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A Macroeconomic Model of Healthcare Saturation, Inequality & the Output-Pandemia Tradeoff*

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Abstract

COVID-19 became a global health emergency when it threatened the catastrophic collapse of health systems worldwide. Its particular mix of rapid spread and severity caused demand for health goods and services and their relative prices to surge, unlike other diseases that are deadlier (e.g. Ebola, MERS) or just as contagious but less severe (e.g. Influenza, H1N1). Governments responded with prolonged lockdowns that caused large drops in economic activity. Empirical evidence shows that lockdowns and healthcare saturation explain a sizable fraction of cross-country variation in observed GDP drops even after controlling for COVID cases and mortality. We explain this output-pandemia tradeoff as resulting from a shock to the Stone-Geary subsistence level of health that is larger at higher levels of capital utilization in a model with capitalists and workers. A health system's degree of saturation is the gap between supply and subsistence levels. The tradeoff is non-linear, with sharply larger welfare costs as lockdowns or healthcare saturation tighten. An externality distorts utilization, because firms do not internalize that lower utilization relaxes healthcare saturation. Optimal lockdowns remove it, but small deviations leave health systems closer to saturation or impose large output costs. Inequality worsens markedly with pandemias, increases sharply their welfare costs, and makes large transfers to workers optimal.

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1 Introduction

A distinguishing feature of the COVID-19 pandemia 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 use of human and material resources for prolonged hospitalizations and in demand for medical and cleaning supplies by the economy as a whole.[1] 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 painful experiences of Bergamo, Guayaquil, Mexico City, New York City, Wuhan, and other cities, showed that collapsing health systems prevented hospitals from providing required care to COVID-19 patients and paralyzed the provision of services to those affected by other conditions, both emergencies and elective treatments, thus increasing excess mortality well above the mortality rate of COVID-19 itself. At the time of this writing, a second surge larger than the first is spreading rapidly across several advanced and developing economies exerting severe pressure on health systems.

Governments responded to the threat of collapse of health systems by imposing severe lockdowns that required all non-essential businesses to close and households to obey strict stay-at-home orders, after attempts with weaker social-distancing restrictions failed to slow the spread of the disease. As we document in the next Section, lockdowns have been in place, with some shifting between relaxing and re-tightening, from March, 2020 until the present in several countries. 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 percent relative to the second quarter of 2019 in a sample with 48 countries (see Section 2 for details). In addition, in many advanced economies, policies implemented to provide liquidity to households and firms affected by the lockdowns produced record-high public deficits and sharp increases in already-high public debt ratios.

The unprecedented economic costs of the lockdowns, on the one hand, and their effectiveness at preventing the collapse of health systems, on the other, pose a critical public policy trade-off: What is the socially-optimal severity of a lockdown that balances the need to contain a pandemia like COVID-19 against its large economic costs? Related to this are other central questions: How does inequality affect the relative impact of pandemias on capital-owners v. wage earners? What is the optimal size of transfers given to workers so they can withstand a lockdown? How does international heterogeneity in economic development and health-system strength affect the output-pandemia tradeoff?

This paper provides answers to these questions by proposing a model that deviates from the commonly-used approach of integrating the dominant 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 pandemia and captured by the saturation of health systems and the shortages of health goods. This approach is motivated by the observation that COVID-19 put health systems at the risk of collapse despite its low mortality and the large share of asymptomatic infections. The severe strain on health systems was evidenced by the suspension

[1] According to the CDC, the median length of hospitalizations for surviving patients in the U.S. as of October, 2020 was 10 to 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 regular hospital services to concentrate on COVID treatment and by the sharp increases in occupancy of hospital beds, particular ICU beds, in demand for medical specialists and nurses, and in usage of critical equipment such as respiratory ventilators (see Section 2 for details). As a result, excess mortality rates rose significantly above those explained by COVID itself. For instance, while COVID's infection fatality rate is estimated at 0.65 percent (according to the CDC), excess weekly deaths as a percent of expected deaths between March and June, 2020, peaked at 154 percent in Spain, 108 in the United Kingdom, 90 in Italy, and 45 in the United States, and in Mexico City excess mortality reached 300 percent in the March-May period.[2]

The theoretical analysis is preceded by an empirical examination of cross-country data that documents the effects of the COVID pandemia on resource scarcity and relative prices for health goods and services. In addition, we provide empirical evidence showing that a non-trivial share of cross-country differences in observed output declines caused by the pandemia is explained by variables that proxy for the severity of lockdowns, resource shortages and pre-COVID health system strength, even after controlling for COVID cases and fatalities.

In the model, the pandemia arrives as a large, temporary shock to the subsistence level of demand for health goods and services in a Stone-Geary utility function, with the size of the shock inversely related to the rate of utilization of physical capital. The degree of saturation of the health sector is represented by the gap between the available supply of health goods and services and their subsistence level. The catastrophic (i.e. nonlinear) nature of a health-system collapse is captured by the Inada condition of Stone-Geary preferences. The tradeoff with economic activity works through the dependency of the subsistence level of demand for health goods on factor utilization. Lower utilization relaxes the capacity of the health system, moving it away from its saturation point, but it implies reduced demand for factors of production, reduced output and cuts in wage and non-wage incomes. This also introduces an externality, because private agents do not internalize the link between utilization and health-system-saturation when choosing utilization. A planner who takes this into account has a social marginal cost of utilization higher than the private marginal cost when a pandemia is active. This results in a socially-optimal reduction in utilization during a pandemia, which can be implemented as a competitive equilibrium by imposing an optimal lockdown (namely, a binding constraint on utilization tighter than the technologically feasible limit).

In order to study the implications of the output-pandemia tradeoff for inequality and the design of liquidity-provision programs, the model includes two types of agents: Capitalists, who collect wages and all capital factor payments from the health and non-health sectors, and workers, who are hand-to-mouth consumers that collect only wage income. The government can use lump-sum transfers or debt to re-distribute resources across agents. We show that inequality, measured by the ratio of relative excess consumption (or relative marginal utilities) of capitalists vis-a-vis workers, worsens during a pandemia. As a result, it is optimal to provide transfers to workers.[3] Hence, the

[2] See https://ourworldindata.org/excess-mortality-covid and https://www.washingtonpost.com/world/the_americas/mexico-citycoronavirus- excess-death-toll/2020/07/02/2baaab3e-bbbb-11ea-80b9-40ece9a701dc_story.html.

[3] Inequality also makes transfers desirable even in the absence of pandemia for a utilitarian planner or a planner who weights capitalists by less than their share of total wealth. Still, optimal transfers are higher during a pandemia because inequality worsens.

optimal policy response to a pandemia includes both a lockdown and transfers to workers.

In the model, the benefits of removing the utilization externality and redistributing resources during the pandemia are independent, which facilitates characterizing the forces that drive them. The externality is driven by the sensitivity of the subsistence level of demand for health to the utilization rate, with aggregate allocations unaffected by agent heterogeneity, inequality and welfare weights. The optimal redistribution is driven by the planner's welfare weights, the fraction of workers relative to capitalists, and the size of the increase in inequality during the pandemia. The latter is in turn determined by how close workers move to their subsistence level of demand for health as a result of the pandemia.

We explore the potential quantitative relevance of the model by examining numerical solutions based on a calibration to U.S. data. Key to this calibration are the determination of the subsistence level of demand for health goods and services in "normal times" (i.e. without a pandemia) and the parameterization of the function that drives the jump in this subsistence level when the pandemia hits. We determine the former by estimating a standard linear-expenditure-system regression using U.S. data. For the latter, we postulate a simple linear function that simplifies the calibration into the choice of a linear coefficient that captures the elasticity of the subsistence level of health goods and services (as a percent of available supply) with respect to the rate of utilization of capital. Since this elasticity is difficult to pin down with existing data, we study an "observed lockdown" scenario that rationalizes the observed decline in second-quarter U.S. GDP as optimal and compare it with alternative scenarios for an interval of values of the elasticity.

The *observed lockdown* results show than an elasticity of 0.091 makes the -8.8 percent drop in GDP of nonhealth goods observed in the second quarter of 2020 in the United States optimal, with an associated optimal lockdown equivalent to a cut in utilization from a normalized rate of 100 percent pre-pandemia to 84.8 percent. This yields a sharp increase in the relative price of health goods to nonhealth goods of about 100 percent. Optimal transfers to workers reach 12.2 percent of GDP. Assuming a pandemia that lasts four quarters, these optimal policies yield a social welfare gain of 1.1 percent in terms of a compensating variation in consumption constant across time and across agents that makes the economy without policy intervention as well off in terms of social welfare as under the optimal policies. With an elasticity of health subsistence to utilization of 0.07, the optimal utilization is about 0.95, which causes a non-health output drop of about half what was observed in the United States, and the implied relative price increase is 60 percent. Hence, small differences in the estimates of the elasticity of health subsistence to utilization yield sharply different outcomes for the size of the optimal lockdown and implied output drop and relative price hike.[4]

Agent heterogeneity and inequality also play an important role in our results. A representative-agent economy with the same parameter values, except assuming all agents are capital-owners, yields sharply smaller welfare gains at the same values of the elasticity of health subsistence to utilization, and has a much higher elasticity upper bound at which the welfare gains grow infinitely

[4]The elasticity cannot exceed an upper bound at which workers hit their subsistence level of demand for health, thus triggering the Inada condition in their preferences. As this upper bound is reached, the welfare gains of the optimal policy grow infinitely large driven by unbounded social gains from redistribution.

large. Hence, the larger benefits of redistribution, and the larger optimal transfers predicted by the model, result from the non-linearity due to the effect of the pandemia moving workers towards their subsistence level of health at a much faster pace than capitalists.

This paper is related to the growing macro literature on COVID-19. To date, most of this literature has emphasized 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 tradeoff and its distributional implications.[5] In the studies based on the SIR/SEIR setup, decentralized equilibria are inefficient because the planner internalizes these dynamics and the social welfare function depends negatively (positively) on the aggregate death (recovery) rate of COVID infections. In contrast, in the model proposed here social welfare is a standard aggregation of individual preferences over consumption and labor, 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 factor utilization and affects workers more severely than capitalists. Moreover, this framework also accounts for large increases in the relative price of health goods when a pandemia hits.

Alvarez et al. (2020), Atkeson (2020) and Eichenbaum et al. (2020) initiated the literature on quantitative Covid macro models that use the SIR setup. In these models, the pandemia affects macroeconomic outcomes through demand and supply effects. Infections and mortality increase with consumption and hours worked. Workers that get sick 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 fatality rate as an increasing function of total infections above a constant mortality rate. This externality is somewhat similar to the utilization externality resulting from the adverse effect of utilization on the health subsistence level in our model, but it differs in that in the SIR models congestion increases Covid fatalities, which the planner dislikes. 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 the Covid fatality rate, and redistribution is desirable because this effect hits workers more severely than capitalists.

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), Baqaee 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

[5]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).

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 agents with low wealth require milder lockdowns and/or larger transfers. Chetty et al. (2020) examine heterogeneous effects on consumption. Using high-frequency data, they find that Covid has had negative effects on consumption, which vary by income quintile: lower-income agents have been affected disproportionately.

The SIR framework has also been used in small open economy models. Arellano et al. (2020) embedded the SIR mechanism into an Eaton-Gersovitz sovereign default model. The sovereign cares about the fatality rate and can impose 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 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 Covid 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 pandemia 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 pandemia, and study how bailouts can help save firms that are experiencing financial distress. Faria e Castro (2020) models the pandemia 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 pandemia are socially optimal.

The rest of the paper is organized as follows. Section 2 provides an empirical analysis illustrating the relevance of healthcare saturation and documenting important empirical regularities of the macro effects of the Covid-19 pandemia. Section 3 describes the model. Section 4 presents the quantitative results of the calibrated model. Section 5 provides some conclusions.

2 Empirical Evidence

In this Section, we review the empirical evidence on COVID-19 that motivates the theoretical model. The discussion is divided into four parts: 1) a review of the resource shortages and constraints on medical systems for managing the pandemia, 2) the impact of the pandemia on the prices of critical medical services and equipment, 3) international evidence on the severity and duration of lockdowns, and 4) a cross-country analysis of the determinants of output collapse during the pandemia.

2.1 Resource shortages and capacity constraints for COVID-19

Saturation of the health system caused by COVID-19 has three important components. The first is the capacity of hospitals to treat COVID patients, particularly to provide them with ventilation therapy. The second is the closure of non-Covid related medical and hospital services, as hospitals are dedicated to COVID patients and medical practices and elective procedures are shut down. The third are the shortages of medical and cleaning supplies as the healthcare and non-healthcare sectors as well as households aim to build up subsistence inventories.

Consider first hospital capacity to treat COVID patients. Evidence from COVID projections and existing studies from the public health literature shows that pandemias pose a tangible risk to cause health systems to collapse. On March 26, 2020, the Institute for Health Metrics and Evaluation (IHME) of the University of Washington issued a forecast of the likely stresses on the U.S. medical system due to COVID-19. Their analysis, based on a state-by-state assessment of medical facilities, warned that in the absence of large-scale public health interventions, particularly mitigation measures (i.e. lockdowns) the demand for intensive care facilities would outstrip existing supply in a matter of days.

