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COVID-19 IN EMERGING MARKETS

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ABSTRACT

Emerging markets have experienced large human and economic costs from COVID-19, and their tight fiscal space has limited the support extended to their citizens. We study the impact of an epidemic on economic and health outcomes by integrating epidemiological dynamics into a sovereign default model. The sovereign's option to default tightens fiscal space and results in an epidemic with limited mitigation and depressed consumption. A quantitative analysis of our model accounts well for the dynamics of fatalities, social distancing, consumption, sovereign debt, and spreads in Latin America. We find that because of default risk, the welfare cost of the pandemic is about a third higher than it is in a version of the model with perfect financial markets. We study debt relief programs and find a compelling case for their implementation. These programs deliver large social gains, improving health and economic outcomes for the country at no cost to international lenders or financial institutions.

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1 Introduction

The coronavirus pandemic has brought enormous challenges for world economies. To control this highly contagious and deadly disease, countries have relied on mitigation measures that limit social interactions, while experiencing contractions in economic activity. Governments in advanced economies have also engaged in large fiscal transfers to support consumption in response to the recession. In emerging markets such transfer programs have been much smaller because sovereigns have limited fiscal space, owing to their chronic problems with public debt crises.[1] Government debt in these emerging markets has modestly increased, yet sovereign spreads increased and several countries defaulted on their debts (among them Argentina, Ecuador, Ethiopia, and Lebanon). This paper studies the interactions between public debt and the epidemic and shows that susceptibility to debt crises magnifies the economic and health costs of the pandemic.

We develop a framework that integrates standard epidemiological dynamics into a model of sovereign debt and default. The epidemic triggers a health crisis, with time paths of infected and deceased individuals. The economy responds to the epidemic with mitigation policies that save lives but depress output. The sovereign issues debt to support consumption but lacks commitment to repay, and thus it might choose to default, with varying intensity and duration. Default risk shapes the fiscal response, as it restricts the amount of borrowing and leads to further contractions in consumption and limited mitigation. The tepid expansion of sovereign borrowing is nevertheless expensive for the economy because it increases the likelihood of a lengthy debt crisis. Such debt overhang problems have negative repercussions on health outcomes, and also for consumption and output, that last beyond the epidemic itself. In this framework default risk increases the welfare cost of the epidemic because it limits the use of debt needed to support consumption and to fight the health crisis and generates persistent contractions in consumption and economic activity.

We apply our framework to data from Latin America, a region that experienced a severe COVID-19 outbreak and has a history of debt crises. As of this writing, about 1.7 million people have died in Latin America from COVID-19. We collect data for fatalities, social distancing, sovereign debt and spreads, and consumption for countries in the region and use them to estimate our model. In the data and the model, the epidemic leads to a fall in consumption of about

1. Gourinchas and Hsieh (2020) were among the first to issue a warning about precarious debt conditions in emerging markets and their potential impact on fighting the pandemic.

7%, an increase in debt of about 8%, and an increase in spreads of about 5%. Our model also fits well other observed economic and epidemiological patterns, including the high death toll. We find that the welfare cost of the epidemic is large: 37% of output for the country and 13% for its lenders, which hold its outstanding debt upon the outbreak. We find that sovereign default risk accounts for about 30% of these costs, by comparing our model with an environment that has perfect financial markets but is otherwise equivalent.

The epidemiological model is the standard Susceptible-Infected-Recovered (SIR) framework as in Atkeson (2020). New infections result from interactions between infected individuals and those who are susceptible to the disease; infected individuals transition eventually to either a recovered state or a deceased state. Like Alvarez, Argente, and Lippi (2021), we assume that the death rate depends on the measure of infected individuals and that social distancing measures can limit new infections but are costly for output. We adopt the sovereign debt and default framework of Arellano, Mateos-Planas, and Ríos-Rull (forthcoming). The sovereign of a small open economy borrows internationally and chooses the intensity of default every period, endogenously determining the duration of the default episode. A fraction of the defaulted debt accumulates; it is capitalized in the stock of outstanding debt, while new credit is endogenously restricted. Partial defaults in this framework amplify shocks and lead to persistent adverse effects on the economy. We consider a centralized problem with a sovereign that values the lives and consumption of the population. The sovereign decides on borrowing, partial default, and social distancing measures to support consumption and manage the infection dynamics, with a goal of preventing deaths. In our framework, default risk responds to the epidemic and shapes its management.

We use a simplified version of our setup with a finite horizon to characterize more sharply the interactions between default and epidemic outcomes. Social distancing measures are an investment in lives and, as such, respond to consumption costs and domestic interest rates, which reflect the shadow cost of borrowing arising from default risk. We show that with perfect financial markets, the marginal cost of social distancing measures tends to be lower, because consumption is funded by the economy's lifetime income. With default risk, in contrast, social distancing measures tend to be inefficiently lax because of the higher marginal cost of consumption arising from a lower lifetime income, default costs, and high domestic rates. We show that default risk leads to under-investment in lives and makes the epidemic more deadly.[2] We also show that the

2. Our finding that default risk discourages social distancing measures relates to the debt overhang literature, which

epidemic leads to an increase in the propensity to default, because of additional incentives to borrow, yet the increase in debt is lower than the increase under perfect financial markets, and the resulting the decline in consumption is sharper.

We evaluate the interaction between financial market frictions and epidemic outcomes in our quantitative model by comparing our baseline with results in two reference models: a case with perfect financial markets and a scenario featuring a more persistent recession. The epidemic results in a sizable loss of life in all economies, but with perfect financial markets, the economy can implement more stringent social distancing measures, which reduce the death toll to about one-quarter of that in the baseline. The economic responses also differ sharply across economies; in our baseline the increase in debt is about one-third of the increase with perfect financial markets, and the consumption declines are persistent and much larger too. If the epidemic causes an increased likelihood of a persistent decline in productivity as well, as in the International Monetary Fund (2021, WEO) forecast for a persistent recession in the region, credit conditions are even tighter, and fatalities exceed those in the baseline. The country borrows less, engages in less social distancing, and experiences an even longer period of depressed consumption. The markedly different health and economic outcomes during the episode across these models result in sizable differences in the welfare costs of the epidemic.

The fact that financial conditions greatly impact outcomes during the epidemic suggests that international assistance programs can deliver considerable benefits to emerging markets burdened by default risk. The International Monetary Fund (IMF), the World Bank, the Inter-American Development Bank, and other international organizations have sponsored debt relief programs to help countries fight COVID-19. We use our model to conduct three counterfactual experiments to evaluate such debt relief initiatives.

The first program we consider is a default-free, long-term loan extended by a financial assistance entity, akin to the programs extended by the IMF. We find that long-term loans have large social benefits, increasing the welfare in the baseline by 7.5% for the country and 7.6% for its lenders. These gains arise from a reduction in deaths and a much milder debt crisis, which are due to more efficient mitigation measures and less reliance on defaultable debt. The second program is a suspension of debt service payments, in line with the World Bank's Debt Service Suspension Initiative (DSSI). We find that such suspensions can benefit both the country and its international lenders, and prevent as much as 8% of fatalities, only when coupled with a

has argued that indebtedness can depress investment, as in Aguiar and Amador (2011).

reduction in the payments accumulated during the suspension. The third program consists of a voluntary restructuring between the country and its private creditors. We find that upon the outbreak of the epidemic, at our baseline parameterization, the economy and its lenders will voluntarily agree to reduce the debt level by close to 5.5% of output, without affecting the value of debt to lenders. The increase in the market price of the outstanding debt from reducing the debt compensates the loss from holding fewer units.

Finally, our work makes a methodological contribution. We develop a framework that integrates the dynamics of defaultable debt with those of epidemiological status in the population. We set up and solve the transition dynamics of a Markov problem in which the sovereign's choices over debt and social distancing measures affect the endogenous evolution of four state variables. The sovereign lacks commitment and makes choices taking as given future policy functions. We provide an algorithm that can be adapted to other applications with transition dynamics in sovereign default models with time-varying, endogenous aggregate state variables.

This section concludes with a brief review of the relevant literature. The rest of the paper proceeds as follows. Section 2 lays out the structure of our model. Section 3 focuses on a simpler version of our setup, which enables us to highlight key interactions between deaths, mitigation of the epidemic, and default risk. Section 4 reports the results for the quantitative analysis of our model, including the data used to discipline it, and the main results on the contribution of default risk on health and economic outcomes from the epidemic. Section 5 presents the evaluation of debt relief programs. Section 6 presents the sensitivity analysis. Section 7 concludes and sets directions for future work.

Literature. Our paper contributes to the growing literature that studies the COVID-19 epidemic and its interactions with economics. Atkeson (2020) was among the first to introduce economists to the classic SIR epidemiology model of Kermack and McKendrick (1927) and use it to study the human cost of the COVID-19 epidemic for the United States. Alvarez, Argente, and Lippi (2021) and Eichenbaum, Rebelo, and Trabandt (2021) study optimal mitigation policies in simple production economies in which the epidemic dynamics follow a SIR model. Their results highlight the trade-off inherent in social distancing policies: they save lives but are costly in terms of economic output. Our epidemiological model follows Alvarez, Argente, and Lippi (2021) setup but adds consumption smoothing incentives like those in Eichenbaum, Rebelo, and Trabandt (2021).

A growing literature considers the role of heterogeneity in the COVID epidemic. Glover et al. (2020) delve into distributional considerations, which are crucial because the old are more at risk from the epidemic, yet the young endure most of the economic costs. They find that social distancing policies are used more extensively by sovereigns with better ability to redistribute. Acemoglu et al. (2021) study disease mitigation in environments with multiple ages and sectors. They find that smart mitigation strategies that target the old and at-risk population are most helpful. Baqaee et al. (2020) and Azzimonti et al. (2020) study how the network structure of economic sectors and geography can be exploited in the design of optimal mitigation policies. Guerrieri et al. (2022) show that negative supply shocks, such as COVID-19, in one sector can depress aggregate demand in settings with multiple sectors and sticky prices. These papers focus on the epidemic's costs for advanced economies, but they do not consider how the functioning of financial markets shapes epidemic outcomes. Our paper fills this gap by focusing on how frictions in financial markets and default risk shape the health and economic responses of the epidemic. To highlight this contribution, we have abstracted from additional heterogeneity considerations. We view our work as complementary to these findings.[3]

A few papers do share our focus on the impact of COVID-19 on emerging markets. Hevia and Neumeyer (2020) highlight the multifaceted nature of the pandemic, a tremendous external shock for emerging markets that includes collapsing export demand, tourism, remittances, and capital flows. Çakmaklı et al. (2020) focus on international input-output linkages, as well as sectoral heterogeneity, by constructing a SIR-macro model calibrated to the Turkish input-output structure, while abstracting from default risk. Espino et al. (2020) study optimal fiscal and monetary policies for emerging markets in a sovereign default model and model COVID-19 as an unexpected combination of shocks. Their results are similar to ours in that they find that default risk increases as a result of the epidemic. Unlike us, they do not consider explicitly epidemiological dynamics, and hence their framework is silent on the health crisis.

The debt and default framework at the core of our work builds on the earlier contributions by Eaton and Gersovitz (1981), Aguiar and Gopinath (2006), Arellano (2008), and Chatterjee and Eyigungor (2012). We adopt the more recent approach in Arellano, Mateos-Planas, and Ríos-Rull (forthcoming), who model debt crises with partial default and an endogenous length. This framework gives meaningful dynamics during default episodes that replicate data, as defaulted debt accumulates over time and the length of the episode depends on the depth of the reces-

3. We have also abstracted from the substitution away from high social contact goods, like services, and toward low social contact goods, like durable goods, as in Kaplan, Moll, and Violante (2020). The greater financial market access in advanced economies could be a contributor to the stronger substitution patterns seen in these countries.

sion. Our quantitative evaluation of debt relief proposals contributes to the literature on debt buybacks. Like Bulow and Rogoff (1988) and Aguiar et al. (2019), we find that international lenders would benefit from debt buybacks during the COVID-19 epidemic through capital gains. Nonetheless, we emphasize that the gains to the country are large and positive because reducing debt overhang can considerably shorten and lessen the debt crisis and save on output costs from default. Furthermore, debt reduction allows the country to adopt stricter social distancing policies, which save lives. We also analyze a debt service suspension initiative in response to the COVID-19 shock, which is related to the recent work of Hatchondo, Martinez, and Sosa-Padilla (2021). They find, as we do, that in a standard sovereign default model, coupling debt service suspensions with haircuts delivers the highest social gains in response to unexpected shocks. Finally, our study of voluntary restructuring relates to the work of Hatchondo, Martinez, and Sosa-Padilla (2014), who evaluate similar proposals in a setup without epidemic dynamics.

2 Model

We consider a small open economy model with a unit measure of identical agents and a sovereign that borrows from international lenders, with an option to default on its debt. We evaluate the dynamics of this economy after it is unexpectedly hit by an epidemic. The dynamics of infection and deaths follow a standard epidemiological SIR model; during the epidemic, a subset of the population endogenously transitions from being susceptible to being infected. These people eventually either recover or die. The outcomes of the epidemic can be altered with social distancing measures. We study a centralized problem with a sovereign making all the decisions for the small open economy.

We start by describing preferences, technology, the market for sovereign debt, and the default option. We then discuss the evolution of the disease and social distancing measures, and we formulate the dynamic problem during the epidemic.

2.1 Preferences and Technology

We consider preferences over consumption and lives. As in Alvarez, Argente, and Lippi (2021), utility increases with consumption c_t and decreases in fatalities $\phi_{D,t}$. The lifetime value to the sovereign is

$$v_0 = \sum_{t=0}^{\infty} \beta^t \left[u(c_t) - \chi \phi_{D,t} \right]. \tag{1}$$

The utility from consumption is concave and equals $u(c) = (c^{1-\sigma} - 1)/(1-\sigma)$, with σ controlling the intertemporal elasticity of substitution. Each fatality imposes a loss of χ, akin to the value of life, and β is the discount factor.

Output in the economy Y_t is produced using labor, the supply of which is potentially depressed by social distancing measures. Agents are endowed with one unit of time, which they use to work, and hence total labor supply equals population N_t. When agents engage in social distancing of intensity L_t, each agent's labor input is reduced to $(1-\theta_Y L_t)$. The parameter θ_Y controls the mapping between social distancing and effective labor units. A small θ_Y, for example, can accommodate work from home labor.[4] The economy's output equals

$$Y_t = z_t \left[(1-\theta_Y L_t) N_t\right]^{\alpha}, \tag{2}$$

where $\alpha > 0$ and z_t is the economy-wide level of productivity. Productivity depends on an underlying level $\tilde{z}$ and falls with sovereign default d_t, so that $z_t = \tilde{z}\gamma(d_t)$, where the function $\gamma(d_t)$ is decreasing and bounded between 0 and 1.[5]

2.2 Debt and Default

The sovereign issues long-term debt internationally and lacks commitment over its repayment. We consider a sovereign default model in which the sovereign can choose to partially default on the debt every period and decides whether to start or end a default episode. We study long-term debt in a tractable way by considering random maturity bonds, as Hatchondo and Martinez (2009) do. The bond is a perpetuity that specifies a price q_t and a quantity of new issuances ℓ_t so that the sovereign receives $q_t \ell_t$ units upon the sale at time t. In each subsequent period, a fraction δ of the debt matures. Every period, conditional on not defaulting, each unit of debt calls for a payment of $\delta + r$.[6] The sovereign can choose to default on a fraction d_t of the current payment due B_t, which encodes the payment due from all previous borrowings. The sovereign transfers to domestic households all proceeds from operating in international debt markets. The resource

4. In this baseline model, we have assumed that all individuals, whether they are infected or not, can work equally well. It is straightforward to consider an extension in which infected individuals are subjected to a productivity penalty or completely unable to work.

5. In our quantitative evaluation, we will also consider an extension with time-varying and stochastic $\tilde{z}_t$.

6. We fix this payment level to normalize the risk-free bond price to 1. This normalization does not alter the maturity of the debt, only its units.

constraint of the economy is given by

$$N_t c_t + (\delta + r)(1 - d_t)B_t = Y_t + q_t \ell_t. \tag{3}$$

The equilibrium bond price q_t is determined by a schedule that depends on the debt B_{t+1} and the evolution of the epidemic states, i.e., the measures of infected, susceptible, and recovered individuals. This dependency arises because, as we will see below, the likelihood of future default depends on the evolution of the epidemic.

Following Arellano, Mateos-Planas, and Ríos-Rull (forthcoming), we assume that a partial default of intensity d_t reduces the current debt service payment to $(1 - d_t)(\delta + r)B_t$ but increases future debt obligation by a κ fraction of the defaulted payment. We annuitize these future debt obligations so that the next period's debt obligations increase by $\kappa d_t(\delta + r)B_t$. The debt due next period B_{t+1} therefore depends on new issuances ℓ_t, on the legacy debt due next period $(1 - \delta)B_t$, and on any defaulted debt that is carried over. The evolution of long-term debt is

$$B_{t+1} = \ell_t + \left[(1 - \delta) + \kappa(\delta + r)d_t\right] B_t. \tag{4}$$

International lenders are risk neutral and competitive. They take as given the international risk-free rate r, their opportunity cost. The bond price q_t compensates lenders in expectation for their losses due to future defaults, and it satisfies

$$q_t = \frac{1}{1 + r} \left\{(\delta + r)(1 - d_{t+1}) + \left[1 - \delta + \kappa(\delta + r)d_{t+1}\right] q_{t+1}\right\}. \tag{5}$$

This price is the expected payoff that lenders get from holding a unit of debt due B_{t+1}. If partial default is zero the next period, $d_{t+1} = 0$, lenders get the full coupon $(\delta + r)$ and the continuation value of the long-term bond $(1 - \delta)q_{t+1}$. A partial default next period of intensity d_{t+1} reduces the coupon that lenders get in period $t + 1$ but increases the subsequent value to them as the defaulted coupons accumulate at rate κ, to become due later.

