown). The dashed, red vertical lines identify $\bar{\theta}$, for which there is no DCE solution.

Figure 5 shows that the planner’s optimal reductions in utilization and non-health GDP are concave in $\theta$. Hence, as the elasticity of subsistence health demand to utilized capital rises, the optimal lockdown in response to a pandemia increases with $\theta$ at a faster rate. Scenarios with low $\theta$s are unlikely to be relevant. They represent weak pandemias for which $h$ varies little in response to cuts in $m$ (e.g., social distancing is not that important to alter contagion) and as a result small cuts in utilization and output, namely weak lockdowns, would suffice to address the utilization externality. This is captured in the figure by the small gap between the black lines that correspond to the NI solutions and the blue curves of the planner’s solutions for $\theta < 0.05$.

Pandemias become relevant as $\theta$ rises above 0.05. In this region, the concavity of the planner’s choices has a key implication: Small “errors” in measuring $\theta$ result in non-trivial errors in the utilization and output cuts adopted to respond to a pandemia. The gaps between the blue and red curves illustrate how these errors vary as the “true” value of $\theta$ varies if the lockdown that would be optimal for $\theta = 0.0918$ is adopted. If $\theta$ is in fact slightly smaller (larger) the lockdown would be too strict (weak) and non-health GDP would be allowed to fall too much (little) relative to what is truly optimal. For example, if $\theta = 0.08$, the ad hoc lockdown of the LO line would cut utilization and output by 3.2 and 2.3 percentage points more than what is optimal, respectively. Relative to pre-pandemia levels, utilization and output would fall by 15.2 and 8.8 percentage points, respectively, compared with optimal drops of 12 and 6.5 percentage points each.

An alternative interpretation of Fig. 5 is as indicative of the implications of cross-country or cross-region heterogeneity in health systems and other relevant pre-pandemia conditions (like income per capita, life expectancy, etc.). Countries with weaker pre-pandemia conditions can be viewed as countries with higher $\theta$, and hence faced with a pandemia they require larger optimal lockdowns which imply larger output drops. The relative size of the health sector also captures cross-country differences in health systems. Equation (35) implies that the utilization externality is weaker in countries where $H$ is larger, and hence for the same $\theta$ the optimal
lockdown and output drop would be smaller in these countries. The same applies to countries where $a$ is larger.

Figure 6 shows how the rise in $p^h$ and the worsening consumption inequality due to a pandemia vary with $\theta$ in the SPE (in blue) and in the DCE cases for NI (in black) and the LO (in red) that matches the observed decline in non-health GDP. Black and red dots denote again the NI and LO outcomes in Table 5. The planner chooses...
higher prices for \( \theta \) values that would make the optimal lockdown of Table 5 excessive (\( \theta < 0.0918 \)), and lower prices when the opposite occurs. In contrast, the SPE price hikes are always smaller than those of the no-lockdown DCE case, because the planner reduces utilization and this moderates the increase in the relative price. Prices are nearly linear in \( \theta \) for the planner but they are convex for both DCE cases, and hence small errors in assessing the value of \( \theta \) to implement lockdowns would result in large differences in price hikes during pandemias.

The price hikes are quite large overall, except for \( \theta \) values that result in negligible drops in utilization and output. In line with the argument that pandemias are weak for \( \theta < 0.05 \), prices in the NI DCE scenario are negligibly different from those produced under the optimal policies for those \( \theta \) values. For \( \theta > 0.05 \), the optimal policy yields price hikes of at least 45% and as much as 105%. Price hikes in the no-lockdown DCE case are uniformly higher, ranging from 50 to 230%. Hence, the model predicts large relative price movements during pandemias.

The graph for the ratios of excess consumption (plotted in a logarithmic scale) shows a constant \( \Omega^{\text{np}} \) for the planner, which follows from the welfare weights calibrated to match the value of \( \Omega \) in the DCE without pandemia (3.46). During the pandemia, consumption inequality is sharply higher in the DCEs for the NI and LO scenarios than for the planner, and it worsens at an increasing rate as \( \theta \) rises driven by the rising \( p^h \) and the worsening income inequality. For \( \theta \) ranging between 0.05 and 0.1, the values of \( \Omega \) in the NI (LO) scenario are in the 6–37 (5–12.5) range, much larger than the 3.46 ratio in normal times. Consumption inequality is higher in the NI than the LO case because the NI case lacks the effect of the ad hoc lockdown moderating the increase in \( p^h \) and the rise of income inequality in the LO case.

The left panel of Fig. 7 shows the optimal transfers and the social welfare gain as \( \theta \) varies. Transfers are plotted as the change in the transfers-GDP ratio relative to normal times (\( \Delta\text{Tr}/\text{GDP} \)) and welfare is measured relative to the no-intervention DCE under a 4-quarter pandemia. \( \Delta\text{Tr}/\text{GDP} \) rises monotonically because consumption inequality increases with \( \theta \) (see Fig. 6) and strengthens the incentives.