IHME's analysis focused on ICU beds, but health systems can collapse well before running out of regular and ICU hospital beds as they run out of medical specialists, nursing staff, equipment and materials needed to treat patients in respiratory distress. Ajao et al. (2015) assessed the capacity of the US healthcare system to respond to increased ventilation therapy demand due to a hypothetical influenza pandemic outbreak under three levels of stress on the health system: (i) conventional capacity (usual and normal patient care); (ii) contingency capacity (minor adaptation of treatment approaches) and (iii) 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 of them limits the ability to provide ventilation therapy. Taking as given the estimated number of ventilators availabe 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 pandemia in the United States, the constraining factor for ventilation therapy in scenario (iii) would be the number of respiratory therapists, not the number of beds. The maximum number of additional patients that could be put in a ventilator would range from 56,300 to 135,000, which would fall short of the number of available beds enabled for ventilation therapy. In fact, 32,300 to 42,300 beds would go unused.

Halpern and Tan (2020) assess U.S. capacity for treating COVID-19 patients under current conditions. Based on surveys of U.S. hospitals, they report that acute care hospitals own 62,188 full-featured mechanical ventilators. Adding other equipment that can be diverted to ventilator use (e.g. from operating rooms and the U.S. stockpile) has the potential to bring the total up to 200,000 devices nationally. Recent projections suggest that approximately 960,000 patients in the US would require ICU ventilatory support, though not all patients would be treated at the same time. But even if the number of patients could be optimally staggered, they conclude the critical factor is staffing. According to the BLS there are approximately 130,000 respiratory therapists in the labor force. However, there are far fewer respiratory intensivists, physicians certified to provide care for critically ill patients. The American Hospital Association estimates that there are roughly 29,000 intensivists nationwide, and about half of acute care hospitals have no intensivists on their staff. Halpern and Tan (2020) conclude, "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 percent 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)

Li et al. (2020) apply the dynamics of the COVID-19 outbreak in Wuhan to the United States and reached similar conclusions as Ajao et al. (2015) and Halpern and Tan (2020). In their analysis, "the projected number of prevalent critically ill patients at the peak of a Wuhan-like outbreak in US cities was estimated to range from 2.2 to 4.4 per 10,000 adults, depending on differences in age distribution and comorbidity (ie, hypertension) prevalence." (p. 1). Based on a population of roughly 210 million adults, this is an afflicted population of 460,000 to 920,000. "[I]f a Wuhan-like outbreak were to take place in a US city, even with social distancing and contact tracing protocols as strict as the Wuhan lockdown, hospitalization and ICU needs from COVID-19 patients alone may exceed current capacity...Plans are urgently needed to mitigate the consequences of COVID-19 outbreaks on local health care systems in US cities." (pp. 5-7).

The second aspect of health system saturation caused by COVID-19 is evidenced by the suspension or drastic reduction in provision of non-Covid-related medical services and treatments. Hospitals expanded capacity to treat COVID patients as envisaged in the critical scenario (iii) of Ajao et al. (2015), by reallocating physical and human resources normally dedicated to other uses to treat COVID patients. In addition, in many instances lockdowns implied closure of medical and dental practices, laboratories, and outpatient surgery facilities. These changes and restrictions caused a sharp increase in mortality, as measured by the standard excess mortality P-Score. We collected cross-country data for P-cores computed using the number of total deaths, COVID- and non-COVID-related, at a weekly frequency minus the average of deaths over the 2015-2019 period and divided by the same 2015-2019 average (the source was https://ourworldindata.org/excess-mortality-covid and some country-specific sources). 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) percent, but in several cases it exceeded 50 percent (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.

Table 1: Excess Mortality P-Scores, Percent

Country	P-score	Country	P-score
Peru	163	Israel	20.3
Spain	154.5	South Africa	18
United Kingdom	108	Colombia	18
Belgium	104.4	Greece	16
Italy	96.8	Austria	16
Mexico	87	Germany	14.5
Netherlands	74.9	Russia	14
Chile	68.7	Finland	13.6
France	65.2	Ireland	12
Turkey	54	Australia	12
Indonesia	50	New Zealand	11.9
Sweden	47.1	Denmark	10.5
United States	44.9	South Korea	9.6
Switzerland	44	Norway	9.5
Brazil	42	Taiwan	9.2
Canada	26.2	Czech Republic	8.9
India	25	Poland	8.3
Portugal	23.8		

Notes: The scores shown are the maximum of weekly P-scores over the January-June, 2020 period computed as the number of total deaths in each week minus the average of deaths over the 2015-2019 period and divided by the same 2015-2019 average. For most countries, weekly P-scores were retrieved from https://ourworldindata.org/excess-mortality-covid on 12/2/2020. Data for Brazil, Indonesia, Mexico, Peru, Russia, South Africa, and Turkey are from https://www.economist.com/graphic-detail/2020/07/15/tracking-covid-19-excess-deaths-across-countries, for Colombia, India and Ireland from https://www.nytimes.com/interactive/2020/04/21/world/coronavirus-missing-deaths.html, and for Australia from the Australian Bureau of Statistics. Data for Indonesia and Turkey cover only Jakarta and Istanbul, respectively.

The third element of resource shortages due to COVID-19 relate to health goods and services and cleaning supplies for the economy as whole. We document the impact of these shortages by examining the evolution of the relative prices of the affected goods and services in the next subsection.

2.2 Rising prices of PPE and medical equipment

The COVID pandemia caused severe shortages of medical equipment and cleaning supplies that resulted in sharp price hikes. In the United States, spikes in prices for cleaning supplies, toilet paper and medical masks prompted consumer groups to complain of price gouging. Attorneys general in several states embarked on "see it / snap it / send it" campaigns, inviting consumers to send images of purported price gouging. A quick Google search of images of "COVID price gouging" yields pictures of 8 oz. bottles of hand sanitizer priced at $50 and Clorox wipes at over $40 per container. The U.S. PIRG consumer watchdog association reported rates of inflation of COVID-19 related consumer goods ranging from 200 percent for thermometers to 1,300 percent for anti-bacterial 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 they rely on surveys of those prices posted 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 in 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).

Similar price dynamics were observed for medical equipment as hospitals and even state governments competed for the limited supply of PPE and ventilators. On April 24, 2020, National Public Radio aired a report entitled "Are Illinois Officials Paying Hugely Inflated Prices For Medical Supplies?" A government audit revealed spending up to $174 million on COVID-related medical supplies and equipment, including $13 million for 200 ventilators, a 100 percent markup over pre-COVID price. The governor stated that "A typical ventilator that's useful in an [intensive care unit] situation, the price starts at $25,000, maybe up to $35,000 or $40,000,"... "When we're paying more than that, that's typically because the market has bid up the prices for any available ventilators. Let me be clear: There are very few ventilators available in the entire world. We are acquiring whatever we can so that we're ready in the event there's a spike in ICU beds and a need for ventilators..."

Wages for travel nurses responded to the increased demand for hospital staff. During the peak COVID periods in the Spring and Summer of 2020, the weekly compensation rate for travel nurses roughly doubled, according to the Health IT website (HIT.net). The "Travel Nurse Compensation Report" data from BLS show more modest salary increases for nurses in early 2020 of less than five percent, but these are somewhat misleading, however, as they aggregate the salaries of specialists in fields where medical services actually declined (e.g. voluntary medical care, private medical practices) along with the salaries of nurses that are ICU and respiratory specialists.

To provide more systemic evidence of the large price fluctuations produced by the Covid-related shortages, Table 2 shows price changes for essential health goods and services during the pandemia. The median price increase for transactions of thirteen key goods, including among others N95 masks, ventilators, thermometers and disinfectants, reached 259 percent from March to April, 2020. The Table also shows inflation rates for aggregate price indexes. Health-services-related price indexes rose at annualized rates ranging from 3.1 to 4.7 percent in the second quarter of 2020, while the price index for private goods-producing industries fell -16.1 percent.[6] Hence, the prices of health services relative to those for private goods-producing industries rose between 19.2 to 20.8 percent, and for the specific health goods listed in Table 2, the median relative price increase exceeded 275 percent.

Table 2: Price Changes of Key Health Goods & Services During the Pandemia

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)		
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

Notes: Personal protective equipment price changes (not annualized rates) reported by the Society for Healthcare Organization Procurement Professionals (SHOPP) correspond to those observed in April 2020 with respect to pre COVID-19 levels. 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.

2.3 Duration and severity of lockdowns

Figure 1 illustrates the severity and duration of the lockdowns implemented in response to the Covid pandemia 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*).[7] This index combines information from nine indicators including school and business closures, and travel bans in a scale from 0 to 100 (with 100 for the strictest). In countries where policies vary within the country, the index corresponds to the strictest area. The index is available for 180 countries.

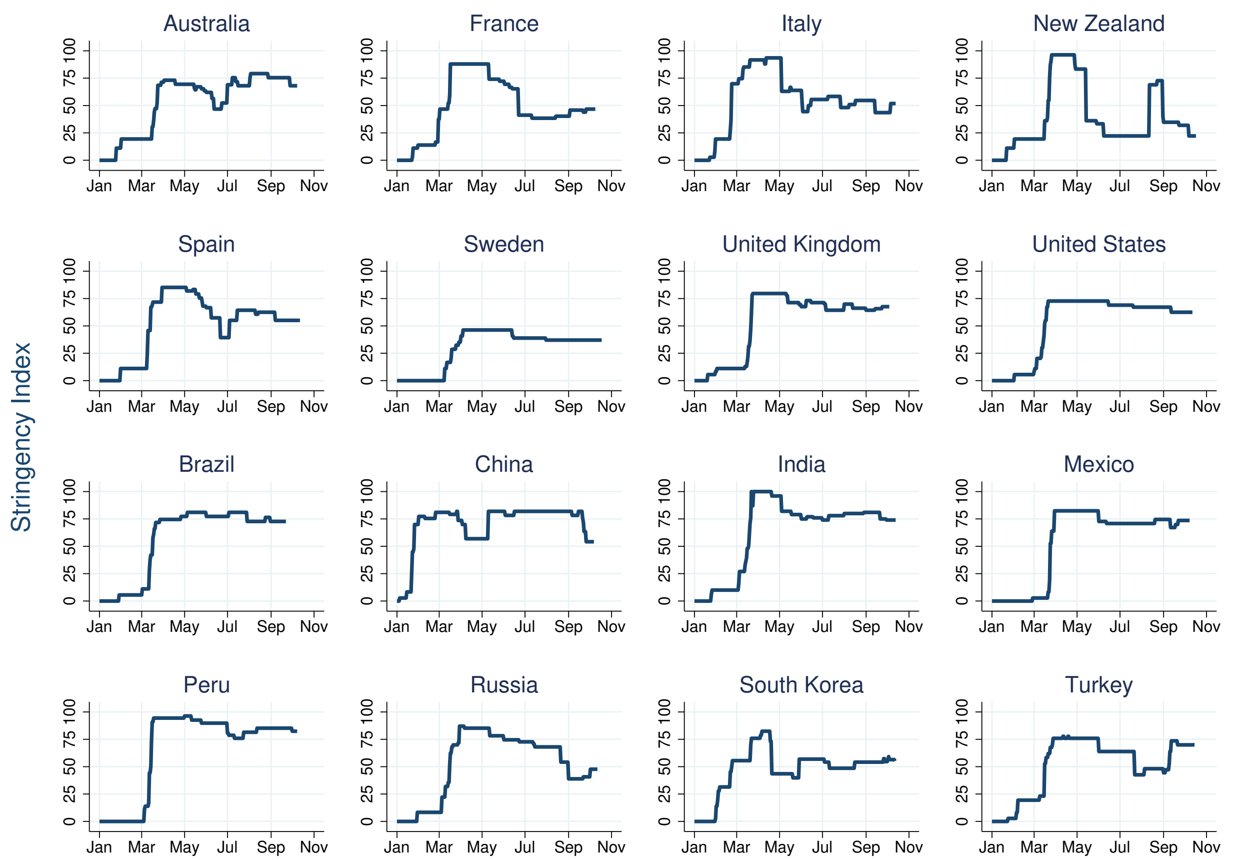
The Figure shows that strict lockdowns were implemented in all countries by mid March, 2020.

[6] 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, etc.

[7] Available at https://www.bsg.ox.ac.uk/research/research-projects/coronavirus-government-response-tracker

In most cases, the index peaked around 75-80 percent, except in Sweden, well-known for its less restrictive stance. Even in Sweden, however, the stringency index reached nearly 50 percent. Moreover, lockdowns have persisted from March to the latest available data as of the date of this paper. The severity of the lockdowns has fluctuated somewhat and in several cases declined (in some like France and New Zealand quite sharply), but as of the latest data all countries still maintained significant restrictions on economic activity relative to the pre-Covid status. Even in Sweden, the stringency index fell slightly from its peak but it remains above 30 percent.