2.3 Epidemic Dynamics

We now describe the outbreak of the epidemic and the subsequent dynamics, which build on the classic SIR structure. Following the outbreak of the disease, a subset of the population transitions endogenously from being susceptible to being infected and, eventually, to being either recovered or deceased. The population N_t is therefore partitioned in three epidemiological groups: susceptible, infected, and recovered. The mass of each group is denoted by μ_t^S, μ_t^I, and μ_t^R, respectively. We assume that the initial population size is 1. The total mass of the deceased is $\mu_t^D = 1 - N_t$. The epidemic starts when a faction of the population becomes infected exogenously, $\mu_0^I > 0$. The rest are initially susceptible, except possibly for a measure of agents already recovered $\mu_0^R \geq 0$, so that $\mu_0^S = 1 - \mu_0^I - \mu_0^R$.

The spread of the epidemic can be mitigated by limiting social interactions, as in Atkeson (2020) and Alvarez, Argente, and Lippi (2021). Social distancing measures of intensity L_t reduce labor input by $\theta_Y L_t$ and social interactions by θL_t. The parameter θ controls the effectiveness of social distancing measures in preventing the spread of infection.

An important component of the SIR model concerns how likely it is for susceptible individuals to become infected. We assume that the probability of infection at time t depends on the measure of outstanding infections μ_t^I, the effective social distancing measures θL_t, and an exogenous component governing the underlying contagiousness of the virus A_t. We interpret A_t as reflecting factors outside our model that affect the transmission of the disease, such as non-pharmaceutical interventions like masking and testing, as well as the emergence of new COVID-19 variants. The mass of newly infected individuals is denoted by μ_t^x and determined by

$$\mu_t^x = A_t \left[(1 - \theta L_t) \mu_t^I \right] \left[(1 - \theta L_t) \mu_t^S \right]. \tag{6}$$

The presence of $1 - \theta L_t$ twice in the above expression reflects the fact that social distancing reduces the social interactions of both the infected and susceptible. The mass of susceptible individuals in period $t + 1$ is that of period t net of any new infections,

$$\mu_{t+1}^S = \mu_t^S - \mu_t^x. \tag{7}$$

Infected individuals remain in this state with probability π_I. The mass of infected individuals in period $t + 1$ equals a π_I share of the infected in period t plus any new infections. The resulting law of motion is

$$\mu_{t+1}^I = \pi_I \mu_t^I + \mu_t^x. \tag{8}$$

With probability $1 - \pi_I$, each infected individual either recovers or dies. Like Alvarez, Argente, and Lippi (2021), we assume that the probability of dying from the disease conditional on being infected $\pi_D(\mu_t^I)$ depends on the measure of current infections, resulting in $\phi_{D,t} = \pi_D(\mu_t^I)\mu_t^I$ fatalities every period. We assume $\pi'_D(\mu_t^I) > 0$ to capture the role of health care capacity for the fatality rate; a large number of infections puts a strain on the health care system, hurting its ability to successfully treat cases. The resolution of infections into recoveries or deaths induces the following laws of motion for these last two groups:

$$\mu_{t+1}^R = \mu_t^R + \left[1 - \pi_I - \pi_D(\mu_t^I)\right]\mu_t^I, \tag{9}$$

$$\mu_{t+1}^D = \mu_t^D + \pi_D(\mu_t^I)\mu_t^I. \tag{10}$$

The epidemic induces a law of motion for the overall population size N_t,

$$N_{t+1} = \mu_{t+1}^S + \mu_{t+1}^I + \mu_{t+1}^R. \tag{11}$$

Finally, we map our model to standard epidemiological terminology. The *transmission rate*, the rate at which the infected spread the virus to others, is $A_t(1-\theta L_t)^2\mu_t^S$. The *effective reproduction number* in any one period t is given by

$$\mathcal{R}_t = \frac{A_t\,(1-\theta L_t)^2}{1-\pi_I}\frac{\mu_t^S}{1-\mu_t^D}, \tag{12}$$

and it reflects the number of infections caused, on average, by each infected individual over their entire spell of infection. Initially, when roughly the entire population is susceptible ($\mu_0^S \approx 1$) and before any social distancing measures are in place ($L_t \approx 0$), the *basic reproduction number* is $\mathcal{R}_0 \approx A_0/(1-\pi_I)$.

As is well known from the epidemiological literature, in such a SIR model, the epidemic eventually winds down as the mass of infected individuals asymptotes to zero. Without social distancing measures, the SIR parameters π_I and $\pi_D(\mu_t^I)$ and the path of A_t determine the duration and severity of the outbreak. Social distancing policies L_t can alter these outcomes. In practice, we adopt an assumption that the epidemic ends no later than H periods after it starts, because, for example, highly effective vaccines and treatments become fully available. In period H all susceptible individuals become functionally recovered, so no new infections can occur. This introduces a natural and numerically convenient terminal condition for the epidemiological transitions in our analysis, but conceptually H can be arbitrarily large. Also note that although the epidemiological effects cease at H, the epidemic's effects on debt, consumption, and output continue after H because of the persistent dynamics of debt.

2.4 The Sovereign's Problem

The sovereign and its international lenders learn about the epidemic in period 0. The outbreak changes the prospects for the economy, because the epidemic will lead to loss of life, disruptions in production, and sovereign defaults. In our centralized problem, the sovereign makes all choices for this economy. It borrows from international financial markets, with an option to partially default, and chooses social distancing policies L_t to reduce the loss of life from the epidemic.[7] We study a Markov problem, which we solve backwards from period H, when only B_t is a time varying state.

Consider the sovereign's problem for any period $t < H - 1$. The state variable for the sovereign consists of the measures of each group $\mu_t = (\mu_t^S, \mu_t^I, \mu_t^R)$ and its debt B_t. The accumulated deaths are the residual, $\mu_t^D = 1 - \mu_t^S - \mu_t^I - \mu_t^R$. The value function for the sovereign depends on these states and on time $V_t(\mu_t, B_t)$. The bond price function depends on future states and time, $q_t(\mu_{t+1}, B_{t+1})$, because default decisions will depend on these variables. The sovereign takes as given future value functions $V_{t+1}(\mu_{t+1}, B_{t+1})$ and the bond price schedule. It chooses optimal borrowing ℓ_t, partial default d_t, and social distancing L_t to maximize its objective, given by

$$V_t(\mu_t, B_t) = \max_{\ell_t,\, d_t \in [0,1],\, L_t \in [0,1]} \left[u(c_t) - \chi \phi_{D,t}\right] + \beta V_{t+1}\left(\mu_{t+1}(\mu_t, L_t), B_{t+1}\right), \tag{13}$$

subject to the resource constraint

$$N_t c_t + (1 - d_t)(\delta + r) B_t = \tilde{z}\gamma(d_t)[N_t(1 - \theta_Y L_t)]^\alpha + q_t(\mu_{t+1}(\mu_t, L_t), B_{t+1})\ell_t;$$

the evolution of debt (4); the SIR laws of motion (6–9), which map current population measures and social distancing policies to future measures $\mu_{t+1}(\mu_t, L_t)$; fatalities induced by these dynamics $\phi_{D,t} = \pi_D(\mu_t^I)\mu_t^I$; and the total population constraint (11). The sovereign internalizes that its choices for debt and social distancing affect the states tomorrow and the bond price.

When choosing L_t, the sovereign trades off the potential benefits from saving lives against the

7. We do not study whether households' own distancing measures would result in activity levels higher or lower than what is called for by our centralized solution. Farboodi, Jarosch, and Shimer (2021) show that in a model that is similar but lacks financial market frictions, sovereign-mandated social distancing improves over private choices, owing to negative externalities in contagion. These findings do not directly translate to our environment, because debt crises bring additional negative externalities arising from agents not internalizing that by self-quarantining they are possibly worsening the debt crisis.

cost in terms of output and consumption. Consumption is low because of the output disruptions from social distancing measures and the limited availability of international credit due to default risk. If financing opportunities are ample and default is unlikely, output disruptions would matter for consumption only through a reduction of lifetime income. Consumption would then adjust to the lower permanent income, but the period-by-period consumption decline need not necessarily mirror the contemporaneous declines in output from social distancing. Below we will highlight these effects by contrasting our setup against the case of perfect financial markets

The sovereign's problem results in decision rules for economic variables: sovereign debt $B_{t+1} = \mathbf{B_{t+1}}(\mu_t, B_t)$, partial default $d_t = \mathbf{d_t}(\mu_t, B_t)$, social distancing $L_t = \mathbf{L_t}(\mu_t, B_t)$, and consumption $c_t = \mathbf{c_t}(\mu_t, B_t)$. The problem also induces policy functions for the evolution of epidemiological variables that depend on the level of debt as well as the distribution of the population over types. Debt affects epidemiological dynamics through its impact on social distancing intensity and timing. Let the equilibrium policy functions for the evolution of measures of susceptible, infected, and recovered individuals be $\boldsymbol{\mu_{t+1}}(\mu_t, B_t)$.

The bond price schedule $q_t(\mu_{t+1}(\mu_t, L_t), B_{t+1})$ satisfies

$$q_t(\mu_{t+1}(\mu_t, L_t), B_{t+1}) = \frac{1}{1+r} \left\{ (\delta + r)(1 - \mathbf{d_{t+1}}) + \left[1 - \delta + \kappa(\delta + r)\mathbf{d_{t+1}}\right] q_{t+1}(\boldsymbol{\mu_{t+2}}, \mathbf{B_{t+2}}) \right\},$$

where future default, borrowing, and social distancing are given by equilibrium policy rules from the sovereign's problem, and they are taken as given at time t by the sovereign and its lenders—a Markov environment. The problem from period $H-1$ onward is similar to the setup described above, except that at period H all susceptible individuals become functionally immune, without a spell of infection. Appendix B provides a definition of the equilibrium.

3 Interactions between Default Risk and the Health Crisis

In this section, we simplify our model in order to characterize analytically the interactions between the default risk and the health and economic outcomes from the epidemic. We establish that the epidemic increases default risk, which in turn worsens the epidemic. Social distancing measures work as investments in lives, and default risk limits the economy's ability to tap future resources, resulting in inefficiently low investment—inefficient social distancing.[8] In sum,

8. This mechanism is linked to the literature emphasizing the impact of limited enforcement on under-investment, examples of which include Thomas and Worrall (1994) and Aguiar and Amador (2011).

default risk leads to worse health and economic outcomes from the epidemic.

The simplified model has only two periods. The economy starts without any debt $B_0 = 0$ and with initial measures of susceptible μ_0^S, infected μ_0^I, and recovered μ_0^R individuals. The value of the sovereign is over consumption and life, $[u(c_0) - \chi\phi_{D,0}] + \beta[u(c_1) - \chi\phi_{D,1}]$. In period 0, the sovereign chooses social distancing L_0, borrowing B_1, and consumption c_0. In period 1, it chooses default d_1 and consumption c_1.

Social distancing L_0 reduces new infections in period 0, thereby reducing fatalities in period 1. Specifically, we can write period 1's fatalities as $\phi_{D,1}(L_0) = \pi_D(\mu_1^I(L_0))\mu_1^I(L_0)$, with the infected mass coming from both the unresolved initial infections and the newly infected, $\mu_1^I(L_0) = \pi_I\mu_0^I + A_0(1-\theta L_0)^2\mu_0^I\mu_0^S$. We assume $\phi_{D,1}(L_0)$ is decreasing and convex in social distancing L_0, $\partial\phi_{D,1}/\partial L_0 \leq 0$ and $\partial\phi_{D,1}^2/\partial L_0^2 \leq 0$. Since the sovereign cannot alter deaths in period 0, $\phi_{D,0}$, or population in period 1, N_1, as both are pinned down by the initial level of infection and epidemiology parameters, we assume for simplicity zero initial deaths, $\phi_{D,0} = 0$. For a cleaner exposition, we also restrict attention to $\theta = \theta_Y = 1$ and $\alpha = 1$. Appendix C lays out the details of this stripped-down version of our model and the assumptions that guarantee an interior solution for partial default d_1 and social distancing L_0. In particular, we require that the output in default $\tilde{z}\gamma(d)$ is differentiable, decreasing, and concave in d.

We construct the solution to the sovereign's problem by working backwards. In period 1, the sovereign cannot borrow and only chooses partial default to weigh its marginal benefit and cost, $-\tilde{z}\gamma'(d_1) = B_1$, where $-\tilde{z}\gamma'(d_1)$ reflects the marginal cost of a higher default intensity in terms of lost production and B_1 is the marginal benefit of lowering repayment. Let the optimal default decision be $d_1(B_1) = (\gamma')^{-1}(-B_1/\tilde{z})$, with $(\gamma')^{-1}$ the inverse of the derivative of γ. Under the assumption that $\gamma(d_1)$ is concave, partial default d_1 increases with B_1. The bond price schedule in period 0 reflects these default incentives, satisfying $q_0(B_1) = \dfrac{1}{1+r}(1 - d_1(B_1))$.

In period 0, the sovereign chooses borrowing B_1 and social distance measures L_0. We derive a standard optimality condition for the borrowing choice as

$$u'(c_0) = \beta(1 + r^d(B_1))u'(c_1),$$

where $1 + r^d(B_1)$ is the *domestic interest rate*. It depends on the risk-free rate and on the elasticity of the bond price schedule with respect to borrowing $1 + r^d(B_1) = (1+r)/(1-\eta(B_1))$, where $\eta(B_1) = -\partial\ln(q_0)/\partial\ln(B_1) \geq 0$. The domestic interest rate reflects the shadow cost of borrowing and, with default risk, it is higher than the risk-free rate, $r^d(B_1) \geq r$. The consumption in period 0 is then a fraction of lifetime income that decreases with the domestic interest rate, so that

$$c_0 = \frac{1}{1 + \frac{1}{1+r}[\beta(1 + r^d(B_1))]^{1/\sigma}} \left(\tilde{z}(1 - L_0) + \frac{1}{1+r} \tilde{z}\gamma(d_1) \right), \tag{14}$$

where period 0 income $\tilde{z}(1 - L_0)$ depends on the social distancing policy and period-1 income is shaped by the default cost $\tilde{z}\gamma(d_1)$ and is discounted at the risk free rate $1 + r$.

Optimal social distancing L_0 equates the marginal cost of reducing current consumption c_0 to the marginal benefit of saving lives in period 1. Future default risk d_1 reduces lifetime income and tends to reduce current consumption c_0, which in turn increases the cost of social distancing. We capture these forces with the following optimality condition:

$$\tilde{z}u'(c_0) = \beta\chi \left(-\frac{\partial \phi_{D,1}(L_0)}{\partial L_0} \right). \tag{15}$$

The left-hand side of (15) is the marginal cost of social distancing in terms of reducing current consumption. For one extra unit of social distancing, output drops by $\tilde{z}$ units, which are worth $\tilde{z}u'(c_0)$. The right-hand side represents the marginal value of social distancing in terms of saving lives. One extra unit of social distancing reduces deaths by $(-\partial\phi_{D,1}/\partial L_0)$, which is worth $\chi(-\partial\phi_{D,1}/\partial L_0) \geq 0$, given that χ is the value of one life.

With the following propositions, we establish that the health and debt crises reinforce each other. We first show that the pandemic leads to a higher default risk in period 1.

Proposition 1 (The epidemic generates default risk)**.** *The default intensity d_1 increases following an epidemic outbreak in period 0.*

See Appendix C for the proof. The epidemic generates default risk because a desire to smooth consumption induces higher borrowing and thus a higher default risk in the future. The increased default risk worsens financial conditions in period 0. In our general model, there are two additional mechanisms that lead to more default. First, following an unexpected epidemic outbreak in the first period, social distancing measures lower the marginal cost of defaulting, and partial default increases. Second, lenders internalize poor future prospects, which tighten the bond price schedule for long-term debt. High borrowing rates further increase higher default incentives.

Next, we illustrate our second point: future default risk reduces social distancing incentives and worsens the epidemic. To show this, we introduce a reference model with perfect financial markets, in which the sovereign commits to fully repaying its debt; that is, $d_1 = 0$. We establish that the social distancing intensity in our baseline model is lower than the efficient level from the setup with perfect financial markets. With limited enforcement, the economy tends to "under-invest" in life-saving measures and ends with too many deaths.

With full commitment, the sovereign chooses consumption and social distancing to maximize its value, subject to the evolution of the epidemic and a lifetime budget constraint. The optimal social distancing in this commitment setup also satisfies equation (15). Perfect financial markets, however, allow the country to smooth consumption across time and support a higher level of consumption in period 0, c_0^e. Specifically, consumption in period 0, c_0^e, satisfies

$$c_0^e = \frac{1}{1 + \frac{1}{1+r}[\beta(1+r)]^{1/\sigma}} \left(\tilde{z}(1 - L_0^e) + \frac{1}{1+r}\tilde{z} \right),$$

where L_0^e is the social distancing policy in this case. For a given social distancing intensity L_0, consumption in period 0 is higher with perfect financial markets for two reasons. First, permanent income under perfect financial markets is higher than in the baseline model because of the absence of default costs. Second, the share of permanent income allocated for c_0 is also higher because the domestic interest rate is given by the risk-free rate r, which is lower than the one with default risk, $r^d(B_1)$. Increased consumption reduces the cost of social distancing and generates more intense social distancing in the perfect financial markets case.