Fig. 6 Relative prices and consumption inequality in pandemia as \( \theta \) varies. \( \Omega \) is defined by the ratio of excess consumption of type-1 to type-2 agents. \( \theta \) denotes the elasticity of the subsistence demand for health goods \( \bar{h} \) with respect to total capital utilized \( mK \). \( \bar{\theta} \) corresponds to the maximum value of \( \theta \) for which there exists a solution for the decentralized competitive equilibrium.
to redistribute across agents so as to maintain the ratio of excess consumptions at \( \Omega^\theta = 3.46 \). \( \Delta \text{Tr}/GDP \) is small for weak pandemics but for \( \theta > 0.05 \) increases in transfers from 5 to 13 percentage points of GDP are optimal.\(^{28} \) Similarly, weak pandemics yield negligible welfare gains from the optimal policies, but for \( \theta > 0.05 \) the welfare gains are a sharply convex function of \( \theta \) and grow infinitely large as \( \theta \) approaches \( \tilde{\theta} \), because at that point workers hit the Inada condition for health consumption in the Stone–Geary preferences. This result also highlights the importance of healthcare saturation in our framework: Even if the infected fatality rate of COVID is very small, healthcare saturation can impose very large social costs.

Figure 7 also shows that the nonlinear effects of implementing policies with measurement error in \( \theta \) discussed earlier have nonlinear welfare implications. For instance, around \( \theta = 0.0918 \), which is the value that renders the observed GDP decline consistent with the optimal policy, if the “true” \( \theta \) is slightly lower (higher) the welfare gain is much smaller (larger).

The right panel of Fig. 7 shows a decomposition of the welfare gains in terms of the fractions due to changes in aggregate allocations and redistribution across agents. The contribution of removing the inefficiency in aggregate allocations is always much smaller than the contribution due to redistribution, which highlights again the relevance of the effects of pandemics on inequality in the model. As \( \theta \) rises, the contribution from changes in aggregate allocations shrinks and that from redistribution rises, because inequality is increasing in \( \theta \). The aggregate inefficiencies account at most for 11% of the welfare gains, and that is for very small welfare gains corresponding to weak pandemics. Redistribution accounts for 88–96% of the welfare gains. This is because type-2 agents move closer to their subsistence level of health consumption as \( \theta \) rises and as this happens they approach the Inada condition that makes the marginal utility of allocating health consumption to them infinitely large. For the optimal policy reported in Table 5, the contribution of redistribution is close to 92%. This result is not inconsistent with the previous finding showing that for that same optimal policy the gains from reducing \( m \) are larger than those from increasing \( \text{Tr} \), because, as noted earlier, reducing \( m \) contributes to both improve aggregate efficiency and reduce inequality.

The role of inequality in these results can be illustrated further by examining the welfare implications of agent heterogeneity. Figure 8 compares social welfare gains of the optimal policies (relative to the no-intervention DCE) as \( \theta \) varies for the calibrated economy with \( \gamma_1 = 0.2 \) and the comparable representative-agent economy with \( \gamma_1 = 1 \). In the latter, the welfare gains are only due to the removal of the utilization externality. The DCE (SPE) aggregate allocations are the same as in the DCE (SPE) with two agents. Both welfare gains display the convex, asymptotic behavior as \( \theta \) reaches \( \tilde{\theta} \). The value of \( \tilde{\theta} \), however, is about 60% bigger in the representative-agent model that has no inequality (since \( \gamma_1 = 1 \)). This occurs because, as explained earlier, the pandemia moves workers toward their subsistence health demand at a much faster pace than entrepreneurs, and hence the health system saturates at lower

\(^{28} \) Recall that \( \Delta \text{Tr}/GDP \) captures both the effect of the exogenous change in transfers and the endogenous response of GDP to the optimal policies. The valuation effect of higher \( p^h \) reduces the ratio.
when inequality is present. At values of \( \theta \) for which both models can be solved, the welfare gains of the optimal policies are negligible for the representative-agent model. A much stronger utilization externality, driven by higher \( \theta \) values (above 0.14), would be needed in order to yield non-trivial welfare gains. At those values, however, the model would predict much larger falls in output than what has been observed (since the higher \( \theta \) values would yield much larger utilization cuts).

Figure 8 also indicates that a pandemic of identical characteristics in terms of the elasticity of health subsistence to utilized capital is much more damaging for countries with higher levels of wealth inequality pre-pandemia (lower \( \gamma_1 \)). The welfare implications of wealth inequality are also nonlinear, because the upper bound \( \bar{\theta} \) at which the health system saturates and the welfare gains of the optimal policies grow infinitely large is decreasing in \( \gamma_1 \).