Figure 1: Stringency Index for Different Countries



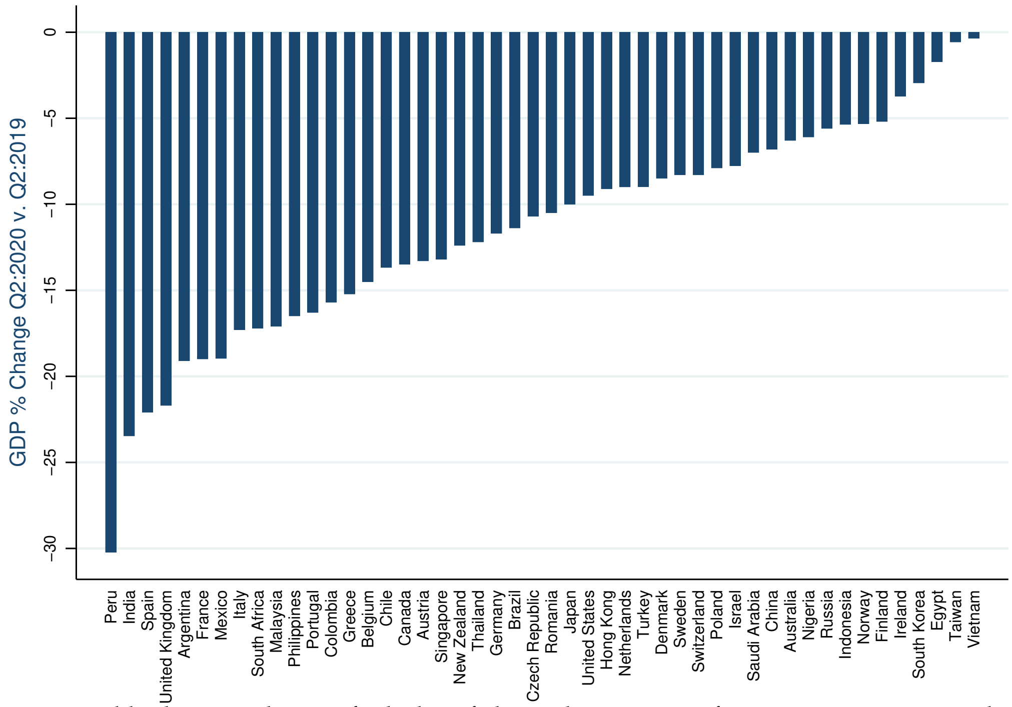
Source: Government Response Stringency Index available from the Oxford COVID-19 Government Response Tracker.

2.4 Economic activity

The strict, prolonged lockdowns resulted in very deep recessions, which in many cases produced the largest recorded quarterly declines in output. Figure 2 shows the year-on-year quarterly drops in GDP in the second quarter of 2020 for 48 advanced and emerging economies.[8] The mean (median) drop was a staggering -11.5 (-10.6) percent.

[8]Most of the data are from http://ourworldindata.org/, https://fred.stlouisfed.org/, and https://www.focus-economics.com/. For China and Hong Kong, the Figure shows the GDP drop in the first quarter, because these countries entered the pandemia earlier.

Figure 2: Year-on-Year Q2 GDP Declines



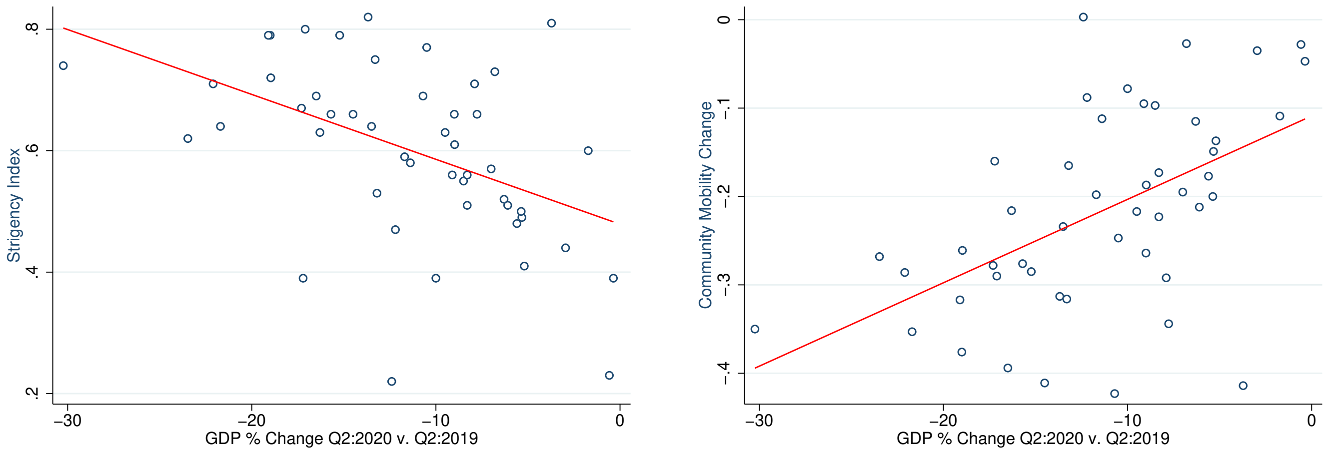
Source: http://ourworldindata.org/, https://fred.stlouisfed.org/, https://www.focus-economics.com/ and country sources.

How much of the fall in output is 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 the magnitude of the decline in GDP in a cross-section of countries. 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 five-week period Jan. 3rd-Feb. 6, 2020).[9] 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 observed quarterly GDP drops (see Figure 3). Output drops were larger in countries with stricter lockdowns, whether measured by a *higher* stringency index or *lower* community 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 panel regression analysis in a cross-section of 35 countries.

[9]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.

Figure 3: Lockdown Severity and Q2:2020 Output Declines



Notes: See footnotes to Figures 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.

The dependent variable in this analysis 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 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, which 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.[10] 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 and 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 ($R_n^2 = 99.2$) and explanatory power (robust $R_w^2 = 0.81$), 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

[10]Leverage plots, influence statistics and histograms indicated outliers in Q2:2020 GDP and in several of the regressors.

November, 2020, which makes them less likely to be determined jointly with Q2:2020 GDP. All of the regression coefficients are significant at the 95-percent level or higher (hospital beds marginally) and have the expected signs. The regression explains roughly 81 percent 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. 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 estimated with less precision (they are marginally significant at the 90-percent 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_n^2 and higher deviance than Columns (1) and (2). Beds are no longer significant. Columns (4) and (6) show that replacing the stringency index with the community mobility measure makes little difference. Both are statistically significant (with opposite signs because higher mobility implies a less severe lockdown), and the other coefficients remain about the same as in Columns (3) and (5), respectively. Column (5) shows that removing hospital beds also weakens sharply the results, with sharply lower R_n^2 and R_w^2 and higher deviance. Column (7) compared with Column (5) shows that using either GDP per capita or the human development index yields very 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 is likely to depend on hospital capacity.

Table 3: Cross-Country Regressions for Output Collapse in Q2:2020

Dependent variable: year-on-year quarterly GDP growth as of Q2:2020								
Regressors	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Stringency	-0.095	-0.084	-0.110		-0.115		-0.116	-0.128
	(0.048)	*(0.109)*	*(0.073)*		*(0.058)*		*(0.062)*	*(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
Mortality	*(0.000)*	*(0.000)*	*(0.004)*	*(0.000)*	*(0.002)*	*(0.001)*	*(0.002)*	*(0.000)*
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_w^2	0.812	0.809	0.711	0.770	0.713	0.711	0.702	0.780
Adjusted R_w^2	0.812	0.809	0.711	0.770	0.713	0.711	0.702	0.780
R_n^2	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

Notes: 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 Figure 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.

In summary, Table 3 yields three key results: (a) non-SIR variables, and in particular those that proxy for cross-country 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 regressions reject the hypothesis that the coefficients on COVID cases and/or deaths are zero; and (c) the effects of non-SIR variables are stronger than those of SIR variables.

3 A Model of the Output-Pandemia Tradeoff

The key feature of the model is the characterization of a pandemia as a large, transitory shock to the subsistence level of demand for health goods and services ($\bar{h}_t$) in a Stone-Geary utility function that is directly related to the utilization rate (m_t). The value of $\bar{h}_t$ is given by:

$$\bar{h}_t = h^\star + z_t f(m_t K), \tag{1}$$

where $h^\star$ is the "normal" subsistence level of 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 an increasing function.[11] A pandemia lasts j periods, so that $z_t = 1$ for $t = 0, ..., j$ and $z_t = 0$ for $t > j$. The pandemia hits the economy as a fully unanticipated, non-recurrent shock.[12] 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, medical equipment, medical specialists, etc).

3.1 Decentralized Competitive Equilibrium

3.1.1 Households

There are two types of households, which together add up to a unit mass of agents. A fraction γ_1 are type-1 agents who own all the wealth (the capital stock used in production of non-health goods and the stock of health goods and services). The two types of agents have identical utility functions.

The optimization problem of an individual of type 1 is to maximize this utility function:

$$\max_{\{c_t^1, l_t^1, h_t^1, d_{t+1}^1\}} \quad \sum_{t=0}^{\infty} \beta^t \left(a \ln \left(c_t^1 - \frac{(l_t^1)^\omega}{\omega} \right) + (1-a) \ln(h_t^1 - \bar{h}_t) \right), \tag{2}$$

subject to the following budget constraint,

$$c_t^1 + p_t^h h_t^1 = w_t l_t^1 - q_t d_{t+1}^1 + d_t^1 + \pi_t + p_t^h h - \tau_t. \tag{3}$$

[11] If this function is concave (convex), a given reduction in utilization is less (more) effective at reducing the stress on the health system.

[12] The pandemia could also be modeled as a stochastic, non-insurable disaster shock, but modeling it as an unanticipated shock is a more realistic approximation of how the COVID-19 shock arrived. Still, exploring the implications of 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.

In the above expressions, c_t^1 and h_t^1 are consumption of non-health and health goods by an agent of type-1, respectively, and l_t^1 is its labor supply. In addition, d_t^1 and d_{t+1}^1 are the agent's holdings of existing and newly-issued public debt. Non-health goods are the numeraire, so p_t^h is the relative price of health goods, w_t is the wage rate, and q_t is the price of government bonds, all in units of non-health goods. Type-1 agents are the only agents who purchase public debt. They 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 π_t and τ_t for each type-1 agent, respectively, both in units of non-health goods.

The utility function is time-separable, with discount factor β, and period utility is 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_t^1 and c_t^1 independent of the latter).[13] At equilibrium, the parameter a is the share of expenditure on non-health goods in excess of the disutility of labor as a share of income also net of the disutility of labor. Similarly, $(1-a)$ is the share of excess expenditure above subsistence on health goods as a share of income net of that subsistence level.

Simplifying the first-order conditions of the above problem yields these optimality conditions:

$$\frac{1-a}{a}\frac{c_t^1 - \frac{(l_t^1)^\omega}{\omega}}{h_t^1 - \bar{h}_t} = p_t^h \tag{4}$$

$$(l_t^1)^{\omega-1} = w_t \tag{5}$$

$$\frac{c_{t+1}^1 - \frac{(l_{t+1}^1)^\omega}{\omega}}{c_t^1 - \frac{(l_t^1)^\omega}{\omega}} = \beta R_t \tag{6}$$

where $R_t \equiv 1/q_t$. Condition (4) equates type-1's marginal rate of substitution between non-health and health consumption to the corresponding relative price. Condition (5) equates the marginal disutility of labor supply to the real wage. Condition (6) equates the intertemporal marginal rate of substitution in consumption to the real return on public debt.

The second type of agents are hand-to-mouth workers who are a fraction $\gamma_2 \equiv 1-\gamma_1$ of the unit-mass of agents. The optimization problem of a single type-2 agent is given by:

$$\max_{\{c_t^2, l_t^2, h_t^2\}} \quad \sum_{t=0}^{\infty} \beta^t \left(a \ln\left(c_t^2 - \frac{(l_t^2)^\omega}{\omega} \right) + (1-a)\ln(h_t^2 - \bar{h}_t) \right), \tag{7}$$

subject to this budget constraint,

$$c_t^2 + p_t^h h_t^2 = w_t l_t^2 + tr_t. \tag{8}$$

Here, c_t^2 and h_t^2 are consumption of non-health and health goods by an agent of type 2, respectively, and l_t^2 is its labor supply. Type-2 agents collect income only from wages ($w_t l_t^2$) and from government

[13]This assumption is essential for the result that aggregate allocations and the optimal lockdown are independent of agent heterogeneity, inequality and optimal transfers, and vice versa.

transfers in the amount tr_t per agent.

The first-order conditions of the above problem reduce to the following optimality conditions:

$$\frac{1-a}{a}\frac{c_t^2-\frac{(l_t^2)^\omega}{\omega}}{h_t^2-\bar{h}_t}=p_t^h, \tag{9}$$

$$(l_t^2)^{\omega-1}=w_t. \tag{10}$$

Condition (9) equates type-2's marginal rate of substitution between non-health and health consumption to p_t^h. Condition (10) equates the marginal disutility of labor supply to the real wage.

3.1.2 Firms

All firms are identical and the representative firm's optimization problem is:

$$\max_{m_t,L_t} \quad \Pi_t=(m_tK)^{1-\alpha}L_t^\alpha-w_tL_t-\chi_0\frac{m_t^{\chi_1}}{\chi_1}K \tag{11}$$

subject to the technlogical constraint on utilization,

$$m_t\leq\bar{m}, \tag{12}$$

where L_t is aggregate labor demand and $\bar{m}$ is the technologically-feasible maximum rate of utilization, which is assumed to be nonbinding. Since the capital stock is constant, utilization costs $\left(\chi_0\frac{m_t^{\chi_1}}{\chi_1}K\right)$ can be seen as the standard cost associated to 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:

$$(1-\alpha)(m_tK)^{-\alpha}L_t^\alpha=\chi_0m_t^{\chi_1-1}, \tag{13}$$

$$\alpha(m_tK)^{1-\alpha}L_t^{\alpha-1}=w_t. \tag{14}$$

The marginal products of utilization and labor equal their corresponding marginal costs. In the case of utilization, the cost is determined by the firm's utilization choice. In the case of labor, the cost is the market-determined wage rate.