Proposition 2 (Default risk worsens the epidemic)**.** *Deaths are higher with default risk than in an economy with perfect financial markets.*

See Appendix C for the proof. With default risk, the consumption cost of social distancing is higher, which results distancing measures of lower intensity. Less mitigation elevates infections and results in more deaths. Financial market conditions also affect the amount of borrowing that countries undertake at the outbreak of the epidemic, and shape their consumption levels. As established in Appendix C, default risk restricts borrowing and depresses consumption relative to its level in the model with perfect financial markets.

4 Quantitative Analysis

We now turn to the quantitative analysis of the general model, with the goal of evaluating our mechanisms and measuring how default risk shapes the economic and health outcomes of the epidemic. First, we lay out an accounting framework to measure disease transmission, and then we discuss the choice of parameters and our moment-matching exercise using Latin American data. Then, we describe the time paths of the economy and assess the extent of the health, economic, and debt crises resulting from the COVID-19 shock. To highlight the role of default risk and economic fundamentals, we compare the outcomes in our baseline with two reference models.[9] The first features perfect financial markets, and the second exhibits a protracted recession due to medium-term uncertainty over aggregate productivity.

4.1 Parameterization and Data

In order to capture the fast dynamics of infection, we set the model period to one week. We fix some parameters to values from the literature and estimate others in a moment-matching exercise. In particular, we use data from nine Latin American countries on fatalities, social distancing, sovereign debt, spreads, and consumption to set the epidemiological and default cost parameters.

To capture congestion effects in the healthcare system, we assume that the probability of dying from the virus depends on the measure of infected individuals, and parameterize $\pi_D(\mu_t^I) = \pi_{D,0} + \pi_{D,1}\,\mu_t^I$, as in Alvarez, Argente, and Lippi (2021). We choose the default cost function of Arellano, Mateos-Planas, and Ríos-Rull (forthcoming), who study partial sovereign default. The productivity cost of default is a concave function of the default intensity, $\gamma(d) = [1 - \gamma_0 d^{\gamma_1}](1 - \gamma_2 \mathbb{1}_{d>0})$, where the indicator $\mathbb{1}_{d>0}$ is 1 if d is positive.

4.1.1 Disease transmission accounting

The transmission rate of the disease in our model depends on the exogenous path of A_t, as well as the endogenous evolution of the measure of susceptible individuals and social distancing. Following Atkeson, Kopecky, and Zha (2020a), we recover A_t from data on fatalities and social distancing using our framework, in a procedure akin to the business cycle accounting approach of

9. We study the joint determination of social distancing measures and fiscal policy. In Appendix I, we disentangle these two sets of policies by considering exogenous time paths for social distancing. We do so to explore the consequences of ignoring the endogenous response of social distancing to financial market conditions.

Chari, Kehoe, and McGrattan (2007) to recover productivity and labor and capital wedges. Here we describe our accounting procedure, which we integrate in the moment-matching exercise below.

The accounting procedure requires data on weekly fatalities, $\phi_{D,t}^{\text{data}}$, social distancing, L_t^{data}, and values for five parameters $\{\pi_I, \theta, \mu_0^S, \pi_{D,0}, \pi_{D,1}\}$. The procedure has two steps. The first step uses data on weekly fatalities $\phi_{D,t}^{\text{data}}$ to infer the mass of infected $\mu_t^{I,\text{data}}$ and susceptible $\mu_t^{S,\text{data}}$ individuals each week. We do so by inverting the mapping $\phi_{D,t}^{\text{data}} = \pi_D(\mu_t^{I,\text{data}})\mu_t^{I,\text{data}}$ to recover the series of infected individuals, $\mu_t^{I,\text{data}}$. With the path of infections at hand, we can compute the evolution of the measure of susceptible individuals using its law of motion, equation (7), so that $\mu_t^{S,\text{data}} = \mu_{t-1}^{S,\text{data}} - (\mu_t^{I,\text{data}} - \pi_I \mu_{t-1}^{I,\text{data}})$, given the initial condition for μ_0^S. The second step uses data on social distancing L_t^{data} and the series $\mu^{I,\text{data}}$ and $\mu^{S,\text{data}}$ from the first step to compute the path of A_t, using equation (6):

$$A_t = \frac{\mu_{t+1}^{I,\text{data}} - \pi_I \mu_t^{I,\text{data}}}{\left[(1-\theta L_t^{\text{data}})\mu_t^{I,\text{data}}\right]\left[(1-\theta L_t^{\text{data}})\mu_t^{S,\text{data}}\right]}.$$

The outcome of this accounting procedure is that the resulting series for A_t, together with the the epidemiological block of the model, deliver *exactly* the observed series for fatalities, given empirical patterns for social distancing and a set of parameters. As we explain below, we will apply this accounting procedure within our moment-matching exercise, in which we estimate a subset of these parameters to match patterns of social distancing and other salient moments.[10]

4.1.2 Parameters set externally

We now describe the parameters set externally. According to the Centers for Disease Control and Prevention (CDC), the duration of illness is on average six days. For our weekly model, this implies a value for π_I, the parameter determining the rate at which infected individuals either recover or die from the disease, of $(1-1/6)^7 = 0.279$. The parameter controlling the effectiveness of social distancing θ is set to 0.5, following the estimates of Mossong et al. (2008). This work studies the role of social contacts for the spread of infectious diseases and reports that about half of infections occur away from the workplace, school, or travel and leisure (i.e., largely within the home). We assume that initially, 3% of individuals are recovered, and we set $\mu_0^S = 0.97$. We use

10. This estimation is similar to the one for the investment wedge in business cycle accounting, which depends on the expected path of all other wedges and the parameters.

a terminal condition at three years after the outbreak of the epidemic, $H = 156$. This terminal condition is largely irrelevant in our baseline model because "herd immunity" is reached before this three-year mark.[11]

We set the annual international risk-free rate to 1%, which is the average real rate for U.S. Treasury bills since 1985. The parameter δ is set to induce an average Macaulay debt duration of five years, in line with estimates for emerging markets. The debt recovery κ is set to 0.54, which is consistent with the evidence in Cruces and Trebesch (2013), once preemptive restructurings are excluded. We set $\tilde{z} = 1$, a normalization of pre-pandemic steady-state output to 1. For the preference parameters, we assume the flow utility over consumption has a constant relative risk aversion with a coefficient σ set to the standard value of 2. The discount factor β is set to match an average domestic real rate of 2% for emerging market inflation targeters, as reported in Arellano, Bai, and Mihalache (2020).

4.1.3 Parameters set internally

All remaining parameters are determined by a moment-matching exercise using Latin America data. The parameters set internally are the epidemiological sequence A_t, which effects the time series for the disease transmission rates, the parameters controlling death rates $\{\pi_{D,0}, \pi_{D,1}\}$, the preference parameter for the value of life χ, the social distancing output cost θ_Y, and the default cost parameters $\{\gamma_0, \gamma_1, \gamma_2\}$. We start by describing the data series and sources and then describe the moment-matching exercise we perform.

Data. We compile data for nine countries in Latin America: Argentina, Brazil, Chile, Colombia, Ecuador, Mexico, Peru, Paraguay, and Uruguay. We collect time series for COVID-19 excess fatalities and case fatality rates, social distancing, and economic aggregate series for consumption, sovereign debt, and sovereign spreads. For each measure, we construct weighted average series across countries, using the 2018 population levels as weights, and use them in our moment matching exercise.

Our measures of fatalities, case fatality rates, and social distancing are from the Institute for Health Metrics and Evaluation (2022), henceforth IHME. COVID-19 fatalities are average daily excess deaths per 100 people. Excess deaths compares total reported deaths in a week

11. Section 6 reports a robustness check over this time horizon by compiling results for terminal conditions at two and four years, respectively.

relative to deaths on the same week in previous years, adjusted for demographics. We use this excess deaths measure to account for potential under-reporting of official COVID-19 deaths in emerging markets. Case fatality rates are constructed as the ratio of estimates for COVID-19 fatalities to total infections. The IHME social distancing measure is based on Google LLC (2022) mobility data, which are constructed from cellphone mobility use and reported weekly relative to a baseline period–the beginning of 2020. We interpret these data as the share of time that individuals socially distance and map them directly to our L_t variable.

The data for consumption and sovereign debt are taken from the International Monetary Fund (2022, IFS) and CEIC (2022), which compile data from local primary sources such as each country's central bank, statistical office, and treasury department. These are quarterly real data for 2019–2021. Sovereign spreads are from Global Financial Data (2022) and consist of the EMBI+ series at a weekly frequency. Appendix D contains details on the data series, construction, and sources.

Table 2 reports summary statistics from these data. The COVID-19 epidemic has resulted in a large loss of life in Latin American. The cumulative number of fatalities by the end of 2021 was 0.27 per 100 people. Given the total population of these nine countries, these numbers imply that about 1.4 million people died from COVID-19 by the end of 2021. In terms of social distancing, our measures imply an intensity of social distancing of 68% at the peak of 2020 and 32% on average that year. In 2021 social distancing continued but at lower intensity. Sovereign debt at the onset of the epidemic was about 60% of 2019 output. In 2020, debt increased by 8%, and consumption declined by about 7%.[12] The pandemic also led to higher sovereign spreads. They increased by 5.5% upon its onset, and on average, they were 2.2% higher in 2020 than they were before the epidemic.

Moment-matching exercise. We use our disease transmission accounting procedure in our moment-matching exercise. In practice, we apply it to recover the series $\{A_0, A_1, ..., A_T\}$ from the beginning of the epidemic until the end of our dataset, the last week of 2021. Given the ongoing COVID-19 crisis, we extrapolate beyond the end of our sample by assuming that eventually A_t follows a simple path controlled by a final value A_{end} and a rate of convergence ρ, so that $A_t = \rho^{t-T} A_T + (1 - \rho^{t-T}) A_{\text{end}}$ for $t \geq T$. We jointly set nine parameters in order to target 12 moments. The parameters are the epidemiological parameters $\{\pi_{D,0}, \pi_{D,1}, A_{\text{end}}, \rho\}$, the value of

12. This modest increase in debt contrasts with the responses in advanced economies. In the G7 countries, government debt increased by close to 30% from the COVID-19 epidemic.

Table 1: Parameter Values

Parameters Set Externally	Value
Epidemiological	
Infection length π_I	0.279
social distancing effectiveness θ	0.5
Initial condition μ_0^R	0.03
Debt and Default	
Recovery factor κ	0.54
Debt duration δ	0.0037
Annual risk free rate r	1%
Preferences	
Intertemporal elasticity $1/\sigma$	0.5
Annual discounting β	0.98
Parameters Set Internally	**Value**
Epidemiological	
Value of life χ	3500
Fatality rates $\pi_{D,0}, \pi_{D,1}$	0.0061, 0.0577
Asymptotic transmission A_{end}, ρ	0.97, 0.99
Default and Social Distancing Costs	
Default $\gamma_0, \gamma_1, \gamma_2$	0.04, 1.62, 0.0178
Social distancing θ_Y	0.8

life χ, the default cost parameters $\{\gamma_0, \gamma_1, \gamma_2\}$, and the output cost of social distancing θ_Y.

We target moments of salient epidemiological and economic variables. The target epidemiological moments are the cumulative COVID-19 fatalities for 2020 and 2021, the mean case fatality rate, and the means and maxima social distancing measures for 2020 and 2021. The economic moments we target are debt to output in 2019, debt increase in 2020, consumption growth in 2020, the peak of the spread after the pandemic, and the mean spread for 2020.

All nine parameters are determined jointly, but some moments in the data are more informative for certain parameter values. The case fatality rate in the model is $\pi_{D,0} + \pi_{D,1}\mu_t^I$, and thus it is effected mainly by the fatality rate parameters $\{\pi_{D,0}, \pi_{D,1}\}$. The value of life, χ, and the output cost of social distancing, θ_Y, affect the incentives for social distancing and therefore COVID-19 fatalities. Higher value of life or lower output cost of social distancing increases social distancing and lowers fatalities. The parameters $\{\pi_{D,0}, \pi_{D,1}\}$ affect fatalities directly, as higher parameter values increase fatalities given a time series for infections, but also they endogenously lead to more social distancing and a lower mass of infected individuals, which tends to decrease fatalities. The quadratic term associated with $\pi_{D,1}$ creates an incentive for the country to prevent sharp spikes in infections, and thus it is important for the timing of social distancing measures. A higher A_{end} implies the disease is highly infectious in the long run. All else equal, this lowers the economy's incentive to engage in social distancing early on, to buy time, and it increases the eventual death toll of the epidemic.

The default cost parameters $\{\gamma_0, \gamma_1, \gamma_2\}$ govern the likelihood of default at different levels of debt and the steepness of the bond price schedule. These forces affect the average debt to output ratio, the magnitude of the increase in debt during the pandemic, and spreads. The dynamics of debt and spreads, together with social distancing policies, induce a time path for consumption.

Table 1 collects all parameter values. The estimated χ is 3500, which is consistent with the value of statistical life (VSL) estimates of Viscusi and Masterman (2017) for our Latin American countries.[13] The estimated base fatality rate $\pi_{D,0}$ is 0.0061, which is within the range used in recent papers studying COVID-19. The output cost of social distancing θ_Y equals 0.8, which implies that social distancing is quite costly for output.[14] The default cost parameters are similar to the values estimated by Arellano, Mateos-Planas, and Ríos-Rull (forthcoming) using an emerging markets panel dataset. Our parameter values imply a loss of 5.8% of productivity for full default (at $d_t = 1$).

4.1.4 Model computation and simulation

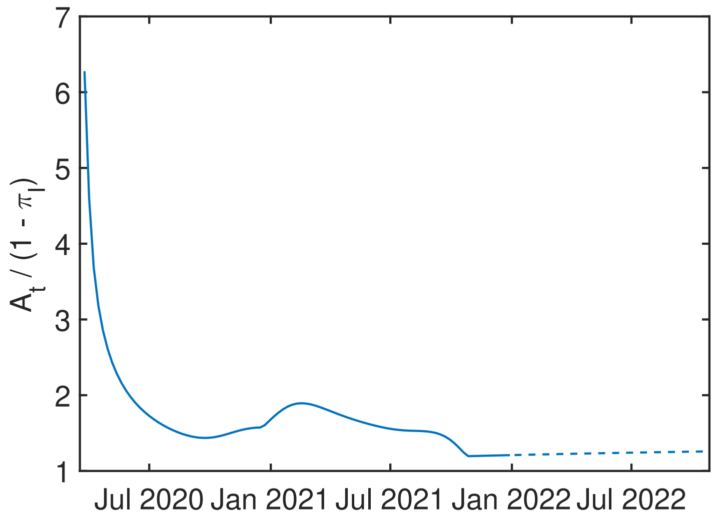
We first compute a model without epidemic dynamics. Its steady state provides initial conditions before the epidemic, and the bond price schedule and value function of this model are needed for expectations of post-pandemic behavior, at $t \geq H$. We then compute our benchmark model backwards, starting from the terminal period H, given parameters and the A_t sequences recovered by our accounting procedure. As shown in Appendix G, the period H problem is very similar to the pre-epidemic problem, as no new infections occur. The solution consists of time-dependent bond prices, policies, and value functions. These functions are solved for arbitrary values of the state space. Appendix G describes details of the computational algorithm.

For our simulation, we start from the steady state of the pre-pandemic model. In the last week of March 2020, the economy is hit unexpectedly by the COVID-19 epidemic: we introduce a small fraction of infected individuals into the population, as implied by our disease transmission

13. Appendix E details the relation between the χ parameter and such VSL estimates in the literature.

14. This is consistent with the findings of Dingel and Neiman (2020) and Saltiel (2020), who argue that only a minority of jobs can be performed at home in developing countries: at most 25%, but as low as 10% for Colombia and Ecuador.

Figure 1: The Time Path of A_t



Note: A_t is the exogenous component of the disease transmission rate implied by our disease transmission accounting procedure. We scale it by $1/(1 - \pi_I)$ to express it in terms of the basic reproduction number.

accounting. We then simulate the model forward.

We plot the estimated path of the exogenous component of the disease transmission rate A_t in Figure 1, scaled by $1 - \pi_I = 0.721$ so that the units are those of the basic reproduction number of equation (12). The figure shows that A_t was high at the beginning of the pandemic and fell over time until January 2021.[15] The series then feature a second wave, which occurs between January and April 2021, after which it falls again. This path is consistent with some features of the COVID-19 epidemic: early in the epidemic, the transmission rate was high because of the lack of information about its airborne nature and the importance of masking and ventilation for protection. Afterwards, testing and masking helped reduce the transmission rate, and these innovations are reflected in the fall of A_t during 2020.[16] There is an increase in A_t in early 2021, in line with the emergence of the contagious Delta variant of COVID-19. The decline thereafter is consistent with vaccination campaigns.[17]

Our computation recovers the policy functions for social distancing $L_t = \mathbf{L_t}(\mu_t, B_t)$, borrowing $B_{t+1} = \mathbf{B_{t+1}}(\mu_t, B_t)$, and partial default $d_t = \mathbf{d_t}(\mu_t, B_t)$, which depend on the state space and

15. Using our estimated A_t path, we can construct an effective reproduction number $\mathcal{R}_t$ (equation (12)) and find that it falls below 1 fairly quickly, by mid-2020, as in the estimation of Atkeson, Kopecky, and Zha (2020b) for a cross section U.S. states and countries.

16. In Figure 5 of Appendix F, we plot time series measures of mask-wearing, averaged over our nine Latin American countries. These two series have a strong negative correlation of -0.85, consistent with the fact that mask wearing decreases the contagiousness of the disease, given social distancing measures.