5.2.3 Assessing the Effectiveness of Suboptimal Policies

We consider next policy errors due to ad hoc deviations from the optimal transfers and lockdown policies that could be the result of political economy considerations, institutional flaws, or other frictions outside the model.

Figure 9 shows welfare costs from policies that deviate from the planner’s optimal policies in the calibrated model (i.e., those reported in Table 5). To construct this figure, we solve the DCE for arbitrary pairs of mandated utilization rates and increases in transfers, calculate the welfare gain that would be obtained by shifting to the planner’s optimal policies, and plot the negative of that gain as the welfare cost of each arbitrary policy pair. The transfers policies span the 0–28% interval, defined in terms of increases relative to transfers in normal times in percent of the GDP of normal times (\( \Delta Tr/GDP_{NP} \)). We use a common value of GDP to scale \( Tr_p \) and \( Tr_{NP} \) in order to isolate the change in transfers per-se (which is the policy instrument) from endogenous changes in GDP. The figure shows curves for welfare costs as a function of \( \Delta Tr/GDP_{NP} \) for four utilization rates \( m = 0.6, 0.7, 0.85, 1 \).
The percent drops in non-health GDP associated with these utilization rates are 25, 18.2, 8.8 and 0, respectively. The curves are discontinuous because transfers...
that are too large would make excess consumption of type-1 agents negative. The SPE’s optimal policies correspond to $m^{sp} = 0.85$ and $\Delta Tr/GDP_{NP}^{sp} = 12.7\%$. By construction, the maximum value for the curve corresponding to $m = m^{sp} = 0.85$ is $\Delta Tr/GDP_{NP}^{sp} = 12.7\%$ and there is zero welfare cost, because this point in the curve matches the SPE. Any deviation from this policy pair reduces welfare. As before, the red and blue dots correspond to the DCE solutions for the NI and LO cases in Table 5. The horizontal line identifies the welfare cost if there is no policy change when the pandemia hits.

This figure yields two important results. First, deviating from the optimal policies can have non-trivial welfare costs but, for the set of policy pairs considered, policy intervention is always preferable to no intervention and mostly by a sizable margin. Relative to the DCE without policy intervention, welfare is at least 0.35% higher with all policy pairs except those with no lockdown ($m = 1$) and small transfer hikes (below 5 percentage points). Note, however, that the ranking of the policies is not monotonic, as the crossing of the curves indicates: With low transfers, stricter lockdowns are better but as transfers increase stricter lockdowns are undesirable.

The second result is that transfers and lockdowns can be traded off widely at a small welfare cost. For instance, a no-lockdown policy with a transfers hike of 18 percentage points yields about the same welfare as one pairing a hike in transfers of about 5 percentage points with a strict lockdown that reduces $m$ to 0.7 and output by 25%, and both policy pairs are only about 0.08% below the SPE in terms of welfare. Even in a scenario in which only one instrument can be used, a hike in transfers of 18 percentage points without a lockdown is only about 0.1 of percent better than a lockdown setting $m = 0.6$ without increasing transfers. This is possible because either a large increase in transfers or a strict lockdown reduce the strong adverse effects on inequality caused by the pandemia. For the same reason, policies that combine weak lockdowns with small hikes in transfers are undesirable and the interaction of the two is nonlinear. For instance, the welfare loss resulting from changing from the optimal lockdown to no lockdown (i.e., the gap between the blue and red curves) grows larger as the size of the increase in transfers is reduced. This is again because both less strict lockdowns and weaker transfers programs allow the pandemia to worsen inequality more.

These results have important policy implications, because the data show that countries with high income per-capita have implemented much larger transfers policies and stricter lockdowns in response to COVID-19 than those with lower income. Data from the IMF Fiscal Monitor show that, through September 2020, the average increase in transfers for advanced economies reached 9.9% while for emerging and less developed countries the averages were 4.4 and 3%, respectively. These data include additional and accelerated spending plus foregone and deferred revenue and exclude business liquidity support (equity injections, loans, asset purchases, debt assumptions, guarantees and quasi-fiscal operations).
per-capita has a correlation with the community mobility measure of \(-0.2\) while the correlation with COVID-related transfers is 0.5. Hence, on average, poorer countries responded to COVID-19 with both weaker lockdowns and smaller fiscal interventions, which is the worst combination in the model.

5.2.4 Unequal Pandemic Impact on Subsistence Health Demand

In this section, we consider asymmetric increases in subsistence health demand triggered by the pandemia.\(^{31}\) In particular, we assume that type-1 agents (entrepreneurs) have the following preferences:

\[
\max \left\{ \{c_t^1, l_t^1, h_t^1\} \leftrightarrow \sum_{t=0}^{\infty} \beta^t \left( a \ln \left( c_t^1 - \frac{\left(l_t^1\right)^{\omega}}{\omega} \right) + (1 - a) \ln \left( h_t^1 - \kappa \bar{h}_t \right) \right) \right\},
\]

with \(\kappa \in [0, 1)\). Preferences for the type-2 agents (workers) remain the same. Since \(\kappa < 1\), entrepreneurs are less affected by the hike in the subsistence demand for health goods than workers.