3.1.3 Government Budget Constraint

The government budget constraint is the following:

$$T_t-TR_t=q_tD_{t+1}-D_t, \tag{15}$$

The left-hand-side is the primary balance, which equals aggregate tax revenue, T_t, minus total transfer payments, TR_t. The right-hand-side equals the resources raised by selling new debt net of the repayment of existing debt.

The fiscal structure could be simplified by abstracting 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. Debt is introduced just so that we can highlight some implications of debt-financed transfers for fiscal solvency, but the two formulations are equivalent because the taxes are non-distortionary (i.e. debt is Ricardian). For a given policy of transfers funded with lump-sum taxes, the debt-equivalent formulation (without taxes) is given by the sequence of debt issuance $D_{t+1} = T_t + D_t$, starting from a given initial debt D_0. The debt formulation requires, however, that the intertemporal government budget constraint must hold, so the present discounted value of the primary balance as of any date t must match the outstanding debt as of that date. Hence, if it is optimal to increase transfers during a pandemia (as we show later) and the transfers are debt-financed, making sustainable the debt D_{j+1} accumulated during the j periods of the pandemia requires increasing the stream of primary balances for $t > j$ so that their present value equals D_{t+j}, which can be accomplished by imposing lump-sum taxes on type-1 agents. This Ricardian equivalence of debt and taxes breaks if taxes are distortionary, in which case the optimal policy problem would need to consider the optimal tax structure, in addition to the optimal lockdown and transfer policies.

3.1.4 Competitive Equilibrium with and without Pandemia

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

$$\gamma_1 l_t^1 + \gamma_2 l_t^2 = L_t, \tag{16}$$

$$\gamma_1 h_t^1 + \gamma_2 h_t^2 = H, \tag{17}$$

and (d) the following aggregation conditions hold:

$$\gamma_1 d_{t+1}^1 = D_{t+1}, \tag{18}$$

$$\gamma_1 \tau_t = T_t \tag{19}$$

$$\gamma_2 tr_t = TR_t, \tag{20}$$

$$\gamma_1 h = H, \tag{21}$$

$$\gamma_1 \pi_t = \Pi_t \tag{22}$$

$$\gamma_1 c_t^1 + \gamma_2 c_t^2 = C_t. \tag{23}$$

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

$$C_t = (m_t K)^{1-\alpha} L_t^{\alpha} - \chi_0 \frac{m_t^{\chi_1}}{\chi_1} K. \tag{24}$$

Since the only shock to the economy is the unanticipated, temporary hike in subsistence demand for health goods during the pandemia, and since there are no endogenous mechanisms to induce dynamics at work in the model, the DCE separates into pandemia (P) and no-pandemia (NP) phases, and within each prices and allocations are constant. The DCE has a closed-form solution. To characterize it, consider first that, since preferences are identical, labor is homogeneous, and all agents are paid the same wage, conditions (5) and (10) imply that all agents offer the same labor supply, which must equal labor demand at equilibrium: $l_t^1 = l_t^2 = L_t$. Therefore, using the labor demand and supply conditions, considering that both must be equal at the equilibrium wage, yields this expression:

$$L_t^{\omega-1} = \alpha (m_t K)^{1-\alpha} L_t^{\alpha-1}, \tag{25}$$

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

$$L_t = \left(\frac{\chi_0 \alpha K}{1-\alpha} \right)^{\frac{1}{\omega}} m_t^{\frac{\chi_1}{\omega}}. \tag{26}$$

Using the above result, factor allocations can be solved for using the firm's optimality conditions (13) and (14):

$$m_t = m^\star = \left(\chi_0^{\alpha-\omega} \alpha^{\alpha} (1-\alpha)^{\omega-\alpha} K^{\alpha(1-\omega)} \right)^{\frac{1}{\chi_1\omega + \alpha\omega - \omega - \chi_1\alpha}} \tag{27}$$

$$L_t = l_t^1 = l_t^2 = L^\star = \left(\chi_0^{\alpha-1} \alpha^{\chi_1+\alpha-1} (1-\alpha)^{1-\alpha} K^{(1-\alpha)(\chi_1-1)} \right)^{\frac{1}{\chi_1\omega + \alpha\omega - \omega - \chi_1\alpha}}. \tag{28}$$

Given the above, it is straightforward to obtain equilibrium solutions for output, profits, wages and aggregate consumption using other optimality conditions and the resource constraint:

$$Y_t = Y^\star = (m^\star K)^{1-\alpha} L^{\star\alpha} \tag{29}$$

$$\Pi_t = \gamma_1 \pi^\star = (1-\alpha)(1 - \frac{1}{\chi_1}) Y^\star > 0 \tag{30}$$

$$w_t = w^\star = (L^\star)^{\omega-1} \tag{31}$$

$$C_t = C^\star = Y^\star - \chi_0 \frac{(m^\star)^{\chi_1}}{\chi_1} K. \tag{32}$$

It is critical to note two important properties of the aggregate DCE allocations, profits and wages solved above: First, they are independent of heterogeneity and inequality in the wealth and income distributions, as is evident by the fact that γ_1 and γ_2 do not enter in the solutions. Second, they are the same during the P and NP phases (i.e. for $t = 0, ..., j$ and for $t > j$).

In contrast with 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:

$$p_t^{\star hP} = \frac{1-a}{a} \frac{C^\star - \frac{(L^\star)^\omega}{\omega}}{H - h^\star - f(m^\star K)} \quad \textit{for t=0, ..., j}, \tag{33}$$

$$p_t^{\star hNP} = \frac{1-a}{a} \frac{C^\star - \frac{(L^\star)^\omega}{\omega}}{H - h^\star} \quad \textit{for t>j}. \tag{34}$$

Prices are higher during the pandemia because of the direct effect on demand for health goods and services due to the increase in $\bar{h}_t$. In turn, this rise in $p_t^{\star hP}$ worsens income inequality because it increases the value of the endowment of health goods that type-1 agents own.

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 conditions (4) and (9) together with the budget constraints of the two types of agents and the above results for aggregate variables we can obtain solutions for the individual consumption allocations as functions of relative prices and the subsistence level of demand for health:

$$c_t^{\star 1}(p_t^{\star h}, \bar{h}_t) = a\left[\pi^\star + p_t^{\star h} h - \tau_t + (L^\star)^\omega - p_t^{\star h}\bar{h}_t - \frac{(L^\star)^\omega}{\omega}\right] + \frac{(L^\star)^\omega}{\omega} \tag{35}$$

$$c_t^{\star 2}(p_t^{\star h}, \bar{h}_t) = a\left[tr_t + (L^\star)^\omega - p_t^{\star h}\bar{h}_t - \frac{(L^\star)^\omega}{\omega}\right] + \frac{(L^\star)^\omega}{\omega} \tag{36}$$

$$h_t^{\star 1}(p_t^{\star h}, \bar{h}_t) = \frac{1-a}{p_t^{\star h}}\left[\pi^\star + p_t^{\star h} h - \tau_t + (L^\star)^\omega - p_t^{\star h}\bar{h}_t - \frac{(L^\star)^\omega}{\omega}\right] + \bar{h}_t \tag{37}$$

$$h_t^{\star 2}(p_t^{\star h}, \bar{h}_t) = \frac{1-a}{p_t^{\star h}}\left[tr_t + (L^\star)^\omega - p_t^{\star h}\bar{h}_t - \frac{(L^\star)^\omega}{\omega}\right] + \bar{h}_t \tag{38}$$

Expressing individual consumption allocations as functions of $(p_t^{\star h}, \bar{h}_t)$ 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 $p_t^{\star h}$ are higher in the P phase, affecting individual consumption allocations as explained below.

Assume $tr_t = 0$ (i.e. a DCE without policy intervention), or alternatively, assume that transfers are unchanged when the pandemia hits. It follows from (36) that $c^{\star 2P}(p^{\star hP}, h^\star + f(m^\star K)) < c^{\star 2NP}(p^{\star hNP}, h^\star)$, because $p_t^{\star h}\bar{h}_t$ 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 $C^\star$ is unchanged, it must be that $c^{\star 1P}(p^{\star hP}, h^\star + f(m^\star K)) > c^{\star 1NP}(p^{\star hNP}, h^\star)$. 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 non-health consumption relative to the disutility of labor. It rises for type-1 agents and falls for type-2 agents.

Something similar occurs with health consumption, except that health consumption is bumped up for all agents as the subsistence level $\bar{h}_t$ rises. Since the supply of health goods is fixed, excess health consumption (i.e., relative to the subsistence level) of type-1 agents rises and that of type-2 agents falls due to the same effects driving non-health consumption allocations. Overall, type-2 agents suffer more with the pandemia. Relative to type-1 agents, their non-health consumption falls and is closer to the disutility of labor and their health consumption is closer to $\bar{h}_t$.

The need to keep consumption of all goods above their subsistence levels imposes and upper bound on the set of $p_t^{\star hP}$ that can be supported as a DCE. In particular, the results in (36) and (38) imply that, in order for type-2 agents to keep $h_t^{\star 2}$ and $c_t^{\star 2}$ above $\bar{h}_t$ and L_t^{ω}/ω, respectively, their residual income must satisfy: $tr_t + (L^\star)^\omega - p_t^{\star h}\bar{h}_t - \frac{(L^\star)^\omega}{\omega} > 0$. Solving for $p_t^{\star hP}$ yields:

$$p_t^{\star hP} < \hat{p}^{\star hP} \equiv \frac{tr^P + (L^\star)^\omega \left(\frac{\omega-1}{\omega}\right)}{h^* + f(m^\star K)} \tag{39}$$

where tr^P is a given value of exogenous transfers provided during the pandemia. Hence, the jump in $p_t^{\star hP}$ caused by $f(m^\star K)$ during a pandemia cannot reach $\hat{p}^{\star hP}$, because otherwise type-2 agents hit their subsistence consumption levels triggering the Inada conditions of their preferences. The market price, which depends on the aggregate demand for health goods, would still be well-defined by condition (33), but it cannot be an equilibrium because type-2 agents saturate the health system.

Combining the above result with the pricing condition (33) implies that $f(\cdot)$ cannot exceed this upper bound:

$$f(m^\star K) < \frac{H}{1 + \frac{1-a}{a}\frac{c^\star - (L^{\star\omega})/\omega}{tr^P + (\omega-1)(L^{\star\omega})/\omega}} - h^*, \tag{40}$$

where $c^\star, L^\star, m^\star$ are the DCE allocations independent of $f(\cdot)$ (see eqns. (27), (28) and (32)).

If debt is used to pay for transfers, the real interest rate is solved for by plugging the solutions obtained above in the Euler equation of type-1 agents (eq. (6)). Since $L^\star$ is constant at all times, and since consumption of type-1 agents shifts from a higher level in the P phase to a lower level in the NP phase, the interest rate equals $1/\beta$ in all periods except between $t+j$ and $t+j+1$ (the transition from pandemia to non-pandemia). The interest rate on debt sold that period is:

$$R_{t+j} = \frac{c_{t+j+1}^{\star 1NP} - \frac{(L^\star)^\omega}{\omega}}{\beta\left(c_{t+j}^{\star 1P} - \frac{(L^\star)^\omega}{\omega}\right)}. \tag{41}$$

Hence, given that $c^{\star 1P} > c^{\star 1NP}$, the interest rate falls in the last period of the pandemia.

Finally, to characterize the effects of the pandemia on inequality, it is useful to consider a measure of inequality given by the ratio of excess consumption of type-1 to type-2 agents denoted $\Omega_t^\star$. Dividing eq. (35) by (36), or (37) by (38), yields:

$$\Omega_t^\star = \frac{\pi^\star + p_t^{\star h}h - \tau_t + (L^\star)^\omega - p_t^{\star h}\bar{h}_t - \frac{(L^\star)^\omega}{\omega}}{tr_t + (L^\star)^\omega - p_t^{\star h}\bar{h}_t - \frac{(L^\star)^\omega}{\omega}} \tag{42}$$

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 $\Omega_t^\star > 1$. This is clearly true for the DCE without transfers, and when transfers are present it holds because we assume that $\tau_t < \pi^\star + p_t^{\star h} h$ (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 $\Omega^{\star P} > \Omega^{\star NP}$, which implies that inequality worsens temporarily with a pandemia.

Without pandemia, since prices and allocations are time-invariant, $\Omega^{\star NP}$ also summarizes the income distribution of the economy. Type-1 agents own the firms and the endowment of H, so their income includes the profits from non-health goods production and the sales of health goods, in addition to the same amount of wage income as type-2 agents. Hence, lower γ_1 implies both higher income inequality and higher $\Omega^{\star NP}$. The adverse effect of the pandemia on inequality occurs because, keeping γ_1 unchanged, the hike in the subsistence level of health goods and in their relative price increases excess consumption for type-1 agents and lowers it for type-2 agents, and this also includes regressive income redistribution as the income from sales of health goods and services rises during the pandemia.