17. See Arellano, Bai, and Mihalache (2022) for a framework with financial frictions and endogenous vaccinations.

also on calendar time t due to the time variation in A_t and the horizon H. We illustrate these functions in Appendix H and show that both epidemiological states μ_t and debt B_t matter for all the decision rules. Social distancing tends to be higher with more infections and lower debt. Partial default tends to be higher with more debt and more infections. Borrowing is higher with more debt and more infections. We also illustrate that the value function and the bond price function are higher with fewer infections and less susceptible individuals, as well as lower debt.

4.2 Model Fit

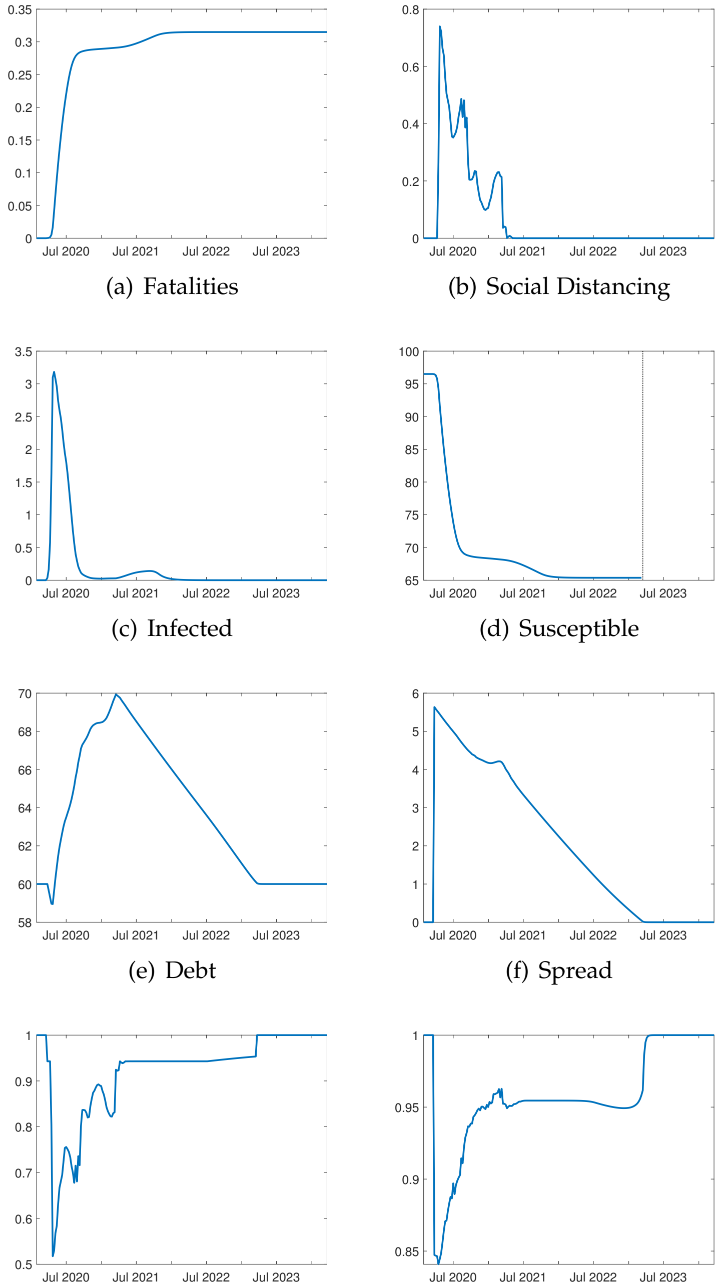
Table 2 reports the targeted data moments and compares them with their model counterparts. Data moments are listed in the first column, and model moments are in the second column. Our model matches well the observed average case fatality rate. Cumulative deaths in the model in 2021 are 0.3, which is comparable to 0.27 in the data. In the model, however, these deaths occur somewhat earlier; there are slightly too many in 2020. The model successfully generates the observed patterns of social distancing. The model generates peak and average social distancing measures in 2020 of 0.74 and 0.25, close to those observed in the data, 0.68 and 0.32. The model also mirrors the data for 2021. In terms of economic variables, the table shows that the model produces moments of debt, consumption, and sovereign spreads comparable to the data. In the model and data, the debt to output in 2019 is 60% and then increases to 68% one year into the epidemic. In the model consumption falls by 7% in 2020, as in the data. In terms of spreads, the model generates a higher average spread for 2020, yet the peak is comparable to that in the data, about 5.5%.[18]

4.3 Baseline Dynamics

We now describe the dynamics of all key variables during the epidemic. Recall that the economy is hit by the epidemic in the last week of March 2020. Figure 2 plots the time paths of epidemiological and economic variables of interest: total fatalities per 100 people, the shares of the population that are infected and susceptible; the intensity of social distancing; sovereign debt and spreads; consumption; and output. The paths are plotted through 2023. The vertical line in panel (d) marks period H, the terminal condition of the epidemic, three years after the outbreak.

18. Section 5 studies several counterfactual debt relief scenarios, which all feature lower and less persistent spreads. It is plausible that implemented or expected international assistance programs account for these lower spreads in the data.

Figure 2: Dynamics in Baseline Model



(a) Fatalities

(b) Social Distancing

(c) Infected

(d) Susceptible

(e) Debt

(f) Spread

(g) Output

(h) Consumption

Note: The measures of fatalities, infected, and susceptible individuals are expressed in percentage of population. Debt is relative to pre-pandemic output. Spread is expressed in percentage, relative to the January 2020 value. Output and consumption are reported relative to their pre-pandemic levels.

Table 2: Model Fit

	Data	Model
Epidemiological moments		
Case fatality rate average	0.64	0.62
Cumulative fatalities 2020 (per 100)	0.07	0.16
Cumulative fatalities 2021 (per 100)	0.27	0.30
Social distancing		
Peak 2020	0.68	0.74
Average 2020	0.32	0.25
Peak 2021	0.30	0.23
Average 2021	0.12	0.05
Economic moments		
Govt debt to output 2019	60.0	60.0
Govt debt increase 2020	8.0	8.4
Consumption decline 2020	−7.2	−7.2
Spread increase peak 2020	5.5	5.6
Spread increase average 2020	2.2	4.8

Notes: All data variables are population-weighted averages across nine Latin American countries. Fatalities are excess deaths, the case fatality rate is the overall average for 2020 and 2021 in percent, social distancing is from mobility measures, sovereign debt is total central sovereign debt and reported relative to output in 2019, consumption is the sum of private and public consumption reported relative to 2019, and spreads are from sovereign EMBI measures reported relative to January 2020. Model statistics and data are measured similarly. See Appendix D for more details.

Panel (a) of Figure 2 plots the evolution of fatalities μ_t^D. Our model predicts that the eventual death toll from the epidemic is 0.32% of the population, which corresponds to 1.7 million people for the Latin American countries in our data, with a total population of 525 million in 2018. Panel (b) plots social distancing L_t and shows that it increases rapidly upon the outbreak, peaking at about 74%, then gradually winds down and lasts about a year and a half. In our model, social distancing responds to the dynamics of the disease, including the time path of A_t shown in Figure 1. Social distancing has a sharp increase around March 2021 to fight the second wave of infection in the data. These social distancing measures reduce the death toll of the epidemic. At our parameter estimates, if we were to impose no social distancing measures throughout the epidemic, the epidemiological laws of motion would predict a death toll of 1.36% of the population or seven million people in the Latin American countries of our sample.

Figure 2's panels (c) and (d) plot the evolution of the measures of infected and susceptible individuals during the episode. The infected portion of the population reaches its peak of 3.1% in July 2020. The fraction of susceptible individuals falls smoothly as the epidemic progresses, until about 65% of the population is still vulnerable to infection. The dashed line in panel (d) illustrates the terminal period H, in which all the remaining susceptible individuals become immune. As we argue below, this terminal condition period comes late, as by then the brunt of infections has passed, and the economy is effectively at "herd immunity."

Panels (e) and (f) show the paths of sovereign spreads and sovereign debt scaled by pre-pandemic output. Spreads jump upon the epidemic's outbreak by about 5.6% and decrease smoothly thereafter. They increase because the epidemic is unexpected and increases default intensity. Sovereign debt grows because additional borrowing is useful to support consumption and also because the sovereign partially defaults on the debt, and defaulted payments accumulate. Debt to output increases until July 2021, when it reaches a peak of about 70% of initial output. Afterwards, debt falls, but quite slowly, as the economy converges toward the steady state late in 2023. The persistently high level of debt during the epidemic leads to a prolonged period of elevated sovereign spreads and partial default.

Finally, panels (g) and (h) in Figure 2 show the paths for output and consumption. Output falls significantly at the outset of the epidemic because of intense social distancing and by about 17% in 2020 overall. Consumption falls too, by about 15% on impact and by 7% in 2020. The consumption decline is smaller than that of output because sovereign borrowing and default support consumption. During 2021 and 2022, levels of consumption and output continue to be lower than they are in the steady state; they are about 5% below their pre-epidemic levels. Resources are scarce because of the default costs associated with the protracted debt crisis. The economy approaches the steady state again in late 2023.

4.4 Epidemic Outcomes in Emerging Markets

In this section, we compare our baseline model with two reference models in order to explore the mechanisms behind the severe pandemic outcomes and tight fiscal space in emerging markets. First, we revisit the impact of default in our quantitative model by comparing it to a setting with *perfect financial markets*. Second, motivated by forecasts of protracted depressed activity in emerging markets, we evaluate a *persistent recession* scenario under which the pandemic is accompanied by a persistent decline in productivity. This exercise is also motivated by the recent decline in growth in emerging markets and the difficulty inherent in disentangling cycle and trend, as discussed by Aguiar and Gopinath (2007).

Table 3 reports key moments for the health, debt, and economic crises, as well as measures of the welfare cost of the pandemic for the baseline and reference economies. We measure the health crisis with the total eventual fatalities per 100 people (in the percentage of the initial population)

Table 3: Epidemic Outcomes and Financial Markets

	Baseline	Perfect Fin. Markets	Persistent Recession
Health Crisis			
Fatalities (per 100)	0.315	0.087	0.320
Length (months)	32.0	40.5	31.5
Debt Crisis			
Peak debt increase	9.9	35.3	8.8
Peak spread	5.6	—	5.1
Length (months)	39.0	—	29.3
Economic Crisis			
Cumulative output loss	32.4	35.8	45.8
... from social distancing	16.6	35.8	16.2
... from default cost	16.7	—	13.0
... from low productivity	—	—	17.6
Consumption, % pre-pandemic			
2020	−7.2	−0.4	−7.0
2021	−4.6	−0.4	−6.5
2022	−4.8	−0.4	−6.0
2023	−1.0	−0.4	−5.5
2024	0.0	−0.4	−3.3
Welfare Loss (% output)			
Country	37.4	27.2	55.9
Lenders	12.9	—	12.0

Note: Fatalities are cumulative by the end of the epidemic, per 100 people. Length of the health crisis is the number of months with positive infections. Peak debt increase is the highest debt increase relative to trend debt reported relative to pre-epidemic output. Peak spread is the highest sovereign spread change post-epidemic. Length of the debt crisis is the number of months with positive partial default. Cumulative output losses are present values relative to pre-epidemic output. Consumption is the level relative to pre-epidemic trends. Welfare losses are in present value relative to pre-epidemic measures in units of annual pre-epidemic annual output: for the country, they are consumption equivalence measures (equation (16)), and for lenders, they are market values of initial debt (equation (17)).

as well as the length of the health crisis, given by the time in months until infections peter out (we use a cutoff value of $\mu_t^I \leq 10^{-6}$). The magnitude of the debt crisis is documented through the increase in debt relative to pre-pandemic output, the length of the default crisis, measured by the number of months with positive default ($d_t > 0$), and the peak in spreads during the episode. For the economic crisis, we consider output and consumption declines. We report cumulative output losses and the decomposition of these losses across social distancing, default costs, and underlying productivity. We also report the decline in consumption by year, relative to pre-pandemic levels.

Table 3 also reports welfare losses from the epidemic for both the country and its international lenders. The country suffers because of the loss of life and the decline in consumption caused by the epidemic and the debt crisis. To evaluate the country's welfare losses, we consider a consumption equivalence measure $c^{\text{eq}}(\mu_0, B_0)$ at the outbreak of the epidemic, implicitly defined by $\frac{1}{1-\beta} u(c^{\text{eq}}(\mu_0, B_0)) = V_0(\mu_0, B_0)$, where $V_0(\mu_0, B_0)$ is the value function at time $t = 0$, at the outbreak of the epidemic, the last week of March 2020. The value function V_0 reflects the subsequent streams of consumption and deaths; our consumption equivalence measure summarizes these two streams into one value, which is the constant consumption flow that equals this value in the absence of any mortality risk. Using the country's discount β, we express the welfare loss as the present value of the consumption equivalence losses:

$$\text{CE present value} = \frac{c^{\text{eq}}(\mu_0, B_0) - c^{\text{pre,eq}}(B_0)}{1-\beta}, \tag{16}$$

where $c^{\text{pre,eq}}(B_0)$ is the pre-epidemic consumption equivalence when debt is B_0.

Lenders suffer losses because the epidemic triggers a debt crisis that they did not anticipate, a drop in the value of the bonds they hold. We report these losses as the change in the value of initial debt B_0, which depends on the market price of this debt at the outset of the epidemic, $\tilde{q}(\mu_0, B_0)$ and the price of that debt pre-pandemic $q^{\text{pre}}(B_0)$ so that

$$\text{Lenders' loss} = \tilde{q}(\mu_0, B_0)B_0 - q^{\text{pre}}(B_0)B_0. \tag{17}$$

The bond price at the outset of the epidemic depends on the default decision and price of the debt at the outset and, given the structure of the bonds, satisfies the following condition:

$$\tilde{q}(\mu_0, B_0) = (1 - d_0(\mu_0, B_0))(\delta + r) + [1 - \delta + \kappa(\delta + r)d_0(\mu_0, B_0)]q_0(\boldsymbol{\mu_1}, \mathbf{B_1}), \tag{18}$$

where the states $\{\boldsymbol{\mu_1}, \boldsymbol{B_1}\}$ are given by the sovereign's decision rules, given initial conditions $\{\mu_0, B_0\}$. We also report lenders' losses in units of pre-epidemic annual output.

4.4.1 Baseline economy

Consider the outcomes in the baseline model with partial default, captured by the first column of Table 3. These statistics summarize the time paths presented in Figure 2. The epidemic results in an eventual death toll of 0.315% of the population and lasts slightly less than three years (32 months). The sovereign-debt-to-output ratio increases by 10 percentage points to support consumption, with its peak happening in 2021. The debt crisis lasts about three and a half years (39 months) with elevated spreads and partial default. The output losses from the epidemic equal 32.4% in present value; about half are due to social distancing, and the rest are from default costs. Consumption is substantially depressed, dropping over 7% in 2020 and almost 5% in the subsequent two years. By 2024 the debt crisis ends, and consumption returns to its pre-pandemic level. Table 3 reports that the welfare losses from the epidemic are significant for the country: 37.4% in terms of pre-epidemic output, which corresponds to a 0.76% drop in consumption equivalence every period. Lenders are also worse off by about 13%, owing to unexpected capital losses. The burden of the epidemic falls largely on the country.

These baseline results predict that the epidemic creates a combined health and economic crisis with a scarring effect on consumption and that the resulting debt crisis is more protracted than the health crisis itself. We now compare the results of this baseline economy with those of our two reference economies, keeping all parameters fixed.

4.4.2 Perfect financial markets

In the reference model with perfect financial markets, the economy can borrow freely at the risk-free rate and social distancing measures affect consumption only through their effect on the present value of output. In period 0, the sovereign chooses sequences of consumption $\{c_t\}$ and social distancing $\{L_t\}$ to maximize its lifetime value (1), subject to a lifetime budget constraint

$$\sum_{t=0}^{\infty} \frac{1}{(1+r)^t} N_t c_t = \sum_{t=0}^{\infty} \frac{1}{(1+r)^t} \tilde{z}[N_t(1-L_t)]^{\alpha}, \tag{19}$$

the SIR laws of motion (6) through (9), and the total population constraint (11).[19]

The epidemic outcomes for this economy are presented in the second column of Table 3. With access to perfect financial markets, the economy fares substantially better. Total deaths are sharply cut to slightly more than a quarter of those in the baseline, about 0.09% of the population. This reduction in fatalities is due to longer and more intense social distancing. Output losses in this case are 35.8%, somewhat greater than in the baseline. The main difference is that output losses in this case arise strictly because of social distancing and not because of default costs, which means the forgone output in this economy is directly linked to investment in saving lives. Debt is used aggressively to support consumption and increases by 35.3%.[20] Even so, because of perfect consumption smoothing, the impact of the epidemic on consumption is limited, taking the form of a permanent but modest 0.4% level drop relative to the pre-pandemic trend. This is in sharp contrast to the large contraction in consumption during the first three years of the pandemic in the baseline.

With perfect financial markets, the economy does not experience a debt crisis, with its associated partial default and elevated sovereign spreads. The welfare costs from the epidemic continue to be quite significant for the country, with none of the burden shared by lenders, who continue to be repaid in full. Welfare under perfect financial markets is 27.2% lower as a consequence of the epidemic. Comparing this welfare cost with the corresponding 37.4% value for the baseline suggests that default risk accounts for about 30% of the cost of the epidemic for the country in the baseline.

4.4.3 Persistent recession

For our second comparison, we evaluate how a lengthy recession interacts with default risk and alters the health and economic outcomes of the epidemic. This comparison is motivated by official forecasts of persistently low growth in emerging markets. The International Monetary Fund (2021, WEO), for example, forecasts that in 2024 output will be 6.5% below trend in Latin America, whereas output will be close to trend in advanced economies.