The aggregate allocations of the DCE are the same as before, since they do not depend on agent heterogeneity. Individual allocations, however, differ. The relative price of non-health goods is now:

\[
p_t^h = \frac{1 - a}{a} \frac{C_t - \frac{(L_t)^{\omega}}{\omega}}{H - \bar{h}_t(\kappa \gamma_1 + \gamma_2)}.
\]

Comparing with Eq. (5), this result implies that the relative price of health goods is lower than in the original model. This is evident because aggregate allocations are identical in both cases and \(\kappa \gamma_1 + \gamma_2 < 1\), since \(\kappa < 1\). The smaller increase in \(p_t^h\) implies that income of type-1 agents rises less and the demand for health goods of both agents is further away from the subsistence levels. Hence, the effects of the pandemia on inequality are weaker.

The planner’s optimal utilization rate is higher than in the original model. The planner’s first-order condition with respect to \(m_t\) is now

\[
z_d f'(m_tK)(\kappa \gamma_1 + \gamma_2) \left(1 - a\right) \frac{C_t - \frac{L_t^{\omega}}{\omega}}{H - \bar{h}_t(\kappa \gamma_1 + \gamma_2)} + x_0 m_t^{x_1 - 1} = (1 - a) \left( \frac{L_t}{m_tK} \right)^{\alpha}.
\]

The left-hand side of this expression shows that the social marginal cost of utilization is lower than in the original model. Since \(\kappa < 1\), the numerator (denominator) is smaller (larger). Hence, the planner’s utilization rate is higher and weaker lockdowns are socially optimal. It is also important to note that in this setup the planner’s utilization choice is no longer independent of agent heterogeneity.

\(^{31}\) See “Appendix 2” for a full characterization of this version of the model.
The planner’s optimal transfers needed to keep inequality from worsening during the pandemia are lower because inequality increases less in the DCE. In particular, transfers become:

\[
\frac{\text{TR}^{\text{sp}, P}}{\gamma_2} = \left[ \frac{C_t - (L_t^p)^\omega}{1 + \gamma_1 (\Omega^p - 1)} + \left( \frac{(L_t^p)^\omega}{\omega} + p_{t, \text{sp}} \left( \frac{H - (\gamma_1 \kappa + \gamma_2) \tilde{h}_t}{1 + \gamma_1 (\Omega^p - 1)} + \tilde{h}_t \right) \right) - (L_t^p)^\omega \right]
\]

where \( p_{t, \text{sp}} \equiv \left( \kappa \gamma_1 + \gamma_2 \right) \frac{C_t - L_t^p}{\omega} \). Hence, \( \kappa < 1 \) reduces the social price of health goods relative to the original model, and this justifies lower transfers.

We solve the model for different values of \( \kappa \). Figure 10 illustrates how optimal policies, prices, excess consumption ratios, and transfers and welfare gains vary with \( \kappa \).

Figure 10 shows the key results for \( \kappa \) in the 0–1 interval for the same scenarios we explored earlier (decentralized equilibrium without intervention, decentralized equilibrium with an ad hoc lockdown, and social planner’s equilibrium). As expected, lower values of \( \kappa \) imply smaller relative price increases during the pandemia. In addition, as \( \kappa \) falls, the utilization externality also shrinks, which in turn implies weaker optimal lockdowns. In terms of the ratio of excess consumption across agents, there is less consumption inequality as \( \kappa \) falls, which is consistent with smaller relative price hikes and less severe lockdowns. Lastly, transfers and social welfare gains decrease as \( \kappa \) falls, which reflect the weaker utilization externality and smaller inequality effect.

The most important finding of this exercise follows from comparing the results vis-a-vis those of the original setup (i.e., those for \( \kappa = 1 \)): The quantitative findings weaken somewhat but remain quite large as we lower \( \kappa \). Even in the extreme case where \( \kappa \) approaches 0 (i.e., type-1 agents barely experience a change in their subsistence demand for health goods during the pandemia), the utilization externality is still sizable, which is reflected in a large lockdown (a cut in utilization of nearly 10 percentage points is socially optimal) and inequality effects are still large (an increase in transfers of nearly 10 percentage points of GDP is socially optimal).