3.2 Social Planner's Problem

The social planner solves the following optimization problem:

$$\max_{\{c_t^j, l_t^j, h_t^j, m_t\}} \quad \phi \left\{ \gamma_1 \sum_{t=0}^{\infty} \beta^t \left[a \ln \left(c_t^1 - \frac{(l_t^1)^\omega}{\omega} \right) + (1-a) \ln(h_t^1 - \bar{h}_t) \right] \right\} + (1-\phi) \left\{ \gamma_2 \sum_{t=0}^{\infty} \beta^t \left[a \ln \left(c_t^2 - \frac{(l_t^2)^\omega}{\omega} \right) + (1-a) \ln(h_t^2 - \bar{h}_t) \right] \right\} \tag{43}$$

subject to resource constraints on labor, health goods, non-health goods, and utilization:

$$\gamma_1 l_t^1 + \gamma_2 l_t^2 = L_t,$$

$$\gamma_1 h_t^1 + \gamma_2 h_t^2 = H,$$

$$\gamma_1 c_t^1 + \gamma_2 c_t^2 \equiv C_t = (m_t K)^{1-\alpha} L_t^\alpha - \chi_0 \frac{m_t^{\chi_1}}{\chi_1} K,$$

$$m_t \leq \bar{m},$$

$$\bar{h}_t = h^\star + z_t f(m_t K).$$

The social welfare function is standard, with weights ϕ and $1-\phi$ on the population of type-1 and type-2 agents, respectively. The ratio of these weights is denoted $\Omega^{sp} \equiv \phi/(1-\phi)$. As in the DCE, $\bar{m}$ is assumed to be nonbinding.

3.2.1 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:

$$l_t^1 = l_t^2 = L_t = \left(\alpha(m_t K)^{1-\alpha}\right)^{\frac{1}{\omega-\alpha}} \tag{44}$$

$$(1-\alpha)\left(\frac{L_t}{m_t K}\right)^{\alpha} = \chi_0 m_t^{\chi_1 - 1} + \frac{1-a}{a}\frac{(C_t - \frac{L_t^{\omega}}{\omega})}{H - \bar{h}_t} z_t f'(m_t K). \tag{45}$$

$$\frac{h_t^1 - \bar{h}_t}{h_t^2 - \bar{h}_t} = \Omega^{sp} \tag{46}$$

$$\frac{c_t^1 - \frac{(l_t^1)^{\omega}}{\omega}}{c_t^2 - \frac{(l_t^2)^{\omega}}{\omega}} = \Omega^{sp} \tag{47}$$

The planner will set allocations at two different constant levels for the P and NP phases. As we show below, aggregate allocations will be set lower during the P phase than in the NP phase. The conditions in (44) 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 (45)-(47) are essential to this paper's argument. Condition (45) determines the planner's optimal utilization choice and it drives the planner's incentive to lockdown the economy. It differs from its counterpart—equation (13) in in the DCE—in that, during a pandemia, the social marginal cost of utilization in the right-hand-side of (45) exceeds its private counterpart by the amount $p_t^{h,sp} f'(m_t K)$ where $p_t^{h,sp} \equiv \frac{1-a}{a}\frac{(C_t - \frac{L_t^{\omega}}{\omega})}{H - \bar{h}_t}$ is the social price of health goods. Hence, utilization is inefficiently chosen in the DCE during a pandemia, 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 $\bar{h}_t$ due to the pandemia. As a result, the planner reduces utilization and this reduces labor demand, output, profits and wages, giving rise to the output-pandemia tradeoff.

The SPE does not have a closed-form solution because of the non-linear nature of condition (45). Using this condition together with (44), the optimal utilization rate (i.e. the optimal lockdown) can be represented as the solution to the following non-linear equation in m_t:

$$(1-\alpha)\left(\frac{\left(\alpha(m_t K)^{1-\alpha}\right)^{\frac{1}{\omega-\alpha}}}{m_t K}\right)^{\alpha} - \chi_0 m_t^{\chi_1 - 1} =$$

$$\frac{1-a}{a}\left[\frac{(m_t K)^{1-\alpha}\left(\left(\alpha(m_t K)^{1-\alpha}\right)^{\frac{\alpha}{\omega-\alpha}}\right) - \chi_0 \frac{m_t^{\chi_1}}{\chi_1}K - \frac{\left(\left(\alpha(m_t K)^{1-\alpha}\right)^{\frac{\omega}{\omega-\alpha}}\right)}{\omega}}{H - \bar{h}_t}\right] z_t f'(m_t K). \tag{48}$$

Without pandemia, $z_t = 0$ and this equation collapses to the same closed-form solution for utilization in the DCE, because there is no externality affecting the utilization decision. The labor allocation, 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 still independent of agent heterogeneity and inequality (and now independent also of the planner's welfare weights). As a result, the planners 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 (i.e. with inequality and agent heterogeneity). The planner's utilization choices depends on $f'(m_t K)$ and $p_t^{h,sp}$, which are determined by aggregate variables that are independent of inequality and distributional incentives. 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. if $\gamma_1 = 1$).

Conditions (46) and (47) 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 welfare weights the planner assigns them. The extent to which redistribution is relevant depends on the extent to which Ω^{sp} differs from $\Omega^{\star P}$ and $\Omega^{\star NP}$ (recall that in the DCE we showed that $\Omega^{\star P} > \Omega^{\star NP} > 1$).

Consider three scenarios. First, a case with $\Omega^{sp} = 1$ (i.e. $\phi = 1/2$). This corresponds to a utilitarian social welfare function in which the planner weighs each agent equally.[14] The planner redistributes resources so as to equalize consumption of health and non-health goods across agents. Second, a case with $\Omega^{sp} = \Omega^{\star NP}$ (i.e. $\phi = \Omega^{\star NP}/(1 + \Omega^{\star NP})$). This is an application of the First Welfare Theorem in which the DCE without pandemia is supported as an SPE.[15] The planner has no incentive to redistribute without a pandemia, but will still want to redistribute during a pandemia because $\Omega^{sp} = \Omega^{\star NP} < \Omega^{\star P}$. Third, a case with $\Omega^{sp} > \Omega^{\star NP}$ (i.e. $\Omega^{\star NP}/(1 + \Omega^{\star NP}) < \phi \leq 1$). This is a case with bias in favor of capitalists, because the planner weighs type-1 agents by more than what the inequality implicit in $\Omega^{\star NP}$ indicates. We will show later that when this is the case it is possible for the optimal policies to be Pareto efficient (i.e. the lifetime utility of both agents increases relative to the DCE). In light of these results, the analysis that follows focuses on $\Omega^{sp} \in [1, \infty)$ (or $\phi \in [1/2, 1]$).

It is worth noting that if the welfare weights satisfy $\phi < \Omega^{\star NP}/(1 + \Omega^{\star NP})$, the planner will engage in redistribution in favor of type-2 agents relative to the DCE even without pandemia. Still, the optimal transfers solely due to the pandemia can be separated from the those that are optimal in "normal times" so as to focus on the *additional* redistribution that is socially desirable when a pandemia hits.

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 non-linear equation (48) yields the planner's optimal utilization rate m_t^{sp}, and

[14] In this case, ϕ can be ignored because it becomes a common factor for the utility of both agent types in the social welfare function, and the planner's allocations become independent of ϕ.

[15] This is evident because with $\Omega^{sp} = \Omega^{\star NP}$ and $z_t = 0$ for all t the SPE's optimality conditions are identical to those of the DCE without pandemia.

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 ϕ, γ_1 and γ_2 do not enter in eq.(48). The higher social marginal cost of utilization leads the planner to reduce m_t^{sp}. Condition (44) 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 tradeoff: 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 Ω^{sp}. Given the SPE's aggregate allocations, the planner assigns to type-2 agents these consumption allocations:

$$c_t^{2sp} = \frac{C_t^{sp} - \frac{(L_t^{sp})^{\omega}}{\omega}}{1+\gamma_1(\Omega^{sp}-1)} + \frac{(L_t^{sp})^{\omega}}{\omega}, \tag{49}$$

$$h_t^{2sp} = \frac{H - h^* - z_t f(m_t^{sp}K)}{1+\gamma_1(\Omega^{sp}-1)} + h^* + z_t f(m_t^{sp}K). \tag{50}$$

The denominators of the first terms in the right-hand-side of the above expressions are equal to 1 for the utilitarian planner (since $\Omega^{sp}=1$), and the solutions give the consumption levels that are common for all agents. For $\Omega^{sp}>1$, these expressions yield consumption levels for type-2 agents that are lower than for type-1 agents. Type-2 (type-1)agents receive "below average" ("above average") consumption levels so that market-clearing in health and non-health goods holds. As explained earlier, the size of Ω^{sp} determines the degree of consumption inequality that is optimal for the planner. For $\Omega^{sp}=\Omega^{\star NP}$ (recall $\Omega^{\star NP}>1$), this yields the same consumption allocations and the same inequality as in the DCE so that no redistribution is optimal without a pandemia.

3.2.2 Decentralization & 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 the COVID pandemia 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:

$$m_t \leq m_t^{sp} \quad \textit{for t=0, ..., j}, \tag{51}$$

$$m_t \leq \bar{m} \quad \textit{for t>j}. \tag{52}$$

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 $m_t^{sp} < m^\star < \bar{m}$ for $t = 0, ..., j$. Recall also that in the DCE, $m^\star$ is the optimal utilization rate with or without pandemia and that, since there is no utilization externality without pandemia, $m_t^{sp} = m^\star$ for $t > j$.

Optimal Transfers: By imposing the planner's health and non-health consumption allocations for type-2 agents (eqns. (49) and (50)) on these agents' budget constraint in the DCE solution (eq. (8)), it follows that the optimal policy rule for government transfers is:

$$\begin{aligned} TR_t^{sp} &\equiv TR^{sp,P} \\ &= \gamma_2 \left[\left\{ \frac{C_t^{sp} - \frac{(L_t^{sp})^\omega}{\omega}}{1+\gamma_1(\Omega^{sp}-1)} + \frac{(L_t^{sp})^\omega}{\omega} + p_t^{h,sp} \left(\frac{H - h^* - f(m_t^{sp} K)}{1+\gamma_1(\Omega^{sp}-1)} + h^* + f(m_t^{sp} K) \right) \right\} \right. \\ &\qquad \left. - (L_t^{sp})^\omega \right] \quad \textit{for } t{=}\ 0, ..., j, \end{aligned} \tag{53}$$

$$TR_t^{sp} \equiv TR^{sp,NP} = \gamma_2 \left[\left\{ \frac{C^\star - \frac{(L^\star)^\omega}{\omega}}{1+\gamma_1(\Omega^{sp}-1)} + \frac{(L^\star)^\omega}{\omega} + p^{\star h} \left(\frac{H-h^*}{1+\gamma_1(\Omega^{sp}-1)} + h^* \right) \right\} - (L^\star)^\omega \right] \quad \textit{for } t{>}j.$$

In the expressions inside square brackets, the terms in braces represent the total value of nonhealth and health consumption of type-2 agents, and the term $(L_t^{sp})^\omega$ is these agents' wage income. Hence, the optimal transfer finances the gap between the planner's desired allocation of total consumption to type-2 agents and the wages they collect (all in units of nonhealth goods). The optimal transfers are constant at different levels within P and NP phases, because the SPE's allocations have the same property.

The planner takes into account that, during a pandemia, the optimal lockdown reduces the market income of type-2 agents by more than that of type-1 agents, since the former only earn wages while the latter collect profits and sales of H in addition to wages. Moreover, the planner internalizes that the relative price of health goods will rise, making health-good purchases costlier, and that the overall result of these effects is that type-2 (type-1) agents move closer to (further from) their subsistence levels of health and non-health goods. The planner will therefore redistribute consumption from type-2 to type-1 agents by more than it does in normal times without pandemia. If $\Omega^{sp} = \Omega^{\star NP}$, there is no redistribution in normal times ($TR^{sp,NP} = 0$), 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 offset some of the fall in wage income, redistribute the decline in aggregate output across agents and maintain their ratio of excess consumptions equal to Ω^{sp}).

As explained earlier, the planner can pay for the optimal transfers during the pandemia with lump-sum taxes on type-1 agents maintaining a balanced budget, or it can finance them by selling debt to those agents. Using debt, the equilibrium interest rates would be given by $R_t = 1/\beta$ for $t = 0, .., j-1$ or $t > j$ and $R_j = (c_{j+1}^{1sp} - \frac{(L_{j+1}^{sp})^\omega}{\omega}) / \left[\beta (c_j^{1sp} - \frac{(L_j^{sp})^\omega}{\omega}) \right]$. Since transfers are constant during the pandemia and the interest rate differs from $1/\beta$ only in period j, the planner would arrive at the end of the pandemia with a debt stock $D^{sp}_{j+1} = (1/R_j)\left[TR^{sp,P}\sum_{i=0}^{j-1}\beta^i + \beta^{j-1}D_0\right]$. In order to maintain fiscal solvency after the pandemia (i.e. satisfy the intertemporal government budget constraint), the government can impose lump-sum taxes T_t for $t > j$ such that the present discounted value of tax revenue equals D^{sp}_{j+1}. The specific sequence of these taxes is undetermined. Any sequence that satisfies the solvency condition yields the same outcome because the taxes are non-distortionary. For instance, since $R_t = 1/\beta$ for $t > j$, a constant lump-sum tax $\bar{T} = (1-\beta)D^{sp}_{j+1}$ satisfies the solvency condition. A tax paying all the debt in one period ($T_{j+1} = D^{sp}_{j+1}$) is also consistent with solvency, but is akin to a default in which the government "pays" all the debt at $t = j+1$ by simply taxing away the entire debt repayment. The planner has no reason to prefer either debt or taxes to pay for transfers during the pandemia, or any particular sequence of taxes post-pandemia consistent with solvency, since they all yield identical allocations and welfare (i.e. there is Ricardian equivalence). In contrast, with distortionary taxes, given the pre-pandemia structure of tax rates, the planner's problem is more complex because it would consider the optimal structure and time-variation of tax rates, and even restricted to time-invariant tax rates, it would consider how dynamic Laffer curves limit sustainable debt levels (see D'Erasmo et al., 2016).