19. For a given B_0, we can back out long-term borrowing recursively from the per-period budget constraints using the optimal allocations as follows:

$$q^f B_{t+1} = N_t c_t + [(\delta + r) + q^f(1-\delta)]B_t + \tilde{z}[N_t(1-L_t)]^\alpha,$$

where the risk-free bond price is $q^f = 1$.

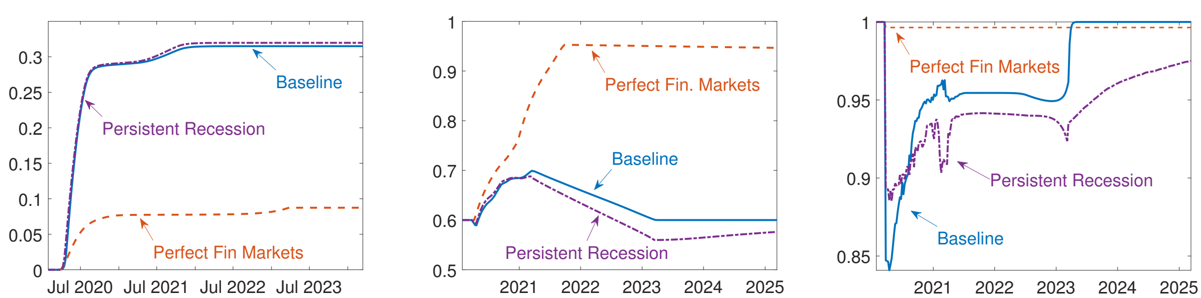
20. With perfect financial markets and $\beta(1+r) < 1$, the economy has an incentive to increase borrowing even without the epidemic. To isolate the effect of the epidemic, we report the increase in debt relative to this preexisting trend.

For this experiment, we augment our baseline model with a stochastic spell of low productivity. We assume that starting in period H, productivity falls to a level $\tilde{z}_{\text{low}}$ and then recovers permanently to the baseline productivity $\tilde{z}$ with probability p every period.[21] We set $\tilde{z}_{\text{low}} = 0.935$, a 6.5% drop based on the forecast for Latin America, and set p so that the spell of low productivity lasts for three years in expectation, a medium-term cycle.

The third column of Table 3 reports our findings for the persistent recession scenario.[22] Fiscal space is even tighter with a medium-term recession, and the country's ability to rely on borrowing to support social distancing and consumption is thus even more limited. At the outbreak of the epidemic, both the country and its lenders foresee a lengthy recession and sizable medium-term uncertainty. These bleak repayment prospects lead to even tighter bond price schedules than our baseline. In equilibrium, the country borrows less, engages in less social distancing, and suffers large welfare losses. Eventual fatalities are 1.6% higher than in the baseline, and debt to pre-pandemic output increases by 1.1% less than in the baseline.

In the persistent recession economy, the cumulative output loss exceeds 45% of annual output, about 16% from social distancing measures and 13% from default costs, both lower than the corresponding losses in the baseline, but an additional 17.6% is lost owing to the low underlying productivity. Unlike the baseline, in which consumption is back to trend by the end of 2023, the scenario with a persistent recession exhibits depressed consumption well into 2024 and beyond, as productivity is slow to recover. Welfare costs are much higher for the country and about the same for lenders in this scenario.

Figure 3: Epidemic Dynamics: Perfect Financial Markets and Persistent Recession



(a) Fatalities (b) Debt (c) Consumption

21. Due to the computationally prohibitive cost of adding uncertainty during the epidemic, we opt for introducing uncertainty following the end of the epidemic.

22. For the persistent recession model, we report moments and plots based on averaging across a large number of productivity simulations.

Dynamics. Figure 3 compares the time paths of fatalities, debt, and consumption in our baseline model with those of the two reference economies.[23] The accumulation of deaths in panel (a) illustrates that access to better financial markets can be a powerful tool to dampen the costs of the health crisis and that sovereign default risk is literally deadly for an economy facing an epidemic. These radically distinct outcomes for the evolution of deaths reflect the different social distancing policies implemented under alternative financial market conditions. The economy with perfect financial markets can support more stringent social distancing because it can use financial resources to support consumption, as illustrated by the run up in debt in panel (b).

Consumption paths are compared in panel (c). With perfect financial markets, consumption falls only to the extent called for by the decline in permanent income from temporary social distancing measures. In the baseline, consumption is severely depressed during 2020, from both social distancing and default costs. By 2022 consumption is low owing to defaults cost alone. After debt returns to its pre-pandemic level in late 2023, the default crisis ends, productivity recovers, and consumption returns to its pre-pandemic value. The persistent recession scenario exhibits a smaller drop in consumption in 2020, as social distancing policies are less aggressive than in the baseline, but consumption is consistently lower thereafter, because of both tighter bond price schedules and the impending loss of productivity. In fact, as illustrated in panel (b), the persistent recession economy chooses to cut debt below its pre-pandemic level before the drop in productivity, as financial conditions are exceptionally unfavorable.

These quantitative findings echo the theoretical results in Section 3, in which we argued that the option to default worsens the death toll of the epidemic, and in turn, experiencing an epidemic outbreak will cause spreads to spike. In contrast with the simple analytics of the two-period model of Section 3, we now emphasize the sizable magnitude of additional output losses and deaths caused by lack of commitment and the associated default. Ample access to credit and effective consumption smoothing reduce the cost of social distancing and enable aggressive mitigation of the disease. Expectations of weak economic activity make access to credit even tighter and amplify the role of default in shaping debt and consumption dynamics.

23. In Figure 3 all values are plotted relative to the corresponding levels in the absence of the epidemic.

5 Debt Relief during COVID-19

We found that the structure of debt markets has a profound impact on epidemic outcomes because the sovereign's debt burden weighs heavily on the economy's ability to mitigate infection through social distancing. International financial assistance programs, therefore, could have the potential to improve outcomes in emerging markets during an epidemic. The International Monetary Fund, the World Bank, the Inter-American Development Bank, and other international organizations implemented robust debt relief programs to support countries during the COVID-19 epidemic. The IMF made available to countries about $250 billion in loans under programs such as the Catastrophe and Containment Relief Trust, the Rapid Credit Facility, and Standby Credit Facilities. The World Bank has worked with the G20 in extending debt relief to about 40 countries through the Debt Service Suspension Initiative, and through the Common Framework, it developed further restructuring guidance for bilateral sovereign debt with official creditors.

Motivated by these programs, we use our model to conduct three counterfactual experiments for debt relief. The first program we consider is a long-term, risk-free loan from a financial assistance entity. The second program is a temporary suspension of debt service payments, motivated by the G20's Debt Service Suspension Initiative (DSSI) and the call for its extension to private creditors by Bolton et al. (2020). The final program is a voluntary restructuring program between the country and its private lenders.

We evaluate how these programs alter the epidemic implications for the health, economic, and debt outcomes, and their welfare properties. Welfare gains and losses are expressed relative to the baseline economy, and as in the previous section, in present value

$$\text{Country welfare gain} = [c^{\text{eq, program}}(\mu_0, B_0) - c^{\text{eq}}(\mu_0, B_0)]/(1-\beta) \tag{20}$$

$$\text{Lenders gain} = \tilde{q}^{\text{program}}(\mu_0, B_0)B_0 - \tilde{q}(\mu_0, B_0)B_0, \tag{21}$$

where $c^{\text{eq, program}}(\mu_0, B_0)$ is the consumption equivalence welfare and $\tilde{q}^{\text{program}}$ is the equilibrium price of the outstanding debt under each program given initial states. We find that these programs have a large positive social value because they shorten the debt crisis, help support consumption, and allow for better mitigation policies that save lives.

Table 4: Debt Relief Counterfactuals

	Loan Program			DSSI		Voluntary
	50%	60%	70%	$\kappa^{\text{DSSI}} = 1$	$\kappa^{\text{DSSI}} = \kappa$	Restructuring
Country welfare gain (% output)	6.2	7.5	7.2	0.1	10.5	6.2
Debt crisis: length reduction (months)	0.8	22.0	33.0	0.8	27.8	13.0
Debt crisis: reduction in peak spread (%)	0.9	3.6	7.3	−0.7	1.0	2.4
Health crisis: deaths prevented (% deaths)	18.9	10.6	0.1	5.8	8.0	3.4
Consumption, avg % increase, '20-'24	1.2	1.9	2.4	−0.4	1.6	1.1
Lenders gain (% output)	1.7	7.6	12.4	0.8	1.8	0.0

Note: The loan program consists of a long-term, default-free loan equivalent to 10% of pre-epidemic output. The first three columns vary the initial debt level upon the outbreak of the epidemic, when the loan is extended. The debt service suspension lasts until the end of 2021. We consider two scenarios for the capitalization of these missed payments as arrears. The voluntary restructuring program reduces the debt of the country from 60% to 54.5%. Welfare gains for the country are the change of consumption equivalence in present value from the debt relief program (20); for lenders they are the change in value of initial debt (21).

5.1 Loan Program

We model a loan program by introducing a financial assistance entity that extends a default-free loan of fixed size to the country at the outbreak of the epidemic. This program is motivated by the large number of loans that the IMF deployed during the COVID-19 era and the findings in Schlegl, Trebesch, and Wright (2019) that the IMF is the most senior lender with very few of its loans in arrears. The sovereign gets F as a lump-sum in period $t = 0$, and after a grace period g, it repays $\tilde{F}$ each subsequent period in perpetuity. The financial assistance entity discounts the future at the international rate r and breaks even, so that the terms of the loan satisfy $\tilde{F} = r(1+r)^g F$. The problem of the sovereign is identical to the one in the benchmark model, except for small alterations to the budget constraints. The constraint at the outbreak of the epidemic adds F to the resources on hand, while the budget constraints after the grace period subtract the payment $\tilde{F}$ from available resources. We evaluate the effects of a loan size of 10% of pre-epidemic output, subject to a grace period of three years.

The first three columns of Table 4 compile the outcomes under this loan program, relative to those of the baseline. We focus on the impact of the program for the debt crisis, as measured by the reduction in the length of the debt crisis and the maximum sovereign spread level, the consequences for the health crisis, as measured by the percentage of deaths prevented, and consumption gains, reported as average increases for 2020-2024 relative to the baseline. We also report welfare gains from the loan, for the country and its lenders.

We consider the effects of the program on our baseline economy, which starts with a debt to output ratio of 60%, as well as the effects of this loan for less and more indebted economies. These economies are identical to our baseline economy in terms of parameters and the epidemic shock, but they have initial debt levels B_0 of 50% and 70% of output, respectively. Table 4 shows that the loan program generates considerable welfare benefits. For the baseline, the welfare gains are 7.5%. For context, recall that the epidemic leads to a decline in welfare of 37.4% and therefore a 20% reduction in welfare costs. These benefits arise because, with the loan program, the debt crisis is shortened, spreads are lower, and consumption falls by less. The default episode is shortened by about two years, while the maximum spread in the baseline is lowered from 5.6% to about 2.0%, a reduction of 3.5%. Consumption is, on average, 1.9% higher than without the loan during the first five years. It is as much as 5% higher in 2022 but is eventually 0.1% smaller, because of the loan payments. Another channel through which the loan program benefits the country is its impact on health outcomes, as it reduces total deaths by 10.6%. Private lenders are better off with the loan program as well, as it increases the value of the outstanding debt they hold at the outbreak of the epidemic. The reduction in default losses from a smaller and shorter debt crisis increases the value of the debt for these bonds by 7.6% of pre-epidemic output. The overall social gain from the loan is a sizable 15.1%, as the country and its lenders gain and the financial assistance entity breaks even.

The loan program benefits less and more indebted economies as well. Welfare gains are smaller for economies with less initial debt, at 6.2%, and somewhat smaller for more indebted economies, at 7.2%.[24] We find that, in general, the welfare gains from the loan program are non-monotonic with respect to initial debt level: how economies choose to deploy these resources varies according to this initial indebtedness. Low debt economies face fewer difficulties in tapping debt markets and hence use most of the loan to invest in saving lives by further tightening social distancing measures. The loan allows the economy to prevent almost 19% of the deaths in the less indebted economy. In contrast, more indebted economies use the loan program mostly to alleviate the debt crisis and to support consumption. The program allows them to reduce the length of the default crisis by almost three years and maximum spreads by 7.3%. The use of the loan program for investing in life-saving social distancing versus investing in better debt crisis outcomes shapes the non-monotonicity of welfare gains as a function of initial debt. In contrast, the gains to lenders from the loan programs are monotonically increasing in the level of

24. The cost of the epidemic itself varies with the level of initial debt: the welfare cost of the epidemic is 26.3% and 47% for the economies with 50% and 70% of debt, respectively.

debt; these gains increase from 1.7% to 12.4% when the economy's initial debt rises from 50% to 70%. The reason is that the extra resources obtained via the loan program are useful for reducing the costs of the debt crisis for more indebted economies, leading to higher capital gains for the holders of the outstanding debt upon the epidemic outbreak.

Our loan program relates to the work by Hatchondo, Martinez, and Onder (2017), who augment a standard long-term debt model with an option for the sovereign to take short-term, risk-free official loans up to an exogenous borrowing limit. They find that upon the surprise introduction of this official lending option, spreads decrease and country welfare improves. However, in the long run, the impact of this program is minimal because the sovereign endogenously adjusts its risky borrowing behavior. In our model without the epidemic, the loan program features effects similar to theirs. However, with the epidemic, our program has permanent effects because the reduction in death changes the outcome of the epidemic in the long run.

The loan program considered here raises natural comparisons with the work on debt buybacks by Bulow and Rogoff (1988) and Aguiar et al. (2019). As in these papers, although the loan is not directed towards buying back the debt, in practice the economy uses it for this purpose. The country receives a relatively large amount F in the first week and uses it almost exclusively to reduce debt, in order to make use of these resources over time. We depart from these papers in that we find large benefits to the country. One reason for this result is that in our economy, the loan can be used for investment in both lives and reducing default costs. The second reason is that we consider consumption equivalence measures under concave utility, and the loan program allows consumption smoothing while production is depressed from social distancing.

5.2 Debt Service Suspension

We evaluate a temporary suspension of debt service payments in our partial default model. Under this program, we assume that at the outbreak of the epidemic, all debt service payments are suspended until the end of 2021, for 92 weeks. The country maintains market access and therefore is able to buy back or issue new bonds throughout. The suspended debt service payments are capitalized as arrears, much like the case of partial default. We consider two cases: on in which the suspended payments are fully capitalized, so that they fully accumulate at the risk-free rate $\kappa^{\text{DSSI}} = 1$, and another in which the payments are only partially capitalized at the same rate as the partial defaulted payments in the baseline, $\kappa^{\text{DSSI}} = \kappa$, with only a κ fraction becoming due in the future. In 2022 the program ends, and the country can resume debt service payments as well as having the option to partially default on these, as in the baseline.

During the suspension of debt service payments, the country's budget constraint is given by

$$N_t c_t = Y_t + q_t^{\text{DSSI}} \left[B_{t+1} - \left(1 - \delta + (\delta + r)\kappa^{\text{DSSI}} \right) B_t \right],$$

instead of (3–4), and the bond price q_t^{DSSI} satisfies

$$q_t^{\text{DSSI}} = \frac{1}{1+r} \left\{ \left[1 - \delta + (\delta + r)\kappa^{\text{DSSI}} \right] q_{t+1}^{\text{DSSI}} \right\},$$

instead of (5), with $q_t^{\text{DSSI}} = q_t$ for all periods t after the end of the program.[25]

The fourth column of Table 4 summarizes the impact of the program when suspended payments are fully capitalized, $\kappa^{\text{DSSI}} = 1$. The debt crisis is effectively delayed under this program: the country does not default during the program, but after it ends and payments are set to resume, the country begins a default episode that lasts almost as long as the one in the baseline. The change in the *timing* of the debt crisis, however, benefits the country modestly, by 0.1%, as it supports more aggressive social distancing during the epidemic outbreak, preventing 5.8% of the deaths that would occur without the program. The somewhat shorter, later debt crisis is associated with lower spreads and smaller losses for the country's initial lenders, by 0.8%. The program supports consumption early on, increasing it by 2.1% and 3.8% in the first couple of years of the epidemic, relative to outcomes without the program, but leads to lower consumption in 2023 and 2024, by about 3.5% to 4.4%, which results in an overall average decrease in consumption.

The suspension of debt service payments can have a more sizable impact if the missed payments are only partially capitalized. The fifth column of Table 4 presents the debt service suspension program with $\kappa^{\text{DSSI}} = \kappa$. Now that some of the payments are written off, the eventual debt crisis following the resumption of payments will be shorter, by over two years, and more resources will be available for the country to mitigate the health and debt crises: 8% of deaths are prevented, and the net result is a 10.5% welfare gain to the country. On average, consumption is higher with the program, with larger increases early on, 3-3.5% in 2020 and 2021. Interestingly, despite losing some of the suspended payments, lenders are also better off, by 1.8%, owing to the shorter eventual debt crisis and the country's lower issuance of additional debt during the

25. Note that we have assumed, without loss of generality, that the country lacks an option to default during the program. As payments are already suspended, partial default would have no benefits but impose costs in terms of lost productivity.

epidemic.