To study the implications of heterogeneity in the pandemic shock further, we document in “Appendix 2.3” a set of results increasing \( \gamma_1 \) up to 30% and changing \( \kappa \) from 1 to 0. In these experiments, a larger fraction of the population benefits from the income effects of higher health prices and suffers less from the shock on \( \tilde{h} \) due to COVID. Even with \( \gamma_1 = 0.3 \) and \( \kappa = 0 \), the lockdown and redistribution incentives are strong and yield a cut in utilization of 7.5 percentage points and an increase in transfers of 8 percentage points of GDP. A more extreme case, in which half the population shares the higher income resulting from higher health prices and its subsistence health demand is completely unaffected by COVID (\( \gamma_1 = 0.5, \kappa = 0 \)), the optimal lockdown still cuts utilization by 4 percentage points and transfers rise by 5.

\[\text{We keep } \theta \text{ at the same value of the baseline calibration. We recalculate initial transfers so that the transfers-to-GDP ratio remains equal to the 14.5% of the pre-pandemia period.}\]
percentage points of GDP. Thus, the model yields non-trivial lockdown and redistribution incentives even with much less pre-COVID inequality and a large fraction of the population not suffering from the shock on subsistence health demand.

6 Conclusions

This paper proposed a model of the macroeconomic effects of pandemias in which the saturation of the health system is the key driving force. This approach is motivated by evidence we provided on resource shortages and capacity constraints of hospitals, sharp increases in the relative prices of key health goods and services, spikes in excess mortality beyond that explained by COVID-19, and a cross-country analysis showing that proxies for healthcare system saturation and the stringency of lockdowns are significant determinants of differences in the size of GDP drops caused by COVID-19, even after controlling for the effects of COVID infection and mortality.
Healthcare saturation is modeled by introducing Stone–Geary preferences with a jump in the subsistence demand for health goods and services during pandemias that is positively related to capital utilization. The model features entrepreneurs and workers in order to capture the effects of pandemias and lockdowns (i.e., mandated reductions in utilization) on consumption and income inequality. An output–pandemia trade-off emerges because firms do not internalize that reducing utilization during a pandemia moves the healthcare system away from its saturation point. The pandemia moves workers closer and faster to the subsistence demand for health than entrepreneurs and it causes a sharp increase in the relative price of health goods and in the excess consumption ratio of entrepreneurs relative to workers. Lockdowns mitigate these adverse effects on inequality by mitigating the shock on subsistence health demand and its impact on the relative price of health. A planner with a standard social welfare function reduces utilization (to tackle the utilization externality) and redistributes consumption and income from entrepreneurs to workers (to keep the excess consumption ratio unchanged). Hence, the optimal policy that decentralizes the planner’s allocations includes a lockdown and increased transfers to workers.

We examined the quantitative predictions of the model using numerical solutions for a calibration to US data. Two key pieces of this calibration related to the subsistence demand for health are its level in normal times and its elasticity with respect to utilized capital. The former was determined using a linear-expenditure-system regression with pre-COVID-19 data, and for the latter we examined results for the interval of elasticity values that support competitive equilibria, since the elasticity has an upper bound at the level that drives workers to reduce their demand for health to the subsistence level. Within this interval, we also studied a set of results for which the elasticity is such that the observed decline in US non-health GDP results from an optimal lockdown, which requires an elasticity of 0.09. This planner’s solution was then compared with competitive equilibria in which policies are unchanged (the no-intervention, NI, case) and in which a lockdown equal to the optimal one is implemented but transfers remained unchanged (the lockdown-only, LO, case).

The results are indicative of the potential relevance of the proposed approach to study pandemias as a problem of health-system saturation and resource shortages and shed light on the challenges facing the design of lockdown and transfer policies to deal with pandemias. The effects of the pandemia on both aggregate efficiency and inequality are significant. For the scenario that rationalizes the observed output drop as an optimal policy, the welfare gains relative to the NI and LO cases are 0.82 and 0.33%, respectively. The increase in excess consumption inequality is fivefold and threefold in these scenarios, respectively. The optimal policy requires a cut in utilization of 15 percentage points (which yields a non-health output drop of 8.8%) and an increase in the transfers-GDP ratio of 10.9 percentage points. The relative price of health rises 101% under the optimal policies and the LO case, and 158% in the NI case. Inequality worsens very sharply during the pandemia, with the excess consumption ratio increasing by factors of 4.8 and 2.8 in the NI and LO cases, respectively. The difference between the two shows that lockdowns have strong effects on inequality, because even without
transfers, a lockdown reduces the hike on subsistence health demand, which reduces the rises in relative prices and the excess consumption ratio.

Examining the set of solutions for the entire interval of feasible elasticities of subsistence health demand to utilized capital shows that the effects of pandemias on macro-aggregates and inequality start to become relevant at elasticities higher than 0.05. The output–pandemia trade-off yields concave, negative relationships between either the planner’s optimal utilization or non-health output and that elasticity. Relative prices and excess consumption ratios in the NI and LO solutions, and the welfare gains under the optimal policies are increasing, convex functions of the elasticity. Hence, small measurement error in the value of this elasticity results in non-trivial differences on the magnitude of optimal lockdown and transfer policies and their effects.