3.3 Social Welfare & Private Utility Gains:

In order to compare the utility that agents derive under the SPE relative to the DCE, define $\Delta U_i \equiv U_i^{SPE} - U_i^{DCE}$ for agents of type $i = 1, 2$ where U_1 and U_2 are the lifetime utility functions shown in (2) and (7). Then, denoting excess consumption levels as $\tilde{C}_t \equiv C_t - L_t^{\omega}/\omega$ and $\tilde{h}_t \equiv h_t - \bar{h}_t$ and using the results from the SPE and the DCE yields these expressions:

$$\begin{aligned}\Delta U_1 = &\sum_{t=0}^{j}\beta^t\left[a\left(\ln\left(\tilde{C}_t^{sp}\right) - \ln\left(\tilde{C}^{\star}\right)\right) + (1-a)\left(\ln\left(\tilde{h}_t^{sp}\right) - \ln\left(\tilde{h}_t^{\star}\right)\right)\right] \\ &+ \left[\sum_{t=0}^{j}\beta^t\left(\ln\left(\frac{\Omega^{sp}}{1+\gamma_1(\Omega^{sp}-1)}\right) - \ln\left(\frac{\Omega^{\star P}}{1+\gamma_1(\Omega^{\star P}-1)}\right)\right)\right. \\ &\left.\qquad + \frac{\beta^j}{1-\beta}\left(\ln\left(\frac{\Omega^{sp}}{1+\gamma_1(\Omega^{sp}-1)}\right) - \ln\left(\frac{\Omega^{\star NP}}{1+\gamma_1(\Omega^{\star NP}-1)}\right)\right)\right]\end{aligned} \tag{54}$$

$$\begin{aligned}\Delta U_2 = &\sum_{t=0}^{j}\beta^t\left[a\left(\ln\left(\tilde{C}_t^{sp}\right) - \ln\left(\tilde{C}^{\star}\right)\right) + (1-a)\left(\ln\left(\tilde{h}_t^{sp}\right) - \ln\left(\tilde{h}_t^{\star}\right)\right)\right] \\ &+ \left[\sum_{t=0}^{j}\beta^t\left(\ln\left(\frac{1}{1+\gamma_1(\Omega^{sp}-1)}\right) - \ln\left(\frac{1}{1+\gamma_1(\Omega^{\star P}-1)}\right)\right)\right. \\ &\left.\qquad + \frac{\beta^j}{1-\beta}\left(\ln\left(\frac{1}{1+\gamma_1(\Omega^{sp}-1)}\right) - \ln\left(\frac{1}{1+\gamma_1(\Omega^{\star NP}-1)}\right)\right)\right]\end{aligned} \tag{55}$$

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

$$\Delta W = \phi\gamma_1\Delta U_1 + (1-\phi)\gamma_2\Delta U_2. \tag{56}$$

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 ΔW, 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 (Λ) that would be needed for the DCE to yield the same social welfare as under the SPE allocations. That is, we compute the value of Λ that solves this equation:

$$\phi \sum_{t=0}^{\infty} \beta^t \gamma_1 \left(a \ln \left(c_t^{1\star}(1+\Lambda) - \frac{(L_t^\star)^\omega}{\omega} \right) + (1-a)\ln(h_t^{1\star} - \bar{h}_t) \right) \\ + (1-\phi) \sum_{t=0}^{\infty} \beta^t \gamma_2 \left(a \ln \left(c_t^{2\star}(1+\Lambda) - \frac{(L_t^\star)^\omega}{\omega} \right) + (1-a)\ln(h_t^{2\star} - \bar{h}_t) \right) = W^{sp} \tag{57}$$

where W^{sp} is given by eq. (43) evaluated at the SPE allocations. Note that, while the duration of the pandemia does not alter allocations and prices in the DCE and SPE (it only determines when the economy switches from the P to the NP phase), it does matter for the size of all of these individual utility and social welfare effects. In particular, the effects of the pandemia on social welfare and individual utility are larger for pandemias that last longer.

The term in the first row in the right-hand-side of equations (54)-(55) for ΔU_1 and ΔU_2 is the same, because it represents the aggregate effects of the planner's management of the output-pandemia tradeoff 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 $\tilde{C}^\star$ is constant at all times. During the pandemia, however, aggregate excess health goods consumption ($\tilde{h}_t^\star$) falls because of the increase in $\bar{h}_t$ for $t = 0, .., j$. The utilization externality implies that these allocations are suboptimal. Hence, during the pandemia the planner lowers the utilization rate, which reduces $\tilde{C}_t^{sp}$ but props-up $\tilde{h}_t^{sp}$. 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 second and third rows in the right-hand-side of ΔU_1 and ΔU_2 reflect the distributional effects of the transfers, with the parts due to the P and NP phases shown in the second and third rows, respectively. $\Omega^{\star P} > \Omega^{\star NP} \geq \Omega^{sp}$ is a sufficient condition for these effects to be negative for ΔU_1 and positive for ΔU_2. These distributional effects are determined by a collection of constant terms that depend on γ_1 and the marginal utility ratios of the planner (Ω^{sp}) vis-a-vis those in the DCE ($\Omega^{\star P}, \Omega^{\star NP}$).[16] The terms for the pandemia phase reflect the result justifying increased transfers to type-2 agents during the pandemia, because the distribution of resources for health and nonhealth

[16] In the $[1, \infty)$ interval of Ω^{sp}, the utilitarian planner ($\Omega^{sp} = 1$) has the strongest desire for reallocating resources. All the terms that include Ω^{sp} vanish from $\Delta U_1, \Delta U_2$, 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 $\Omega^{sp} > 1$.

consumption is suboptimal and worsens during the pandemia (since $\Omega^{\star P}$ rises). The terms for the post-pandemia phase show that, as explained earlier, the planner redistributes resources to type-2 agents even without a pandemia (as long as $\Omega^{sp} < \Omega^{\star NP}$).

For quantitative analysis, expressions (54) and (55) provide an intuitive way of separating the social welfare gain into key components: First, the gains due to neutralizing the utilization externality. Second, the gains due to the redistribution that the planner finds optimal to undertake when a pandemia occurs. Third, the gains due to redistribution even without a pandemia, because of the planner's dislike for inequality in general.

Evaluating ΔU_1 and ΔU_2 separate from social welfare is also helpful for assessing whether the optimal policy is Pareto efficient (i.e. $\Delta U_1, \Delta U_2 \geq 0$). For this to be the case, the utility gain for type-1 agents from neutralizing the utilization externality must exceed their loss due to the redistribution in favor of type-2 agents. 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 $\Omega^{*NP}(\gamma_1)$ and assume we set $\Omega^{sp} = \Omega^{*NP}(\gamma_1)$. As we increase γ_1 keeping Ω^{sp} fixed, the utility of type-1 agents rises (locally) because the cost of redistribution falls, since the second row of ΔU_1 increases (becomes less negative) and the third row is zero (since $\Omega^{sp} = \Omega^{*NP}(\gamma_1)$). 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 paremeterization such that for given Ω^{sp} there is an interval of γ_1 values such that $\Delta U_1, \Delta U_2 \geq 0$.

4 Quantitative Analysis

In this Section, we assess the quantitative relevance of the mechanism driving the optimal lockdown and transfer payments during a pandemia via the degree of saturation of the health system. In particular, we examine the performance of the model based on a calibration in which the selection of the model's parameter values is disciplined by setting them to be consistent with U.S. data. It is worth noting, however, that the model we presented is streamlined with the intent of highlighting the mechanism we proposed, and we left for future research its interactions with other potentially important mechanisms, particularly those working through dynamic propagation (e.g. capital accumulation, financial frictions, durable goods, habit persistence, etc.).

4.1 Calibration

Table 4 lists the model's 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 following a conventional calibration approach. The model is set to a quarterly frequency with a standard discount factor of $\beta = 0.99$. The Frisch elasticity of labor supply is set to 2, which is also a standard value in the literature, and since the Frisch elasticity in the model is $1/(\omega - 1)$, we obtain $\omega = 1.5$. The labor share in production is set to $\alpha = 0.7$, which is a common value based on historical U.S. data. Utilization is normalized so that $m = 1$ without pandemia, which is equivalent to full capital utilization. The depreciation (or utilization cost) function is modified slightly to adopt a formulation typical of dynamic macro models (see Mendoza et al., 2014): $\delta(m_t) = \chi_0 \frac{m_t^{\chi_1}}{\chi_1}$. Without pandemia, since $m_t = 1$, the capital depreciation rate satisfies $\delta = \frac{\chi_0}{\chi_1}$, where δ is set to a depreciation rate of 0.0164 per quarter, consistent with the calibration to U.S. 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 χ_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. (25) for $K = 6.04$ and $m = 1$, and then the condition that $\delta = \frac{\chi_0}{\chi_1}$ yields $\chi_1 = 6.10$. Finally, $\gamma_1 = 0.2$ because the top quintile of the U.S. wealth distribution owned nearly 90% of the wealth in 2017 (Leiserson et al., 2019), and for simplicity we focus mainly on the case in which $\Omega^{sp} = \Omega^{\star NP}$, so that the SPE supports the DCE without pandemia and there is no incentive to redistribute except when a pandemia hits.

Table 4: Calibrated Parameter Values

Parameter	Value	Reference
β	0.99	Standard for quarterly frequency
ω	1.5	Frisch Elasticity of labor supply equals 2
α	0.7	Standard labor Share
K	6.04	Capital stock to match K/GDP=3
$m^\star$	1	Normalization
χ_0	0.10	Optimality condition for utilization with $m^\star = 1$
χ_1	6.10	1.64% depreciation rate, Mendoza et al. (2014)
γ_1	0.2	Top quintile owns 90% of U.S. wealth in 2017, Leiserson et al. (2019)
H	1	Normalization
$h^\star$	0.0948	Linear expenditure system regression
a	0.756	Average nonhealth-to-health consumption and GDP ratios, 2009-2018
θ	0–0.095	Interval up to feasible DCE upper bound

To calibrate the Stone-Geary preferences, we start by normalizing the fixed supply of health goods and services so that $H = 1$. Hence, $h^\star$ represents the percent of the available supply of health goods allocated for subsistence in normal times. To set the value of $h^\star$, we use estimates from a standard linear-expenditure-system regression of the 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 equilibrium pricing condition for the NP phase, eq. (34), using the resource constraint for non-health goods and the market-clearing condition for health goods.[17] The value of $h^\star$ corresponds to the coefficient on p_t^h, which yields $h^\star = 0.0948$ with a standard error of 0.0235 and a probability value of 0.0002.[18]

The share of non-health expenditures a is determined by imposing on the same pricing condition

[17]After simplifying terms, combining these expressions yields $P^h y^h = \frac{1-a}{a}\left(1 - \frac{\delta(\cdot)K}{y^{nh}} - \frac{\alpha}{\omega}\right) P^{nh} y^{nh} + h^\star P^h$.

[18]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 U.S. economy.

(34) the estimated value of $h^\star = 0.0948$ 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 so as to capture averages from data where the ratios stabilized, after a long period in which both rose steadily. This yields $a = 0.756$.

The last item that needs to be specified is the function $f(m_t K)$ that maps utilization into subsistence demand for health goods during a pandemia. The function is assumed to be monotonically increasing but it could be convex, concave or linear. As noted earlier, a concave (convex) formulation would represent an economy in which reductions in utilization are less (more) effective at reducing the stress on the health system during a pandemia. For simplicity, we assume a linear function $f(m_t K) = \theta m_t K$. Since we know little about θ and, given the linear specification and the value of K, equation (40) yields an upper bound $\tilde{\theta}$ that can support a DCE with pandemia, we explore model solutions for θ in the $[0, \tilde{\theta})$ interval. Moreover, within this interval, we identify the value of θ that would make the drop in non-health GDP observed during the pandemia consistent with an optimal lockdown. This scenario is denoted as the "observed lockdown" (OL) scenario. Using the decline of 8.8 percent in non-health GDP of the United States in the second quarter of 2020 relative to the first quarter, the implied θ that yields the drop in utilization needed for this output drop to be optimal is $\theta^{OL} = 0.0918$. The corresponding utilization rate is 0.848 and hence $f(mK) = 0.0918 * 0.848 * 6.04 = 0.47$. Thus, accounting for the observed lockdown as an optimal policy outcome requires a sharp increase in the subsistence level of demand for health goods and services from 9.48 to $9.48 + 47 = 56.4$ percent of the available supply.