It is widely understood that in this class of models with incomplete markets, default is potentially welfare-enhancing because it creates ex-post contingency following shocks, albeit with downsides associated with the direct cost of default—here, the $\gamma(d_t)$ penalty to productivity. The reason why debt service suspension can be especially effective is that it replicates the benefit of default, the ex-post contingency, without any resource costs. Suspending debt service payments enhances the country's ability to weather the pandemic, even if payments are only delayed, but the program can have an especially large impact if the payments are at least in part forgiven. These findings are consistent with the results in Hatchondo, Martinez, and Sosa-Padilla (2020), who find that debt standstills are best accompanied by haircuts in a standard sovereign default model with long-term debt and no epidemic dynamics.

5.3 A Voluntary Restructuring

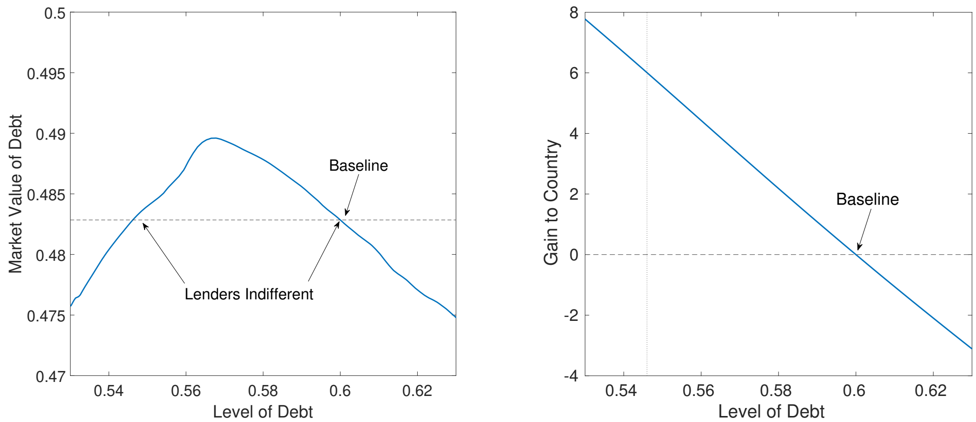
Given the severity of the pandemic-induced debt crisis, we evaluate the possibility of a voluntary restructuring program between the country and its creditors at the outset of the epidemic. Such a program occurs if both the country and its lenders agree to a reduction in the initial level of debt from B_0 to B_0^{res}. A restructuring program is always beneficial for the country because its value $V_0(\mu_0, B_0)$ is everywhere weakly decreasing in debt. its gains in our baseline model are illustrated in panel (b) of Figure 4. The pivotal question is whether lenders that hold the outstanding debt would voluntarily agree to such a reduction. In our quantitative analysis, we find that the answer is yes, because restructuring the debt sufficiently increases repayment capacity.[26]

Lenders will agree to a voluntary reduction in debt only if their value weakly increases following such a program. As discussed in Section 4.4, the value to lenders of the outstanding debt $\tilde{q}(\mu_0, B_0)B_0$ depends on its effective price at the outset of the epidemic, $\tilde{q}(\mu_0, B_0)$. The key property that makes a voluntary restructuring possible is that the price of the outstanding debt is decreasing in this level of debt. The market value of the outstanding debt, price$\times$quantity, can increase from a reduction in the level of debt, the quantity, if the unit price increases fast enough, a property reminiscent of the "Laffer curve" for borrowing exhibited by models with sovereign default risk.

We can evaluate the scope for voluntary restructuring in our quantitative model by computing

26. This reform relates to the voluntary exchange program of Hatchondo, Martinez, and Sosa-Padilla (2014), who randomly give the sovereign an opportunity to offer its lenders a voluntary restructuring program, with a size determined by Nash bargaining, in an otherwise standard long-term debt model.

Figure 4: Scope for Voluntary Restructuring of the Outstanding Debt



(a) Value to Lenders of Outstanding Debt (b) Gain to Country from Debt Reduction

the lenders' value for the outstanding debt B_0 right as the pandemic starts. Panel (a) of Figure 4 plots this value as a function of the level of initial debt B_0, both axes scaled by the pre-pandemic steady state output level. It shows that the lenders' value increases with debt up until the level of debt is about 57%, flattens out, and decreases beyond that. As a consequence, any initial debt level greater than or equal to 57% creates scope for voluntary restructuring, as lenders can gain by agreeing to such debt relief. The figure also shows that with default risk, the lenders' value for debt is quite depressed relative to its value in the case of risk-free debt. A risk-free present value of 60% is worth only 48.3%, once default is priced in. The "baseline" label points to the initial level of debt of 60% in our baseline economy. The fact that this initial level of debt is on the downward-sloping portion of the lenders' value curve gives room to voluntary restructuring: *holders of outstanding debt stand to gain from reductions in the level of debt.* The most ambitious voluntary restructuring to which lenders are willing to agree is a reduction of the country's debt to about 54.5% from the pre-pandemic steady state level of 60%. Any further reduction would make them strictly worse off, and they would not entertain it on a voluntary basis. We focus on the impact of this debt restructuring program for the country, as lenders neither lose nor gain value. As the right panel of the figure and the last column in Table 4 show, the country gains about 6.2%, more than the approximately 5.5% reduction in debt. These large welfare gains for the country reflect significant improvements in the debt and associated crises. By implementing the program, the debt crisis is shortened over one year, spreads are lowered by 2.4%, and epidemic deaths are reduced by 3.4%, while consumption can increase by 1.1% on average.

In summary, we found wide scope for international assistance in the form of official lending or debt service suspension, as well as avenues for voluntary restructuring of lenders' claims. Whether the resulting relaxation of fiscal constraints leads to better epidemic outcomes or shorter debt crises hinges largely on the country's initial conditions, chiefly its debt level at the outbreak of the pandemic. Moreover, lenders are weakly better off under all scenarios and reforms considered, relative to the sizable capital loss caused by the unforeseen epidemic outbreak.

5.4 Debt Relief for the Persistent Recession Scenario

In Section 4.4, we saw that if agents expect a lengthier recession, epidemic and welfare outcomes are substantially worse. It is instructive to briefly consider how our debt relief programs can impact such a scenario.

We find that the loan program and the debt service suspension initiative are more impactful in the persistent recession scenario than in the baseline. The loan program lowers eventual fatalities by 12.6% (compared with 10.6% in the baseline) while reducing the debt crisis by slightly over one year. Similarly, a debt service suspension with $\kappa^{\text{DSSI}} = \kappa$ prevents 9.4% of fatalities (versus 8% for baseline) while shortening the default episode by 19 months.

We found, however, no scope for voluntary restructuring in the case of a persistent recession. This is because a persistent recession results in more restricted borrowing possibilities, which endogenously shrink equilibrium borrowing, as shown in Table 3. Less borrowing results in a shorter period with partial default. As voluntary restructuring relies on the price of loans increasing enough with less debt by reducing future partial default. In the case of the persistent recession, default is endogenously reduced with the very tight borrowing schedule, leaving no room for further reduction.

6 Sensitivity Analysis

We complete our analysis by evaluating the sensitivity of our findings to alternative parameterizations of our model and key assumptions. We vary the utility cost of fatalities, the role of capacity constraints in healthcare, the length of the epidemic episode, and the unexpected emergence of new variants and "waves" of infection. Table 5 compiles these results, which we discuss below.

Table 5: Sensitivity and Alternative Scenarios

	Baseline	VSL $\chi = 3000$	Capacity $\pi_{D,1} = 0.04$	Short Event $H = 2$	Long Event $H = 4$	Unexpected Second Wave
Health Crisis						
Fatalities (% pop)	0.315	0.415	0.347	0.311	0.316	0.340
Length (months)	32.0	25.5	29.0	26.5	31.8	29.0
Debt Crisis						
Peak debt increase	9.9	5.2	7.5	10.0	9.9	9.7
Peak spread	5.6	3.6	4.6	5.7	5.2	4.3
Length (months)	39.0	23.0	31.5	40.0	39.0	37.8
Economic Crisis						
Cumulative output loss	32.4	19.7	26.1	33.1	32.3	29.9
...from soc. dist.	16.6	9.5	13.4	16.9	16.5	14.6
...from def. cost	16.7	9.7	13.4	17.2	16.7	16.2
Consumption, % pre-pandemic						
2020	−7.2	−5.0	−6.2	−7.2	−7.2	−5.3
2021	−4.6	−4.7	−4.7	−4.5	−4.6	−4.6
2022	−4.8	−0.0	−3.1	−4.7	−4.8	−4.8
2023	−1.0	0.0	0.0	−1.4	−1.0	−0.5
Welfare Loss (% output)						
Country	37.4	33.6	36.6	37.4	37.4	39.1
Lenders	12.9	8.7	11.0	12.8	12.6	10.2

6.1 The Utility Cost of Fatalities

Our moment matching exercise called for a value of $\chi = 3500$. The second column of Table 5 reports the consequences of lowering χ to 3000. In terms of the value of statistical life (VSL) and in light of the calculations in Appendix E, this change can be interpreted as a reduction in the number of residual years of life from 10 to 8.44. The main consequence of this reduction in χ is that the country is willing to tolerate 31% more fatalities. Social distancing efforts are reduced, consumption falls by less, and the debt crisis is shorter and less severe. As a result, lenders' losses are smaller, and the scope for voluntary restructuring is reduced to about half of that in the baseline.[27]

6.2 Health Care Capacity Constraints

The third column of Table 5 shows the consequences of lowering $\pi_{D,1}$ from 0.057 in our baseline parameterization to 0.04. This parameter controls the importance of the quadratic term in $\pi_D(\mu^I)$, the function that translates the stock of infections into fatalities each week. This quadratic term captures capacity constraints and congestion in health care, so that the case fatality rate is higher when there are many active infections simultaneously. Our baseline parameter value is jointly determined by moment matching but is driven mainly by the timing and size of social distancing measures. A large quadratic coefficient gives the country strong incentives to impose tight social distancing, so as to prevent a large number of simultaneous deaths and to smooth infections over time. We find that by weakening this incentive, with a lower $\pi_{D,1} = 0.04$, the country relaxes social distancing, resulting in a shorter health crisis and shallower economic and debt crises. This milder debt crisis is beneficial to the lenders and thus reduces the scope for voluntary restructuring. At the margin is country is less willing to fight the infection under looser health care capacity constraints. Cumulative fatalities increase by 10% but the country and its lenders are slightly better off, owing to the much improved economic outcomes.

6.3 The Terminal Condition

In our model, for tractability, we have imposed a terminal condition to the epidemic episode by assuming that after H periods, a highly effective vaccine or treatment becomes available. At H, the measure of susceptible individuals drops to zero, and the pandemic ends, if it did not

27. Note that because we have altered preferences, the welfare cost to the country from the pandemic is not comparable to the value in the baseline.

do so already endogenously. In the baseline, we set H so that the pandemic ends no later than three years after the outbreak and, endogenously, we find that the health crisis is shorter, so that by period H infections have already dwindled away. Even so, it is natural to ask whether H plays a key role through the expectations of agents in the model. To this end, we consider two alternative scenarios, in columns four and five of Table 5, by assuming that H is two or four years from the outbreak, respectively. Overall, results are similar to the baseline in terms of health, economic, and debt outcomes. Eventual fatalities are modestly different under a shorter pandemic. If the country expects a fully effective vaccine and treatment to become available sooner, in two years, it engages in slightly more aggressive social distancing, and fatalities drop by about 1%. Interestingly, in this case the debt crisis is much longer than the health crisis, about 15 months longer, but of about the same length as in the baseline. These findings imply that whether an epidemic terminal condition occurs two, three, or four years after the start of the epidemic matters little for the quantitative features of our results.

6.4 An Unexpected Second Wave

A salient feature of the COVID-19 epidemic has been the emergence of new virus variants, which have led to new waves of infections and fatalities. In the last column of Table 5, we report results from an extension of our model in which we allow for the unexpected emergence of such a variant. At the outbreak of the epidemic, agents in the model expect the exogenous component of the transmission rate A_t to follow the time path in Figure 1 only until early 2021 and then to decay at the rate ρ. In January 2021 we surprise them with the full realized path for A_t, with an unexpected increase in early 2021, broadly consistent with the Delta variant prevalent at the time, as reported by the World Health Organization (2022). As the country initially expects a less infectious disease, it engages in laxer social distancing throughout 2020, only to then be surprised by the second wave. The end result is marginally more modest economic and debt crises but 8% more fatalities. Ex-post welfare, based on the eventual outcomes for consumption and fatalities over time, implies a cost of 39.1% of annual output for the pandemic, compared with 37.4% in the baseline. The difference is due to the unexpected negative surprise of the new variant. If the country had foreseen it, it would have engaged in more aggressive social distancing, as in the baseline.[28]

28. The benefits of well functioning financial markets are amplified with this additional shock. We find that the welfare costs from the pandemic under perfect financial markets are very similar whether or not the second wave is expected, which is not the case in the presence of default risk.

7 Conclusion

We have studied the COVID-19 epidemic in emerging markets by integrating epidemiological dynamics in a sovereign debt model and found that doing so can replicate salient features of the data on deaths, social distancing, consumption, and sovereign debt and spreads. The pandemic is associated with many fatalities, depressed output and consumption, and worsened fiscal conditions, including partial default. With financial frictions, the death toll and severity of the debt crisis reinforce each other as social distancing becomes increasingly costly.

By comparing our model with an otherwise equivalent one with perfect financial markets, we found that slightly less than a third of the welfare cost of the pandemic episode is due to default risk. Motivated by this finding, we asked whether debt relief programs that ease financial conditions could cushion the impact of the pandemic. We find that they deliver sizable social gains that accrue mainly to the country, with no cost to financial assistance entities orchestrating the programs. In light of these results, we find that the recent debt relief policies promoted by the International Monetary Fund and other international organizations are appropriate and timely for combating the costs associated with COVID-19. We hope that our work contributes to the discussion on the optimal domestic and international policy response to epidemic outbreaks in emerging markets.

Our results relied unavoidably on several abstractions that in turn open up promising avenues for subsequent work. We did not address the decentralization of optimal social distancing measures in our model and the related question of whether the private sector alone would under- or over-provide social distancing. Note that in our setting, the private sector could depress activity excessively, as it may not internalize the effects on the fiscal conditions of the sovereign, including the resulting debt crisis. This stands in contrast with the better-understood externality whereby the private sector does not social distance enough, as agents do not internalize the role they might play in contagion and deaths in the broader economy. Finally, we conjecture that the mechanism we explored, relating financial conditions to mitigation efforts, could also operate at the individual level. For example, wealthier and financially unconstrained agents might socially distance and isolate more aggressively, while agents unable to smooth consumption through borrowing might choose to expose themselves and others to increased risk. We further suspect that such a cross-sectional pattern would be salient not only in emerging markets but in advanced economies as well.

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Appendix to "Deadly Debt Crises: COVID-19 in Emerging Markets"

by Cristina Arellano, Yan Bai, and Gabriel Mihalache

A Recursive Formulation before the Epidemic

The recursive problem for the sovereign before the epidemic resembles the one in Arellano, Mateos-Planas, and Ríos-Rull (forthcoming). We assume that the sovereign does not expect the epidemic to arise in the future, there are no fatalities, and the measure of total population remains at one throughout. We study a Markov problem for the sovereign. In period t, with debt holding B_t, the sovereign chooses new issuance ℓ_t and partial default intensity $d_t \in [0, 1]$ to solve

$$V^{\text{pre}}(B_t) = \max_{\ell_t,\, d_t \in [0,1]} u(c_t) + \beta V^{\text{pre}}(B_{t+1}), \tag{22}$$

subject to the evolution of the debt in equation (4), the resource constraint of the economy (3) with $N_t = 1$, and the bond price function $q^{\text{pre}}(B_{t+1})$. The Markov structure generates a time-invariant bond price schedule that depends on future default and borrowing decisions:

$$q^{\text{pre}}(B_{t+1}) = \frac{1}{1+r} \left\{ (\delta + r)(1 - d_{t+1}(B_{t+1})) + [1 - \delta + \kappa(\delta + r) d_{t+1}(B_{t+1})]\, q^{\text{pre}}(B_{t+2}(B_{t+1})) \right\}. \tag{23}$$

This problem induces pre-epidemic decision rules for the evolution of sovereign debt $B_{t+1} = \mathbf{B}^{\text{pre}}(B_t)$, default $d_t = \mathbf{d}^{\text{pre}}(B_t)$, and per capita consumption $c_t = \mathbf{c}^{\text{pre}}(B_t)$. It also delivers the bond price schedule $q^{\text{pre}}(B_{t+1})$ and value function $V^{\text{pre}}(B_t)$. We use these results to set terminal conditions for the following problem during the epidemic. In the baseline experiment, we use the steady state values for debt B_t from this problem as its initial condition.

B Definition of Epidemic Equilibrium

The epidemic equilibrium consists of sequences of functions for consumption $\mathbf{c_t}(\mu_t, B_t)$, the sovereign's borrowing policy $\mathbf{B_{t+1}}(\mu_t, B_t)$, default $\mathbf{d_t}(\mu_t, B_t)$, and social distancing $\mathbf{L_t}(\mu_t, B_t)$; the value function $V_t(\mu_t, B_t)$; the bond price schedule $q_t(\mu_t, B_{t+1})$; and the epidemiological laws of motion $\boldsymbol{\mu}_{t+1}(\mu_t, B_t)$ that summarize the mass of susceptible, infected, and recovered for period

$t = 0, 1, 2, ...$ such that, given the initial state (μ_0, B_0) and the availability of the vaccine in period H,

(i) For periods $t > H$, the epidemic is eliminated, $\mu_t^S = 0$, $\mu_t^I = 0$, and $\mu_t^R = \mu_H^R + \mu_H^S + (1 - \pi_{D,0}/\pi_I)\mu_H^I$ under the assumption that at period H, a fraction $\pi_{D,0}/\pi_I$ of the infected die and the rest recover. The optimal social distancing intensity is zero, $\mathbf{L_t}(\mu_t, B_t) = 0$. The sovereign's borrowing and default policies, the value function, and the bond price schedule are the same as the pre-epidemic ones, $V_t(\mu_t, B_t) = V^{\text{pre}}(B_t)$, $\mathbf{d_t}(\mu_t, B_t) = \mathbf{d}^{\text{pre}}(B_t)$, $\mathbf{B_{t+1}}(\mu_t, B_t) = \mathbf{B}^{\text{pre}}(\mu_t, B_t)$, and $\mathbf{q_t}(\mu_t, B_{t+1}) = \mathbf{q}^{\text{pre}}(B_{t+1})$.