The planner undoes the large negative effect of the pandemia on inequality through the direct effect of the transfers and the indirect effect of the lockdown (which mitigates the relative price hike and the rise of the excess consumption ratio). The two effects combined contribute over 90% of the welfare gains of the optimal policies. The aggregate effect of the lockdown removing the utilization externality accounts for the other 10%. Inequality also makes the model more plausible. A planner in a representative-agent version of the model only gains by removing the utilization externality and thus needs larger elasticities of subsistence health demand to utilized capital (above 0.13) in order to yield non-trivial welfare gains. But these elasticities would yield unrealistically large output drops.

Deviating from the optimal policies has non-trivial welfare costs. However, policy intervention is preferable to no intervention for a large set of lockdown and transfer policy pairs. Moreover, transfers and lockdowns can be traded off widely at a small welfare cost, because either a large increase in transfers or a strict lockdown reduce the strong adverse effects of the pandemia on inequality. For the same reason, policies that combine weak lockdowns with small hikes in transfers are the worst choice. This result has important policy implications, because emerging and least developed countries responded to COVID-19 with both weaker lockdowns and smaller fiscal interventions than advanced economies. Income per capita has a correlation with lockdown effectiveness of roughly − 0.2 whereas its correlation with COVID-related transfers is 0.5. The mean increase in transfers in advanced economies has been at least 2.25 times larger than in emerging and least developed countries.

We also use an extension of our model to test its robustness. This extension allows for heterogeneous impacts of the pandemia on the rise of the subsistence demand of agents in the economy. Entrepreneurs experience milder impacts from the saturation of the healthcare system. Our quantitative findings suggest weaker lockdowns and increases in transfers when entrepreneurs are less impacted by the pandemia. In addition, we also vary the fraction of entrepreneurs in the economy. We find that, even in extreme cases like the one where half of the population is unaffected by the pandemia, optimal lockdowns and increases in transfers are still sizable, where we observe a decrease of 4% in utilization and an increase of 8 points of GDP in transfers.
Our results also have important implications for the analysis of cross-country or cross-region responses to COVID-19. The model predicts that a pandemic is more damaging for countries with higher wealth inequality and/or weaker health systems or other pre-pandemia conditions (e.g., income per capita, life expectancy, etc.). Weaker pre-pandemia conditions can be viewed as implying higher elasticities of subsistence health demand to utilized capital which imply larger optimal lockdowns and output drops. The relative size of the health sector also captures cross-country differences in health systems. For a given elasticity, the model predicts weaker effects of pandemics in countries with larger health sectors or larger shares of non-health expenditures.

This study is a first step in a research agenda exploring the saturation of the healthcare system as the mechanism driving macroeconomic models of pandemics. The model we presented is streamlined with the intent of highlighting the essential elements of this mechanism, leaving for further research enriching the model to explore dynamic and cross-country propagation, particularly in models with capital accumulation and financial frictions, and to study the interaction of optimal lockdown and transfer policies with optimal taxation and public debt sustainability.

Appendices

Appendix 1: Sectoral Stock Returns

In this section, we present suggestive evidence that price hikes, shortages and lockdowns had a differential impact on the profitability of publicly listed companies in the health sector relative to their peers in the Services sector. Figure 11 shows the monthly cumulative returns for firms in four sectors: Health, Health excluding the companies that developed COVID vaccines, Services (restaurants, travel, entertainment), and the S&P index. The data cover the period from January 2020 through May 2022 and are drawn from Bloomberg.

The returns on the Health index increased by 150% over the course of the sample. The gap between the Health and Health Non-Vaccine indices suggest that the returns to shareholders of the companies that developed the COVID vaccines explained more than half of the sustained increase in profits of the health sector. Both indices exceeded the S&P aggregate throughout the period while the services sector – the sector most hard-hit by lockdowns – had the weakest performance until early 2021. Returns on the services sector improved during 2021–2022 when lockdown measures started to be relaxed and vaccines became more widely available.

The list of stocks in each sector are the following:

1. Health Stocks

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33 Cumulative returns by sectors consider simple averages across companies.
(a) Vaccines: PFE, MRNA, NVAX, JNJ, REGEN, GLAXO.
(b) Health Non-Vaccines: PG, MMM, KMB, CLX, DGX, ABT, ABBV, MRK, MESO, LLY, BNTX.