4.2 Quantitative findings

Table 5 shows the results for the DCE without pandemia (DCE_{NP}) and two DCE and SPE pandemia scenarios. One is the OL case, in which we find the value of θ such that the $SPE_{P,OL}$ solution returns the observed drop in non-health U.S. GDP (i.e. $\theta = \theta^{OL} = 0.0918$). This is compared with results for a variant of the DCE with an ad-hoc cut in utilization set to yield the same observed output drop during the pandemia, labeled $DCE_{P,OL}$. This differs from $SPE_{P,OL}$ because, while the aggregate allocations are the same (i.e. there is no utilization externality since $DCE_{P,OL}$ and $SPE_{P,OL}$ yield the same utilization rate by construction), the planner still finds it optimal to redistribute resources across agents. The second scenario, with columns labeled $DCE_{P,NL}$ and $SPE_{P,NL}$, compares solutions assuming there is no ad-hoc lockdown (NL) in the DCE. We cannot solve this NL scenario with $\theta^{OL} = 0.0918$ because without ad-hoc lockdown $\tilde{\theta} = 0.083$ in the DCE, so instead we set $\theta = 0.075$ which yields the same relative price increase as the OL scenario.[19]

The aggregate allocations for $DCE_{P,OL}$ and $SPE_{P,OL}$ show that the 8.8 percent output drop is associated with a utilization cut of 15 percentage points and declines in consumption and labor of about 6 percent. Moreover, p^h rises by about a 100 percent relative to prices without a pandemia.

[19]It follows from eq. (40) that the upper bound $\tilde{\theta}$ required for type-2 agents to avoid hitting $\bar{h}$ in the DCE_P increases with the size of an ad-hoc utilization cut imposed on the DCE solution. Hence, the interval of feasible θ values shrinks as the assumed ad-hoc utilization cut is reduced. The upper bound in the $DCE_{P,OL}$ solution is $\tilde{\theta} = 0.095$, compared with $\tilde{\theta} = 0.0834$ in the $DCE_{P,NL}$ solution.

Table 5: Competitive & Social Planner's Equilibria: Alternative Scenarios

Variable	Normal Times (*levels*) $\text{DCE}_{NP} = \text{SPE}_{NP}$	Observed Lockdown (*percent changes*) $\text{DCE}_{P,OL}$	$\text{SPE}_{P,OL}$	No Lockdown (*percent changes*) $\text{DCE}_{P,NL}$	$\text{SPE}_{P,NL}$
		$\theta = 0.0918$		$\theta = 0.075$	
Aggregate variables:					
Ω	10.768	187.08	10.768	69.113	10.768
$\bar{h}$	0.095	0.564	0.564	0.548	0.502
$Y(\text{GDP}^{\text{NH}})$	2.012	-8.843	-8.842	0	-5.819
m	1	-15.176	-15.176	0	-10.11
L	1.256	-5.986	-5.985	0	-3.918
Π	0.505	1.849	1.849	0	2.414
C	1.913	-6.023	-6.022	0	-3.647
w	1.121	-3.039	-3.039	0	-1.979
p^h	0.348	101.099	101.099	100.06	78.85
$p^h H(\text{GDP}^{\text{H}})$	0.348	101.099	101.099	100.06	78.85
Individual variables:					
c^1	4.49	21.75	-4.462	23.444	-2.445
c^2	1.269	-30.595	-7.402	-20.743	-4.711
h^1	3.395	-20.603	-36.624	-20.879	-31.716
h^2	0.401	43.574	77.457	44.158	67.076
$\tilde{c}^1$	3.551	29.838	-3.304	29.642	-1.553
$\tilde{c}^2$	0.33	-92.526	-3.303	-79.8	-1.556
$\tilde{h}^1$	3.3	-35.436	-51.917	-35.198	-44.959
$\tilde{h}^2$	0.306	-96.284	-51.916	-89.903	-44.957
Transfer & Welfare:					
TR/GDP (%)	n.a.	n.a.	12.29	n.a.	9.53
Welfare Gain (%)	0	0	1.129	0	0.646
ΔU^1	0	0	-1.161	0	-0.977
ΔU^2	0	0	10.088	0	6.349
ΔW	0	0	0.473	0	0.253

Notes: The "Normal Times" column corresponds to the equilibrium without pandemia (DCE and SPE are identical because the calibration assumes $\Omega^{sp} = \Omega^{\star NP}$). Allocations and prices in the Observed Lockdown and No Lockdown scenarios are reported as percent changes relative to the Normal Times scenario, except $\bar{h}$ and Ω are shown in levels because m and $\bar{h}$ are percentages and Ω is a ratio. Transfers as a share of GDP (TR/GDP) and welfare gains are percentages as defined in the text, and ΔU^1, ΔU^2, ΔW are changes in utility and welfare, also as defined in the text.

The consumption allocations differ sharply across agents in the $DCE_{P,OL}$ vis-a-vis $SPE_{P,OL}$. Relative to DCE_{NP}, c^1 rises 21.8 percent while c^2 falls 30.6 percent in the $DCE_{P,OL}$. Since labor disutility is the same for both agents, this implies that excess consumption of nonhealth goods also rises sharply for type-1 agents and falls sharply for type-2 agents. Regarding health goods consumption, note that in the DCE_{NP} type-2 agents consume less than the subsistence level under $DCE_{P,OL}$, hence h^2 *rises* 43.6 percent relative to its level in the DCE_{NP} so as to yield positive excess consumption. Since $H = 1$, this implies that type-1 agents must reduce their consumption of health goods, by 20.6 percent relative to what they were consuming under DCE_{NP}. Excess health goods consumption also shrinks for type-1 agents under $DCE_{P,OL}$ relative to DCE_{NP}, but it is substantially higher than for type-2 agents.

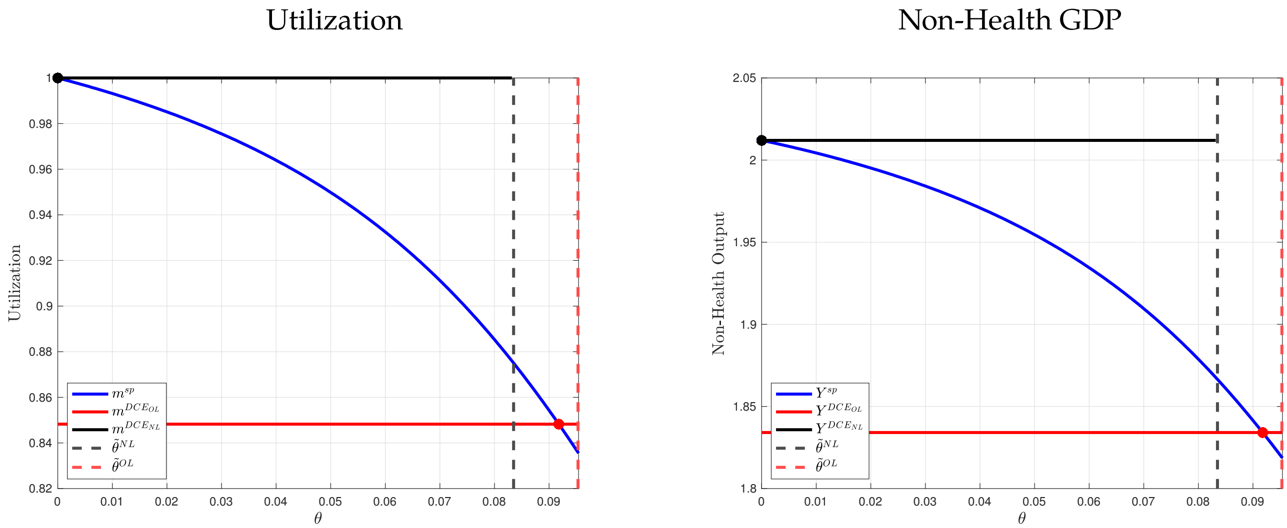
The planner's redistribution under $SPE_{P,OL}$ reduces c^1 and h^1 so as to increase c^2 and h^2. In particular, it moves type-2 agents further away from the level at which the saturation of the health system is reached. This requires an amount of transfers equivalent to 12.3 percent of total GDP. Moreover, this policy yields a sizable welfare gain of 1.13 percent, assuming a pandemia that lasts 4 quarters. As noted earlier, this is solely due to the social welfare gains of redistribution, because by construction in this OL scenario the DCE and SPE feature the same utilization rate, and thus there are no welfare gains due to the utilization externality.

The no-lockdown scenario differs from the OL case in that now there is no drop in utilization in the DCE with pandemia, which is what the theory predicts in the absence of an ad-hoc utilization cut. Hence, all aggregate allocations in the $DCE_{P,NL}$ solution remain at their levels without pandemia. Relative prices increase by about 100 percent as in the OL case by design (i.e. $\theta = 0.075$ was chosen from the set of feasible values so as to yield the same price hike). The consumption allocations of health and nonhealth goods across agents move in the same directions and by magnitudes that are roughly similar, except the drop in c^2 is much smaller (-20.7 v. -30.6 percent in the $DCE_{P,OL}$). Moreover, the regressive redistribution in the $DCE_{P,NL}$ is driven solely by the effect of higher p^h increasing the income type-1 agents derive from sales of health goods, with profits, wages and labor supply unchanged. In contrast, in the $DCE_{P,OL}$, wage income of each agent falls 8.8 percent as the wage rate and labor supply fall 3 and 6 percent, respectively, and profits paid to type-2 agents rise 1.8 percent. Hence, income inequality worsens more in the OL than in the NL case, and this causes larger inequality in excess consumption with $\Omega^{\star P}$ rising to 187 in the OL case v. 69 in the NL case.

In contrast with the OL case, $DCE_{P,NL}$ and $SPE_{P,NL}$ differ not only because the planner redistributes resources across agents but it also alters utilization and aggregate allocations. The planner cuts utilization by 10 percentage points, because now the utilization externality is in full force, since there is no ad-hoc utilization cut in the $DCE_{P,NL}$. The optimal drop in nonhealth GDP is about -5.8 percent with declines in aggregate consumption and labor near -4 percent. The subsistence demand for health goods rises to 50 percent under the optimal policies. Redistribution in the $SPE_{P,NL}$ relative to the $DCE_{P,NL}$ is again roughly similar to what we reported for the OL case. The social welfare gain is 0.65 percent, roughly 2/3rds of that obtained in the OL scenario. This is the case because, although there is now a welfare gain due to the utilization externality, the bump in $\bar{h}$ is 6 percentage points smaller and the planner allocates a smaller increase in health consumption to type-2 agents.

Figures 4 and 5 illustrate how the quantitative results vary as θ changes in the $[0, \tilde{\theta})$ interval. Figure 4 shows utilization and non-health GDP. Since $\tilde{\theta}$ applies only to the DCE solution, not the SPE, and it increases with the size of the assumed ad-hoc lockdown imposed on the DCE, the vertical lines identify $\tilde{\theta}$ for the NL and OL scenarios (i.e. $\tilde{\theta} = 0.0834$ and 0.095, respectively). The SPE solution is plotted for θ in the $[0, 0.095]$ interval. The two horizontal lines correspond to the DCE solutions for NL (with $m^{\star} = 1$) and OL (with $m^{\star} = 0.848$). These lines are horizontal because the DCE aggregate allocations are independent of θ due to the utilization externality. Drawing any other horizontal line at some m value would correspond to the DCE for an ad-hoc lockdown at that same m value.

Figure 4: Utilization and Non-Health Output in Pandemia

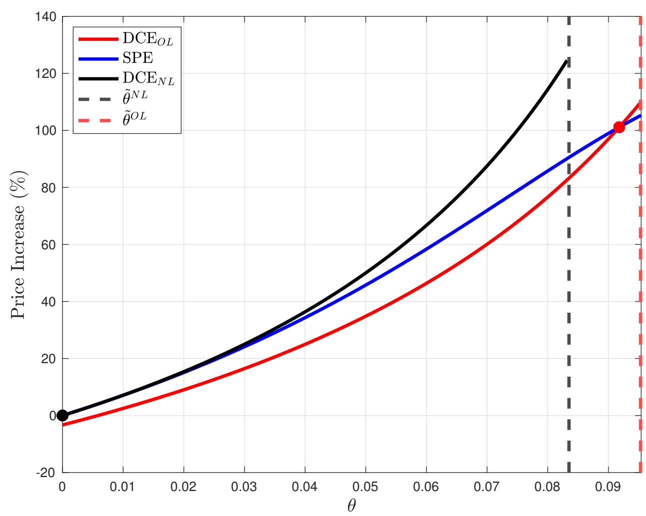


For a given θ in the horizontal axis of the plots of Figure 4 , we can use the plots to examine how the optimal lockdown (i.e. utilization rate) and output chosen by the planner differ from the DCE. For the NL (OL) case, if $\theta = 0$ ($\theta = 00.0918$) the corresponding DCE values of m are socially optimal, because at those θ values the SPE yields the same utilization and non-health GDP, since the SPE curve and the corresponding DCE line intersect. The DCE utilization and nonhealth output remain the same at their corresponding NL and OL levels as θ varies, but they change for the SPE. The concave SPE curves show that the utilization externality causes the planner to select an increasingly larger optimal lockdown with a larger associated output drop as θ rises by a fixed amount. For instance, if the "true" value of θ were 0.075, the optimal lockdown reduces utilization from 100 to 90 percent and non-health GDP falls 5.8 percent. These are the socially optimal choices for which the government balances optimally the output-pandemia tradeoff.