(ii) For any period $0 \le t \le H$, taking as given the value function and the bond price schedule for period $t+1$, the sovereign's value function and policies solve

$$V_t(\mu_t, B_t) = \max_{B_{t+1},\, d_t \in [0,1],\, L_t \in [0,1]} [u(c_t) - \chi \phi_{D,t}] + \beta V_{t+1}(\mu_{t+1}(\mu_t, L_t), B_{t+1}),$$

subject to the resource constraint

$$N_t c_t + (1 - d_t)(\delta + r)B_t = \tilde{z}\phi(d_t)N_t(1 - L_t) + q_t(\mu_{t+1}(\mu_t, L_t), B_{t+1})(B_{t+1} - (1 - \delta)B_t),$$

the SIR laws of motion (6–9), fatalities $\phi_{D,t} = \pi_D(\mu_t^I)\mu_t^I$ for $t < H$ and $\phi_{D,t} = \pi_{D,0}/\pi_I \mu_t^I$ for $t = H$, and $N_t = \mu_t^S + \mu_t^I + \mu_t^R$.

(iii) For any period $t \le H$, taking as given the sovereign's policies in period $t+1$ and the epidemiological state, the bond price schedule satisfies

$$q_t(\mu_{t+1}(\mu_t, L_t), B_{t+1}) = \frac{1}{1+r}\left\{(\delta + r)(1 - \mathbf{d_{t+1}}) + [1 - \delta + \kappa(\delta + r)\mathbf{d_{t+1}}]\, q_{t+1}(\boldsymbol{\mu_{t+2}}, \mathbf{B_{t+2}})\right\}.$$

(iv) The evolution of the epidemiological state $\boldsymbol{\mu_{t+1}}(\mu_t, B_t)$ is consistent with the SIR laws of motion (6–9) and equilibrium social distancing $L_t = \mathbf{L_t}(\mu_t, B_t)$.

C Proofs

Before proceeding to the proofs of Propositions 1 and 2, we first set up the stripped-down, two-period version of the model from Section 3. The economy starts with zero debt $B_0 = 0$ and population N_0, which consists of measure μ_0^S susceptible, μ_0^I infected, and μ_0^R recovered individuals; that is, $N_0 = \mu_0^S + \mu_0^I + \mu_0^R$. In the last period, period 1, the sovereign cannot issue more debt, $B_2 = 0$.

The sovereign has limited commitment and can choose to default on its debt. With zero initial debt, the sovereign will not default in period 0. It chooses consumption (c_0, c_1) and social distancing (L_0, L_1) in both periods and borrowing B_1 and partial default $d_1 \in [0, 1]$ in period 1 to maximize its objective

$$\max \left[u(c_0) - \chi\phi_{D,0}\right] + \beta \left[u(c_1) - \chi\phi_{D,1}(L_0)\right], \tag{24}$$

subject to the budget constraints of each period,

$$\begin{aligned} N_0 c_0 &= \tilde{z} N_0 (1 - L_0) + q_0(B_1) B_1, \\ N_1 c_1 + (1 - d_1) B_1 &= \tilde{z}\gamma(d_1) N_1 (1 - L_1); \end{aligned}$$

the evolution of infected, susceptible, and recovered

$$\mu_1^I(L_0) = \pi_I \mu_0^I + A_0(1 - \theta L_0)^2 \mu_0^I \mu_0^S, \tag{25}$$

$$\mu_1^S(L_0) = \mu_0^S - A_0(1 - \theta L_0)^2 \mu_0^I \mu_0^S, \tag{26}$$

$$\mu_1^R = \mu_0^R + (1 - \pi_I)\mu_0^I - \phi_{D,0}; \tag{27}$$

the fatalities induced by infection

$$\phi_{D,1}(L_0) = \pi_D(\mu_1^I(L_0))\mu_1^I(L_0); \tag{28}$$

the evolution of total population

$$N_1 = N_0 - \phi_{D,0}; \tag{29}$$

and the bond price schedule

$$q_0(B_1) = (1 - d_1(B_1))/(1 + r). \tag{30}$$

It is easy to see that the sovereign will not impose any social distancing in the last period, $L_1 = 0$, since doing so does not affect the spread of the disease and death. The sovereign also cannot influence the death toll in period 0, $\phi_{D,0}$, nor can it influence the total population in period 1, N_1. Given that both $\phi_{D,0}$ and N_1 are determined by the initial level of infection and epidemiology parameters, we assume for simplicity that $\phi_{D,0} = 0$.

In the stripped-down version of the model, we make the following assumptions to guarantee interior solutions to partial default $d_1 \in [0,1]$ and social distancing $L_0 \in [0,1]$ to better illustrate the interaction mechanism between the health and debt crisis. These assumptions are relaxed in the general model.

Assumptions

1. The discount factor is such that $\beta(1+r) \leq 1$. The social distancing effectiveness takes the value of 1, $\theta = 1$. The case fatality rate is constant, $\pi_D(\mu_0^I) = \pi_{D,0}$. The value of life χ satisfies
$$\chi \geq \frac{\tilde{z}^{1-\sigma}}{2\beta\pi_{D,0}A_0\mu_0^I\mu_0^S}\left(1+\frac{1}{1+r}\right)^{-\sigma}\lambda^{-\sigma},$$
where $\lambda = \left[1+\beta^{\frac{1}{\sigma}}(1+r)^{\frac{1-\sigma}{\sigma}}\right]^{-1} < 1$.

2. The function $\gamma : [0,1] \to \mathbb{R}$ is differentiable, decreasing $\gamma' < 0$, concave $\gamma'' < 0$, and with $\gamma(0) = 1$ and $\gamma'(0) = 0$.

3. Let $\bar{d}$ be the maxima of the function $f(d) = -(1-d)\gamma'(d)$. We assume $f(\bar{d}) \geq \lambda$.

Note that Assumption 2 implies $\gamma'(d)$, and so $f(d)$ are continuous functions. By the maximum theorem, there exists a $\bar{d} \in [0,1]$ that maximizes the f function. Furthermore, $f(0) = f(1) = 0$, since $\gamma'(0) = 0$. It has to be the case that $0 < \bar{d} < 1$.[29]

C.1 Proof of Proposition 1

Proof. We start with the baseline's equilibrium conditions under the assumption of interior solutions for default and social distancing. We then verify that Assumptions 1-3 guarantee that the solution is indeed interior. The equilibrium default, borrowing, consumption, and social

29. An example of γ function satisfying assumptions 2 and 3 is $\gamma(d) = 1 - \gamma_0 d^{\gamma_1}$ with $\gamma_1 > 1$ and $\gamma_0 \geq \lambda((\gamma_1 - 1)/\gamma_1)^{1-\gamma_1}$. In this case, $\gamma'(d) < 0$, $\gamma''(d) < 0$, $\gamma(0) = 1$, and $\gamma'(0) = 0$. The maximum is $\bar{d} = (\gamma_1 - 1)/\gamma_1$ with $0 < \bar{d} < 1$. At the maximum, $f(\bar{d}) \leq \lambda$, since $\gamma_0 \geq \lambda((\gamma_1 - 1)/\gamma_1)^{1-\gamma_1}$.

distancing, $\{d_1, B_1, c_1, c_0, L_0\}$, satisfy the following five equations:

$$-\tilde{z}\gamma'(d_1)N_1 = B_1, \tag{31}$$

$$u'(c_0) = \beta(1 + r_d(B_1))u'(c_1), \tag{32}$$

$$N_1 c_1 + (1 - d_1)B_1 = \tilde{z}\gamma(d_1)N_1, \tag{33}$$

$$c_0 = \frac{1}{1 + \frac{1}{1+r}[\beta(1 + r_d(B_1))]^{1/\sigma}} \left(\tilde{z}(1 - L_0) + \frac{1}{1+r}\tilde{z}\gamma(d_1) \right), \tag{34}$$

$$\tilde{z}u'(c_0) = \beta\chi \left(-\frac{\partial \phi_{D,1}(L_0)}{\partial L_0} \right), \tag{35}$$

where $1 + r_d(B_1) = (1 + r)/(1 - \eta(B_1))$ is the domestic interest rate, with $\eta(B_1)$ defined as the elasticity of bond price with respect to borrowing $\eta(B_1) = -\partial \ln(q_0)/\partial \ln(B_1) \geq 0$. Equation (31) is the first order condition on partial default d_1 in period 1; equation (32) is the Euler equation for borrowing B_1; equation (33) is period 1's budget constraint; equation (34) results from the sum of budget constraints in both periods and the Euler equation (32); and equation (35) comes from the first order condition for social distancing.

Using equations (31)-(34), we can show that d_1 satisfies the following equation for any social distancing level L_0:

$$M(d_1; L_0) \equiv -(1 - d_1)\tilde{z}\gamma'(d_1) - \left\{ \frac{\tilde{z}\gamma(d_1)}{1 + \frac{1}{1+r}[\beta(1 + \tilde{r}_d(d_1))]^{1/\sigma}} - \frac{[\beta(1 + \tilde{r}_d(d_1))]^{1/\sigma}\tilde{z}(1 - L_0)}{1 + \frac{1}{1+r}[\beta(1 + \tilde{r}_d(d_1))]^{1/\sigma}} \right\} = 0, \tag{36}$$

where $\tilde{r}_d(d_1)$ is the domestic interest rate after incorporating the optimal condition of d_1 (31) and the bond price schedule (30); that is,

$$\tilde{r}_d(d_1) = \frac{1 + r}{1 - \frac{\gamma'(d_1)}{\gamma''(d_1)(1 - d_1)}} \geq 1 + r.$$

Let the solution to equation (36) be $d_1 = H_d(L_0)$. We first verify that for any L_0, partial default is interior; that is, $0 < d_1 < 1$. When $d_1 = 0$,

$$M(0; L_0) = -\tilde{z} \left\{ \frac{1 - [\beta(1 + r)]^{1/\sigma}(1 - L_0)}{1 + \frac{1}{1+r}[\beta(1 + r)]^{1/\sigma}} \right\} < 0,$$

which holds as $\gamma'(0) = 0$, $\gamma(0) = 1$ and $\beta(1+r) < 1$ by assumptions 2 and 1. When $d_1 = \bar{d}$,

$$M(\bar{d}; L_0) = \tilde{z} f(\bar{d}) - \left\{ \frac{\tilde{z}\gamma(\bar{d})}{1 + \frac{1}{1+r}[\beta(1+r_d(\bar{d}))]^{1/\sigma}} - \frac{[\beta(1+r_d(\bar{d}))]^{1/\sigma}\tilde{z}(1-L_0)}{1+\frac{1}{1+r}[\beta(1+r_d(\bar{d}))]^{1/\sigma}} \right\}$$
$$\geq \tilde{z} f(\bar{d}) - \tilde{z} \left\{ \frac{1}{1+\frac{1}{1+r}[\beta(1+r)]^{1/\sigma}} \right\} = \tilde{z}[f(\bar{d}) - \lambda] \geq 0.$$

The first inequality holds because $\gamma(\bar{d}) \leq \gamma(0) = 1$, $r_d(\bar{d}) \geq r$, and $[\beta(1+r_d(\bar{d}))]^{1/\sigma}\tilde{z}(1-L_0) \geq 0$. The last inequality holds because of Assumption 3. By the intermediate value theorem, for any L_0, there exists an interior partial default $0 < d_1 \leq \bar{d} < 1$ such that $M(d_1; L_0) = 0$.

The equilibrium without an epidemic satisfies equations (31)-(34) with $L_0 = 0$, since there is no benefit to locking down without an outbreak. Namely, the equilibrium consumption, borrowing and default with an epidemic are the same as those without an epidemic if the optimal social distancing level is zero. Hence, we need to prove that for any optimal social distancing level $L_0 > 0$, the corresponding d_1 is also higher; that is, $\partial H_d(L_0)/\partial L_0 \geq 0$.

We now show the partial default is higher with epidemic:

$$\frac{\partial H_d}{\partial L_0} = -\frac{\partial M/\partial L_0}{\partial M/\partial d_1} \geq 0.$$

The inequality holds because $\partial M/\partial L_0 \leq 0$ and $\partial M/\partial d_1 \geq 0$ for $d_1 \leq \bar{d}$. Hence, the optimal default with an epidemic is higher than default without one, owing to positive social distancing.

□

C.2 Proof of Proposition 2

Proof. Under perfect financial markets, the sovereign commits to repay its debt and chooses consumption (c_0, c_1) and social distancing (L_0, L_1) to maximize its objective (24), subject to the lifetime budget constraint

$$N_0 c_0 + \frac{1}{1+r} N_1 c_1 = \tilde{z} N_0 (1 - L_0) + \frac{1}{1+r} \tilde{z} N_1 (1 - L_1),$$

fatalities (28), SIR laws of motion (25–27), and the evolution of population (29). Recall that we assume $\phi_{D,0} = 0$, and so $N_1 = N_0$. In this case, we can back up the optimal borrowing from period 0's budget constraint $B_1 = (1+r)[N_0 c_0 - \tilde{z} N_0 (1 - L_0)]$. Let the optimal consumption and social distancing under perfect financial markets be (c_0^e, c_1^e, L_0^e). Similarly, as in (34) in the baseline, consumption c_0 is a share of the lifetime income:

$$c_0^e = \frac{1}{1+\frac{1}{1+r}[\beta(1+r)]^{1/\sigma}} \left(\tilde{z}(1-L_0^e) + \frac{1}{1+r}\tilde{z} \right). \tag{37}$$

The optimal social distancing L_0^e weights the marginal benefit and cost as in (35). Plugging in the optimal consumption c_0^e into (35), we find the equation characterizing optimal social distancing under perfect financial markets:

$$\left(\frac{\tilde{z}(1-L_0) + \frac{1}{1+r}\tilde{z}}{1+\frac{1}{1+r}[\beta(1+r)]^{1/\sigma}} \right)^{-\sigma} \tilde{z} = 2\beta\chi\pi_D^0 A_0 \mu_0^I \mu_0^S (1-L_0), \tag{38}$$

where the right-hand side is the marginal benefit of social distancing—that is, $\beta\chi\left(-\frac{\partial\phi_{D,1}(L_0)}{\partial L_0}\right)$. According to Assumption 1, the left-hand side is lower than the right-hand side when $L_0 = 0$, and the left-hand side is higher than the right-hand side when $L_0 = 1$. Hence, by the intermediate value theorem, the optimal L_0^e is between 0 and 1.

Similarly, plugging in the consumption (34) and default intensity (31) into the first order condition for social distancing (35), we can show that the optimal social distancing in our baseline satisfies

$$\left(\frac{\tilde{z}(1-L_0) + \frac{1}{1+r}\tilde{z}\gamma(d_1)}{1+\frac{1}{1+r}[\beta(1+\tilde{r}_d(d_1))]^{1/\sigma}} \right)^{-\sigma} \tilde{z} = 2\beta\chi\pi_{D,0} A_0 \mu_0^I \mu_0^S (1-L_0). \tag{39}$$

As in the perfect financial markets case, there is an interior solution for social distancing. It is easy to show that under $d_1 = 0$, the optimal social distancing in our baseline is the same as the one from perfect financial markets L_0^e. However, with $d_1 > 0$, for the same level of L_0, the left-hand side of (39) becomes larger than that of (38) owing to both lower $\gamma(d_1)$ and a higher domestic interest rate $\tilde{r}_d(d_1)$ in the baseline model. Hence, the marginal benefit of locking down is smaller as long as $d_1 > 0$, which leads to a lower social distancing level than L_0^e. In summary, the social distancing level in our baseline is equal to or lower than L_0^e. With lower social distancing, the death toll $\phi_{D,1}$ is higher in our baseline model. □

C.3 Lower Consumption and Borrowing under Default Risk

We can show that both consumption and borrowings under default risk are lower than those under perfect financial markets in period 0.

Let's first consider the consumption under the perfect financial market. Plugging the optimal social distancing condition (35) into equation (37), the efficient consumption at period 0, we can further write

$$c_0^e = \left[2\beta\chi\pi_D^0 A_0 \mu_0^I \mu_0^S/\tilde{z}\right]^{-\frac{1}{\sigma}} (1 - L_0^e)^{-\frac{1}{\sigma}}. \tag{40}$$

Similarly, consumption under default risk satisfies

$$c_0 = \left[2\beta\chi\pi_D^0 A_0 \mu_0^I \mu_0^S/\tilde{z}\right]^{-\frac{1}{\sigma}} (1 - L_0)^{-\frac{1}{\sigma}}. \tag{41}$$

Comparing the two consumption equations (40) and (41), we see that economies with lower social distancing also have lower consumption. According to Proposition 2, social distancing is lower with default risk; that is $L_0 < L_0^e$. Hence, consumption is lower when there is default risk.

We can also back up the optimal borrowing from period 0's budget constraint,

$$B_1 = (1+r)N_0 \left[c_0 + \tilde{z}L_0 - \tilde{z}\right].$$

It is also easy to see that borrowing is lower with default risk as the economy has lower consumption and social distancing.