2. Services Stocks

(a) Restaurants: EAT, BLMN, CAKE, CMG, DRI, DIN, DPZ, PZZA, SHAK, SBUX, TXRH, WEN, YUM.
(b) Travel
   i. Hotels/Resorts: MAR, H, WYNN, IHG, CHH, HLT.
   ii. Cruise lines: RCL, NCLH, CUK.
   iii. Airlines: LUV, AAL, UAL, JBLU, DAL, SAVE.
   iv. Booking agencies: EXPE, TRIP, BKNG.
(c) Entertainment
   i. Movie Theaters: CNK, IMAK, AMC.
   ii. Amusement parks: SIX, FUN, PLAY, SEAS.
   iii. Malls/retail: SPG, MAC, PEI.
   iv. Other: LYV.

Fig. 11  Monthly cumulative returns by sector. Notes The Health sector includes publicly listed companies that developed COVID vaccines and firms that produce health-related goods. The services sector includes publicly listed companies in the restaurant, travel and entertainment sectors. See “Appendix 1” for more details.
Appendix 2: Model Extension

In this section, we provide a full characterization of the model in Sect. 5.2.4, in which the pandemia has unequal effects on the subsistence demand for health goods across different agents.

Appendix 2.1: Decentralized Competitive Equilibrium

An individual of type 1 (entrepreneur) maximizes the utility function:

$$\max_{\{c^1_t, l^1_t, h^1_t\}} \sum_{t=0}^{\infty} \beta^t \left[ a \ln \left( c^1_t - \frac{(l^1_t)^{\omega}}{\omega} \right) + (1 - a) \ln \left( h^1_t - \kappa \bar{h} \right) \right],$$  \hspace{1cm} (49)

subject to the budget constraint

$$c^1_t + p^h h^1_t = w^1_t l^1_t + \pi^1_t + p^h h - \tau^1_t.$$  \hspace{1cm} (50)

Individuals of type 2 (workers) face the problem described in Sect. 4. Specifically, they maximize the discounted lifetime utility

$$\max_{\{c^2_t, l^2_t, h^2_t\}} \sum_{t=0}^{\infty} \beta^t \left[ a \ln \left( c^2_t - \frac{(l^2_t)^{\omega}}{\omega} \right) + (1 - a) \ln \left( h^2_t - \bar{h} \right) \right],$$  \hspace{1cm} (51)

subject to this budget constraint,

$$c^2_t + p^h h^2_t = w^2_t l^2_t + \tau^2_t.$$  \hspace{1cm} (52)

The first-order conditions imply

$$1 - a \frac{c^1_t - \frac{(l^1_t)^{\omega}}{\omega}}{h^1_t - \kappa \bar{h}} = p^h = 1 - a \frac{c^2_t - \frac{(l^2_t)^{\omega}}{\omega}}{h^2_t - \bar{h}}.$$  \hspace{1cm} (53)

Using the market clearing condition for health goods $\gamma_1 h^1_t + \gamma_2 h^2_t = H$ along with equation (53) we have that the relative price of health goods is given by

$$p^h = \frac{1-a}{H - \bar{h}(\kappa \gamma_1 + \gamma_2)},$$  \hspace{1cm} (54)

where $C^*$ and $L^*$ denote the equilibrium aggregate allocations for aggregate consumption and labor in the decentralized competitive equilibrium.\(^{34}\) The individual allocations for agents type 1 and 2 are defined by

\(^{34}\) Note that these allocations, as in Sect. 4, are independent of individual heterogeneity.
Appendix 2.2: Social Planner’s Equilibrium

The social planner solves the following maximization problem:

$$\max_{\{c^i, l^i, h^i, m_t\}} \sum_{i=1,2} \left\{ \phi_i \gamma_i \sum_{t=0}^{\infty} \beta^t \left[ a \ln \left( \frac{c^i_t - \left( \frac{L_t^g}{\omega} \right)^{\omega}}{\omega} \right) + (1 - a) \ln \left( h^i_t - \kappa \bar{h}_t \right) \right] \right\},$$

subject to:

$$\gamma_1 l^1_t + \gamma_2 l^2_t = L_t,$$
$$\gamma_1 h^1_t + \gamma_2 h^2_t = H,$$
$$\gamma_1 c^1_t + \gamma_2 c^2_t \equiv C_t = (m_t K)^{1-a} L_t^g - \chi_0 m_t^\chi_1 / \chi_1,$$
$$m_t \leq \bar{m},$$
$$\bar{h}_t = h^* + z_t f(m_t K),$$

with $\kappa^1 = \kappa$ and $\kappa^2 = 1$. $\phi_i$ denotes the weight of the social welfare function on type-$i$ agents, and the ratio of these weights is denoted $\Omega^{sp} \equiv \phi_1 / \phi_2$. We set $\Omega^{sp} = \Omega^{*NP}$, as in Sect. 4.