The Figure also shows that the observed lockdown can be excessive if θ is slightly lower than 0.0918 (i.e. if the government imposed the observed lockdown thinking that it would be optimal based on assuming that $\theta = 0.0918$ but in fact the "true" θ is lower). For instance, if $\theta = 0.075$, the *correct* optimal lockdown would set utilization 5 percentage points higher than the DCE with the observed lockdown (0.9 v. 0.848), which yields a non-health GDP drop 3 percentage points smaller (-5.8 v. -8.8 percent). The values of $\bar{h}$ differ by six percentage points, 56.4 percent with the observed lockdown v. 50.2 percent for the correct optimal lockdown. Hence, the model predicts that, because of the concavity of the optimal lockdown, small errors overestimating the elasticity of the subsistence level of health to the utilization rate during a pandemia cause large errors in the severity of lockdowns and their associated recessions, relative to what is socially optimal. On the other hand, the optimal lockdown is unlikely to *exceed* the correct observed lockdown by much, because in this case the value of θ that makes the observed lockdown optimal is close to the corresponding feasibility upper bound $\tilde{\theta}$. If the correct θ were closer to this $\tilde{\theta}$, utilization and output would drop only slighltly more than under the DCE with the observed lockdown.

Figure 5 shows how the percent increase in p^h during a pandemia varies with θ in the SPE and in the DCE cases for no lockdown and observed lockdown. The planner chooses higher prices for θ values that would make the observed lockdown excessive, and lower prices when the opposite occurs. In contrast, the SPE price hikes always exceed those for the no-lockdown DCE case, because in this case the planner always finds it optimal to reduce utilization below its DCE level. The price hikes are very sizable, unless we consider θ values that would result in negligible drops in utilization and output. For $\theta > 0.05$, the optimal policy yields price hikes of at least 45 percent and as much as 105 percent. Price hikes in the no-lockdown DCE case would be uniformly higher. In the observed-lockdown DCE they would be in the 35 to 125 percent range. Hence, the model predicts large relative price movements during pandemias.

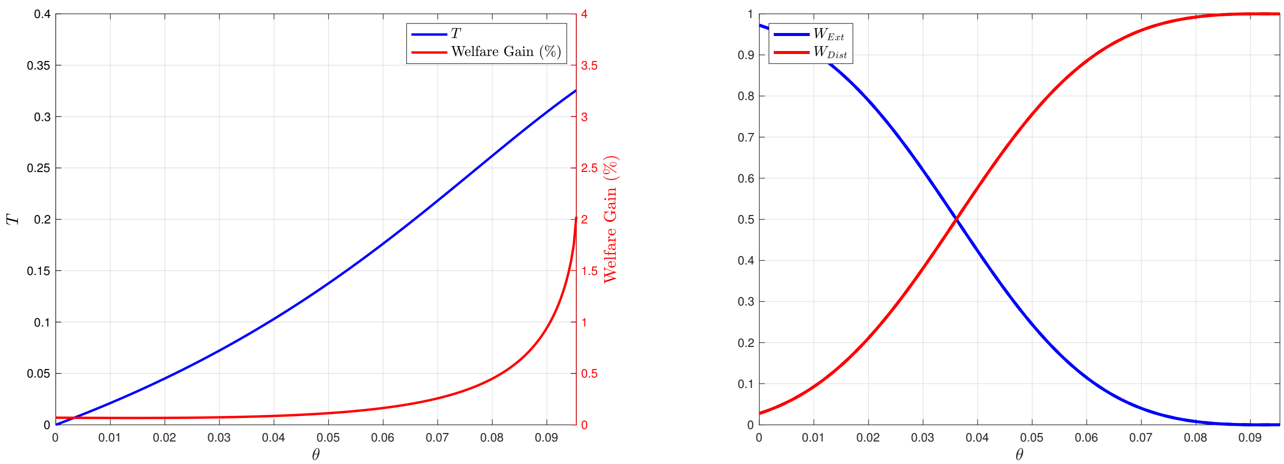
Figure 5: Price Increases in Pandemia



The left panel of Figure 6 shows optimal transfers and the social welfare gain of the optimal policy (assuming a 4-quarter pandemia) as θ varies, comparing the SPE relative to the observed-lockdown DCE. Transfers increase monotonically because, in line with the findings for prices, the larger price increases cause larger regressive redistribution as the value of the endowment of health goods and services owned by type-1 agents rises, and as their profits from non-health goods production increase too. The welfare gains follow an increasing, convex shape that diverges to infinity as θ reaches the upper bound at which type-2 agents approach the subsistence level of health consumption. The right panel of Figure 6 shows the fraction of the welfare gains due to the utilization externality relative to the one due to redistribution. Interestingly, although the utilization externality strengthens as θ rises, the redistribution gain is the one that becomes relatively more important. This is again because type-2 agents move closer to their subsistence level of health consumption as θ rises and as this happens they approach the Inada condition that makes the marginal utility of allocating health consumption to them infinitely large. This Figure also indicates that redistribution is in general more important for social welfare in the model: For low θ, the utilization externality accounts for most of the welfare gains but these gains are small, whereas for high θ most of the welfare gains are due to redistribution and the gains are large.

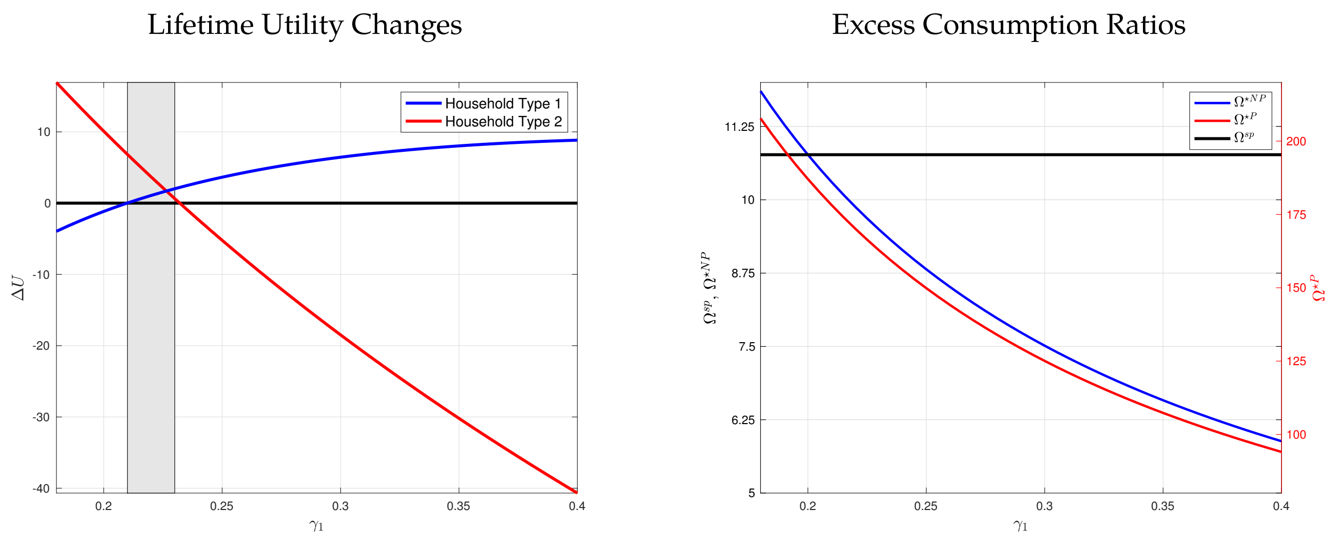
Figure 6: Transfers & Welfare Gains: Pandemia with Observed Lockdown in DCE

Transfers and Welfare Gains | Composition of Welfare Gains



The left panel of Figure 7 shows an important result regarding Pareto efficiency. The plot shows how the lifetime utilities of type-1 and type-2 agents vary as the fraction of type-1 agents rises, keeping social welfare weights fixed at the level such that the SPE supports the DCE without pandemia and θ at the level that makes the observed lockdown socially optimal. The utility gains for the observed-lockdown DCE with the calibrated value of $\gamma_1 = 0.2$ reduces utility for type-1 agents and increases it for type-2 agents. However, if γ_1 is slightly higher and falls within the interval marked by the shaded area in the Figure, both agents are better off with the optimal policy. Thus, as suggested in the previous Section, given social welfare weights, the SPE can be Pareto efficient if γ_1 is sufficiently high so as to reduce the cost of redistribution for type-1 agents below the benefit of removing the utilization externality.

Figure 7: Utility Changes, Excess Consumption Ratios & Fraction of Type-1 Agents

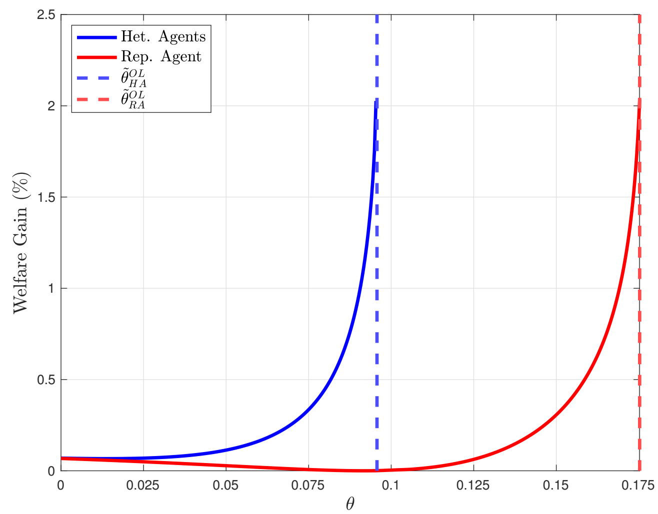


Notes: Calculations are based on the observed lockdown scenario.

The relevance of excess consumption inequality in the model is illustrated in the right panel of Figure 7, which shows Ω^{sp}, $\Omega^{\star NP}$ and $\Omega^{\star P}$ (right axis) as γ_1 rises up to 0.4. The value of Ω^{sp} (which is roughly 11) is the value such that the SPE supports the DCE without pandemia. The plot shows that, with the calibrated parameter values, the measure of inequality provided by the ratio of excess consumptions (i.e. the ratio of marginal utilities) shows non-trivial inequality even without a pandemia, but always significantly more when a pandemia hits. The values of $\Omega^{\star P}$ are in the 80-225 range while $\Omega^{\star NP}$ is in the 6-11.5 range. Hence, the pandemia worsens inequality in excess consumption significantly.

Figure 8 shows the importance of agent heterogeneity (or income inequality as captured by the value of γ_1). We compare social welfare gains of the optimal policy for the observed lockdown case as θ 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 and aggregate allocations are the same as in the DCE (relative to the DCE with two agents) and in the SPE (relative to the SPE with two agents). Both welfare gains display the convex, asymptotic behavior as θ reaches the upper bound at which agents hit the subsistence level of health goods. This upper bound is much larger, however, in the representative-agent model that has no income inequality (since $\gamma_1 = 1$), because the health system saturates earlier when inequality is present. At values of θ for which both models can be solved, the welfare gains of the optimal policy are negligible for the representative-agent model. The utilization externality in this case would need to be driven by much larger values of θ (above 0.14) in order to yield non-trivial welfare gains. At those values, however, to model would predict much larger falls in output than what has been observed (since the higher θ values would yield much larger utilization cuts). Hence, the model predicts that inequality plays a key role in tempering the size of the optimal lockdowns, and this is due to the adverse effects they have in the distribution of excess consumption across agents.

Figure 8: Welfare Gains - Representative v. Heterogeneous Agents



Notes: Calculations are based on the observed lockdown scenario.

5 Conclusions

This paper proposed a model of the macroeconomic effects of pandemias in which the saturation of the health system if the key driving force. A cross-country empirical analysis shows that proxies for healtcare system saturation and the stringency of lockdowns are significant determinants of differences in the severity of the recessions caused by COVID-19, even after controlling for the effects of COVID infection and mortality rates.

Healthcare saturation is modeled by introducing Stone-Geary preferences with a jump in the subsistence level of health goods and services during pandemias that is negatively related to the utilization rate. The model generates an output-pandemia tradeoff because firms do not internalize that reducing utilization during a pandemia moves the healthcare system away from its saturation point. Inequality matters because the pandemia moves wage-earners closer to the subsistence level of health than capitalists. Hence, the optimal policy includes a lockdown and transfer payments to wage earners.

A quantitative exercise calibrated to U.S. data illustrates the potential relevance of the mechanism driving the model and the hurdles facing the design of optimal lockdown and transfer policies to deal with pandemias. Social welfare gains of the optimal mix of lockdown and transfers are large, but small miscalculations in the elasticity of the subsistence level of health to changes in utilization result in large errors in the design of lockdowns. During pandemias, the relative price of health goods rises sharply and both income and consumption inequality worsen significantly. As a result, optimal transfers are large and contribute a sizable fraction of the welfare gains of the optimal policy.

This study is a first step in a research agenda exploring the saturation of the healthcare system as the engine of macroeconomic models of pandemias. Further research is needed to examine the implications of this mechanism in models with dynamic and cross-country propagation mechanisms, particularly 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.

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