The optimality conditions of the social planner are given by

$$l^1_t = l^2_t = L_t = (a(m_t K)^{1-a})^{\frac{1}{a-1}},$$

and

$$(1 - a) \left( \frac{L_t}{m_t K} \right)^a = z_t f'(m_t K)(\kappa \gamma_1 + \gamma_2) \frac{(1 - a)}{a} \frac{\left( C_t - \frac{L_t^g}{\omega} \right)}{H - \bar{h}_t (\kappa \gamma_1 + \gamma_2)} + \chi_0 m_t^\chi_1 - 1,$$

Profits are identical to the solution in Sect. 4.1.4.
Using condition (63) and the market clearing condition for non-health goods, we have that the optimal consumption for type-2 agents is

\[
\frac{c_1^t - \frac{(l_1^t)\omega}{\omega}}{c_2^t - \frac{(l_2^t)\omega}{\omega}} = \Omega^{sp}.
\]

Using condition (63) and the market clearing condition for non-health goods, we have that the optimal consumption for type-2 agents is

\[
c_{2sp}^t = \frac{C_{sp}^t - \frac{(L_t^p)\omega}{\omega}}{1 + \gamma_1(\Omega^{sp} - 1)} + \frac{(L_t^p)^\omega}{\omega},
\]

where \(C_{sp}^t\) and \(L_t^p\) denote the allocations for aggregate consumption and labor that solve the equilibrium conditions (60) and (61). Using Eq. (62) along with the market clearing condition for health goods, we obtain the optimal allocation of health goods for type-2 agents:

\[
h_{2sp}^t = \frac{H - (\gamma_1K + \gamma_2)(h^* + z_f(m_{sp}^p K))}{1 + \gamma_1(\Omega^{sp} - 1) + h^* + z_f(m_{sp}^p K)},
\]

where \(m_{sp}^p\) denotes the social planner’s optimal capital utilization. We can recover the optimal allocations for consumption of health and non-health goods for type-1 agents using the market clearing conditions for health and non-health goods in conjunction with the optimal allocations for type-2 agents.

Lastly, the optimal transfers during the pandemic that decentralize the social planner’s allocations can be obtained by combining (64), (65) and the budget constraint of type-2 agents (52):

\[
\frac{TR_{sp}^P}{\gamma_2} = \left[\frac{C_{sp}^t - \frac{(L_t^p)\omega}{\omega}}{1 + \gamma_1(\Omega^{sp} - 1)} + \frac{(L_t^p)^\omega}{\omega} + p_{t}^{sp} \left(\frac{H - (\gamma_1K + \gamma_2 \bar{h}_t) + \bar{h}_t}{1 + \gamma_1(\Omega^{sp} - 1) + \bar{h}_t}\right)\right] - \frac{(L_t^p)^\omega}{\omega}.
\]

Appendix 2.3: Sensitivity Analysis

In this section, we present a sensitivity analysis of the model extension described in this Appendix. In particular, we vary the fraction of agents that benefit from the income effects of higher health prices (\(\gamma_1\)) as well as the impact that the pandemic has on their subsistence health demand (\(\kappa\)). Figure 12 presents heatmaps that reflect how optimal utilization and transfers vary with these two parameters.

Figure 12 shows that the optimal capital utilization is higher (i.e., weaker lockdowns) the larger the fraction of entrepreneurs in the economy. This result appears because as \(\gamma_1\) increases, the fraction of worker-type agents shrinks, which happens to
be the share of agents that suffer the most from the pandemic. Because of the need of weaker lockdowns with larger values of $\gamma_1$, we see that transfers from entrepreneurs to workers are lower. We can also see that optimal capital utilization and transfers respond to changes in $\kappa$, as shown in Sect. 5.2.4. Specifically, we see that lockdowns are milder and transfers lower the lower the value of $\kappa$. The result is intuitive as lower values of $\kappa$ imply that there is a fraction of agents that are less affected by the pandemic (via rises in their subsistence demand for health goods).

In terms of the interactions between $\gamma_1$ and $\kappa$, Fig. 12 suggests that we observe the weakest lockdowns and smallest transfers when $\kappa = 0$ (lowest value) and $\gamma_1 = 0.3$ (highest value). Even in a scenario like this one, the lockdown and redistribution incentives are quite strong. Specifically, the optimal policy yields a reduction in utilization of 7.5 percentage points and an increase in transfers of around 8 percentage points of GDP.

Acknowledgements The views expressed in this document are those of the authors and not those of the Federal Reserve Bank of Chicago or the Federal Reserve System. We would like to thank participants at the IMF’s 22nd Jacques Polak Annual Research Conference for helpful comments as well as Alessandra Fogli for her insightful discussion. We also thank participants at the Fifth Annual Conference on International Economics organized by the Federal Reserve Bank of Dallas, University of Houston, and Bank of Mexico, DePaul University, Boston College, SECHI 2021, University of Florida, and WATE 2021 for useful comments and suggestions. We are grateful to Andrea Foschi and Erin Gibson for excellent research assistance.

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Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

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