D Data Sources

Owing to data availability, we consider nine Latin American countries: Argentina, Brazil, Chile, Colombia, Ecuador, Mexico, Peru, Paraguay, and Uruguay.

Health and mobility data. Our data on health and mobility come from the Institute for Health Metrics and Evaluation (2022) at a daily frequency. The variables of interest include mobility, masking (percentage of the population reporting always wearing a mask when leaving home), daily excess deaths, and infection fatality rates. The infection fatality rate corresponds to the case fatality rate in our model. We time aggregate to a weekly frequency by averaging daily observations within each week, except for excess deaths, which we sum. We then take the weighted average of each series for our nine Latin American countries, using the 2018 population as weights.

National Accounts. We collect quarterly real, seasonally adjusted national accounts data of all nine countries to construct growth statistics. The International Monetary Fund (2022, IFS) reports real national accounts data for Argentina, Brazil, Chile, Colombia, Ecuador and Mexico. The national accounts data for the other 3 countries (Paraguay, Peru and Uruguay) are obtained from the CEIC (2022) Global Database.

First, we construct the annual growth rate of consumption in each country. Specifically, we calculate the growth rate of c_{it} in 2020 and 2021, relative to 2019. Considering each country features a different growth level during the pre-pandemic period, we further calculate the annual growth in real GDP for each country, using the growth data reported by the International Monetary Fund (2021, WEO). We then construct the detrended annual growth as the deviation from the potential growth path. Denote the pre-pandemic growth rate of country i as $\bar{g}_i^y$. The detrended growth path is given as

$$g_{i,2020}^y = \ln\left(y_{i,2020}\right) - \ln\left(y_{i,2019}\right), \quad \bar{g}_{i,2000}^y \quad = \frac{1 + g_{i,2020}^y}{1 + \bar{g}_i^y} - 1.$$

Second, we calculate quarterly population-weighted average growth for each quarter after 2020, relative to the 2019 average $y_{i,2019}$. Corresponding to the detrended annual growth, we also construct the detrended quarterly growth for each country and then take the population-weighted average of the detrended quarterly growth.

Spreads. We collect the emerging markets bond index (EMBI) data for all nine countries from JP Morgan Chase. The raw EMBI data are at daily frequency, so we first time aggregate up to weekly frequency by keeping the observed EMBI for the first day of each week as that week's value. Second, we take the population-weighted average of EMBI as the aggregate spread series.

E Value of Statistical Life χ

The magnitude of our χ parameter, which controls the welfare loss caused by fatalities in our weekly model, can be mapped to standard VSL estimates, like those in Viscusi and Masterman (2017), using the following procedure.

Take for example the value they report for Brazil of 1.695 million US dollars (2015 real dollars) for 40 years of residual life. Using our risk-free rate (r) we can express it as a weekly flow f, which solves

$$1.695 \times 10^6 = \frac{1 - 0.9996^{40 \times 52}}{1 - 0.9996} f, \tag{42}$$

where $0.9996 \approx 1/(1+r)$ weekly and $40 \times 52 = 2080$ weeks of residual life. We find $f = 1200$, which implies a willingness to pay \$1.2 to reduce the probability of death by 0.1%. Using consumption data from the World Bank, we find that \$1.2 is equivalent to 0.85% of weekly consumption in 2015 real dollars. We then use the functional form assumption on $u(c)$, and the subjective discount factor (β) to solve for the implied χ, based on 10 years of residual life lost by each COVID-19 fatality:

$$\frac{1-\beta^{10\times 52}}{1-\beta}u(1) - 0.001\chi = \frac{1-\beta^{10\times 52}}{1-\beta}u(1-0.0085). \tag{43}$$

This computation implies that, if we were to set χ according to the estimates for Brazil alone, the data would call for a value of 4073. When repeated for each country in our sample and then averaged using 2018 population as weights, the corresponding value is 3788, only slightly higher than the $\chi = 3500$ selected by our moment-matching exercise.

F Exogenous Disease Transmission Rate A_t

As described in Section 4.1, we recover the time series from A_t using an accounting procedure from data on fatalities and as part of our moment-matching exercise. The variation in A_t is exogenous to the model, and we view it as arising from virus variants, seasonality effects, and interventions other than social distancing practices, such as masking.

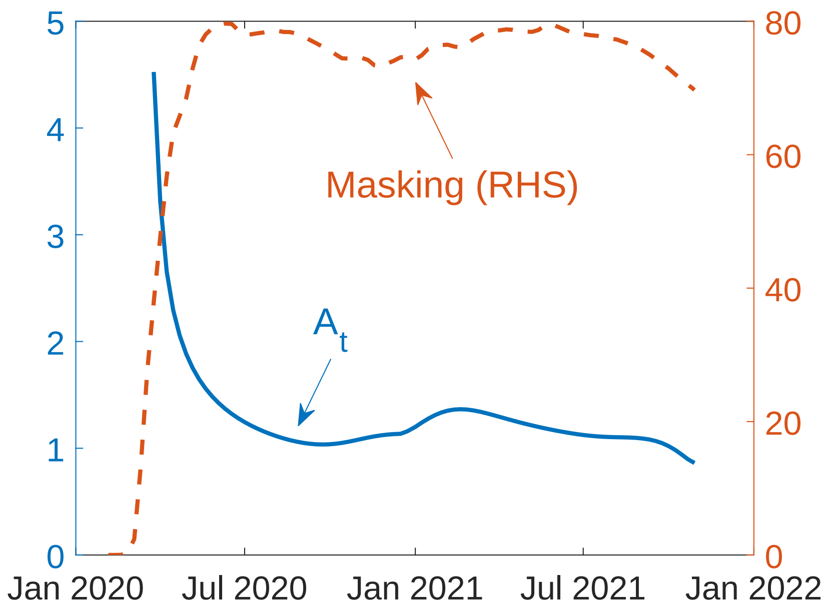
Figure 5 plots the estimated series A_t, together with the masking patterns in the 9 Latin American countries we consider. Masking data are from the IHME and measured as the percentage of the population that say that they always wear a mask when going out in public. These series are highly negatively correlated, with a correlation equal to -0.85.

We are reassured that the estimated time series for A_t display patterns that are correlated with masking patterns and feature an increase in disease transmission in early 2021 that can be attributed to the Delta variant.

G Computational Algorithm

In this appendix, we describe the computation of our model. We augment the original problem with taste shocks on the choice of debt B_{t+1}, following Dvorkin et al. (2021), and then we lay out the computation algorithm, which solves backwards in time for value and policy functions. The

Figure 5: Exogenous Component of Disease Transmission (A_t) and Masking



taste shock for the choice of B_{t+1} enhances numerical stability and the convergence properties of our model with long-term, defaultable debt. The set of B is discrete, and each element in the set is associated with an iid taste shock, distributed Gumbel (Extreme Value Type I). The parameter controlling the magnitude of taste shocks is ρ_B.[30]

Model with Taste Shocks. For the purposes of this appendix, we switch the state from $(\mu_t^S, \mu_t^I, \mu_t^R)$, the one in the main text, to $(\mu_t^S, \mu_t^I, \mu_t^D)$. Given that the sum of the four group is always 1, $\mu_t^S + \mu_t^I + \mu_t^R + \mu_t^D = 1$, the two formulations are equivalent. With slight abuse of notation, we use $\mu_t = (\mu_t^S, \mu_t^I, \mu_t^D)$ as the SIR state variable. The sovereign's problem becomes

$$W_t\left(\mu_t, B_t, B_{t+1}\right) = \max_{L_t, d_t} \; u(c_t) - \pi_D(\mu_t^I)\mu_t^I + \beta V_{t+1}\left(\mu_{t+1}(\mu_t, L_t), B_{t+1}\right), \tag{44}$$

subject to the resource constraint and the SIR laws of motion

$$c_t = \tilde{z}\phi(d_t)(1 - L_t) + \frac{\left\{B_{t+1} - \left[1 - \delta + \kappa(\delta + r)d_t\right] B_t\right\} q_t(\mu_{t+1}(\mu_t, L_t), B_{t+1}) - (\delta + r)(1 - d_t)B_t}{1 - \mu_t^D} \tag{45}$$

30. Other recent applications of discrete choice methods to sovereign default settings include Gordon (2019) and Mihalache (2020), among others.

$$\mu_t^x = A_t(1-\theta L_t)^2 \mu_t^{\text{pre}} \mu_t^I \tag{46}$$

$$\mu_{t+1}^{\text{pre}} = \mu_t^{\text{pre}} - \mu_t^x \tag{47}$$

$$\mu_{t+1}^I = \pi_I \mu_t^I + \mu_t^x \tag{48}$$

$$\mu_{t+1}^D = \mu_t^D + \pi_D(\mu_t^I)\mu_t^I. \tag{49}$$

Let the optimal default and social distancing choices be $d_t(\mu_t, B_t, B_{t+1})$ and $L_t(\mu_t, B_t, B_{t+1})$, respectively. The choice probabilities over B_{t+1} are given by

$$Pr\left(B_{t+1}|\mu_t, B_t\right) = \frac{\exp((W_t(\mu_t, B_t, B_{t+1}) - \overline{W}_t(\mu_t, B_t))/\rho_B)}{\sum_{\tilde{B}_{t+1}} \exp((W_t(\mu_t, B_t, \tilde{B}_{t+1}) - \overline{W}_t(\mu_t, B_t))/\rho_B)},$$

where $\overline{W}$ is the maximum option net of taste shocks, $\overline{W}_t(\mu_t, B_t) = \max_{B_{t+1}} W_t(\mu_t, B_t, B_{t+1})$. The value V, in expectation over taste shocks, satisfies

$$V_t(\mu_t, B_t) = \overline{W}_t(\mu_t, B_t) + \rho_B \log\left\{\sum_{B_{t+1}} \exp \frac{W_t(\mu_t, B_t, B_{t+1}) - \overline{W}_t(\mu_t, B_t)}{\rho_B}\right\}.$$

We write the bond price schedule for any choices (L_t, B_{t+1}) in state μ_t as

$$\begin{aligned} q_t\left(\mu_{t+1}, B_{t+1}\right) = & \frac{1}{1+r}\sum_{B_{t+2}} \Pr\left(B_{t+2}|\mu_{t+1}, B_{t+1}\right) \times \\ & \left\{(\delta+r)(1-d^*_{t+1}) + \left[1-\delta+\kappa(\delta+r)d^*_{t+1}\right] q_{t+1}\left(\mu_{t+2}(\mu_{t+1}, L^*_{t+1}), B_{t+2}\right)\right\}, \end{aligned}$$

where $d^*_{t+1} = d_{t+1}(\mu_{t+1}, B_{t+1}, B_{t+2})$ and $L^*_{t+1} = L_{t+1}(\mu_{t+1}, B_{t+1}, B_{t+2})$ and equilibrium policies evaluate at the relevant future state.

Computational Algorithm. Note that in period t, the state variable μ_t^D affects the period t allocation only through the per-capita debt burden $B_t/(1-\mu_t^D)$ and per-capita borrowing $B_{t+1}/(1-\mu_t^D)$. In particular, μ_t^D does not affect current or future losses from death. At our benchmark SIR parameters, the eventual death toll is less than .4%, and hence its impact on per capita debt is small. Therefore, we approximate the original problem with a simplified one with SIR state variables restricted to (μ_t^S, μ_t^I) and rewrite the resource constraint as

$$c_t = \tilde{z}\phi(d_t)(1-L_t)^\alpha + \left\{B_{t+1} - \left[1-\delta+\kappa(\delta+r)d_t\right]B_t\right\} q_t(\mu_{t+1}(\mu_t, L_t), B_{t+1}) - (\delta+r)(1-d_t)B_t. \tag{50}$$

We verified that the simplified problem approximates well the original one. This simplification, however, reduces the state space by one variable and dramatically saves computation time.

We first solve the stationary equilibrium, which both is the solution for the pre-epidemic equilibrium and governs behavior after period H. We then solve backwards over time the equilibrium under SIR dynamics.

1. Stationary equilibrium

   (a) Guess value function $V^{\text{pre}}(B)$ and bond price schedule $q^{\text{pre}}(B')$.

   (b) For each (B, B'), solve for the optimal default decision. We find the solution d^* of the following first order condition for partial default,

   $$-\tilde{z}\phi'(d) = (\delta + r)B\left[1 - \kappa q^{\text{pre}}(B')\right].$$

   Evaluate the consumption per capita c from the resource constraint

   $$c = \tilde{z}\phi(d) + \left\{B' - [1 - \delta + \kappa(\delta + r)d]\, B\right\} q^{\text{pre}}(B') - (\delta + r)(1 - d)B$$

   at three default choice levels, $d = \{d^*,\ 0,\ 1\}$, and pick the default intensity that results in the highest consumption per capita under (B, B'). Let the optimal default be $d^{\text{pre}}(B, B')$ and the corresponding consumption be $c^{\text{pre}}(B, B')$.

   (c) Compute the flow value from (B, B') at the optimal default intensity $d^{\text{pre}}(B, B')$. Then, we evaluate $W^{\text{pre}}(B, B') = u(c^{\text{pre}}(B, B')) + \beta V^{\text{pre}}(B')$.

   (d) Calculate the probability of choosing each B',

   $$\Pr\left(B'|B\right) = \frac{\exp((W^{\text{pre}}(B, B') - \overline{W}^{\text{pre}}(B))/\rho_B)}{\sum_{\tilde{B}'} \exp((W^{\text{pre}}(B, \tilde{B}') - \overline{W}^{\text{pre}}(B))/\rho_B)},$$

   and the maximum W^{pre} for each B, $\overline{W}^{\text{pre}}(B) = \max_{B'} W^{\text{pre}}(B, B')$.

   (e) Update $V^{\text{pre}}(B)$; $V^{\text{pre}}(B) = \overline{W}^{\text{pre}}(B) + \rho_B \log\left\{\sum_{B'} \exp \frac{W^{\text{pre}}(B,B') - \overline{W}^{\text{pre}}(B)}{\rho_B}\right\}$.

   (f) Update the bond price schedule $q^{\text{pre}}(B')$,

   $$q^{\text{pre}}\left(B'\right) = \frac{1}{1+r}\sum_{B''} \Pr\left(B''|B'\right)\{(\delta + r)(1 - d(B', B''))$$
   $$+ \left[1 - \delta + \kappa(\delta + r)d^s(B', B'')\right] q^{\text{pre}}\left(B''\right)\}.$$

(g) Check whether V^{pre} and q^{pre} converged. If both did, stop; otherwise, go back to step 1(b).

2. Period H problem (terminal condition)

   In period H all susceptible individuals are marked as recovered; a fraction $\pi D, 0/\pi_I$ of the infected dies, while the rest recover:

$$W_H\left(\mu_H, B_H, B_{H+1}\right) = \max_{d_H}\left\{u(c_H) - \left[\frac{\pi_{D,0}}{\pi_I}\right]\mu_H^I\chi + \beta V^{\text{pre}}\left(B_{H+1}\right)\right\}, \tag{51}$$

   subject to the resource constraint (50). Let the solution be $V_H^{\{0\}}(\mu_H, B_H)$, $d_H^{\{0\}}(\mu_H, B_H, B_{H+1})$, $Pr^{\{0\}}\left(B_{H+1}|\mu_H, B_H\right)$, $q_H^{\{0\}}(\mu_{H+1}, B_{H+1})$, and $L_H^{\{0\}}(\mu_H, B_H, B_{H+1}) = 0$.

3. Period $0 \leq t < H$ problem

   (a) Start with $q_{t+1}^{\{0\}}(\mu_{t+2}, B_{t+2})$, $d_{t+1}^0(\mu_{t+1}, B_{t+1}, B_{t+2})$, $L_{t+1}^0(\mu_{t+1}, B_{t+1}, B_{t+2})$, $Pr^{\{0\}}\left(B_{t+2}|\mu_{t+1}, B_{t+1}\right)$, and $V_{t+1}^{\{0\}}(\mu_{t+1}, B_{t+1})$.

   (b) Construct bond price $q_t^{\{1\}}\left(\mu_{t+1}, B_{t+1}\right)$:

$$\begin{aligned} q_t^{\{1\}}\left(\mu_{t+1}, B_{t+1}\right) = \frac{1}{1+r}\sum_{B_{t+2}} \Pr^{\{0\}}\left(B_{t+2}|\mu_{t+1}, B_{t+1}\right)\Big\{(\delta+r)(1-d_{t+1}^{\{0\}}) \\ + \left[1-\delta+\kappa(\delta+r)d_{t+1}^{\{0\}}\right] q_{t+1}^{\{0\}}\left(\mu_{t+2}(\mu_{t+1}, L_{t+1}^{\{0\}}), B_{t+2}\right)\Big\}, \end{aligned}$$

   where $d_{t+1}^{\{0\}} = d_{t+1}^{\{0\}}(\mu_{t+1}, B_{t+1}, B_{t+2})$ and $L_{t+1}^{\{0\}} = L_{t+1}^{\{0\}}(\mu_{t+1}, B_{t+1}, B_{t+2})$.

   (c) Solve for the optimal default and social distancing policies for each B_t and B_{t+1} pair,

$$W_t\left(\mu_t, B_t, B_{t+1}\right) = \max_{L_t, d_t} u(c_t) - \pi_D(\mu_t^I)\mu_t^I\chi + \beta V_{t+1}^{\{0\}}\left(\mu_{t+1}(\mu_t, L_t), B_{t+1}\right),$$

   subject to the resource constraint (50) and the SIR laws of motion. Specifically, we search over a fine grid for L_t. For each $(\mu_t, B_t, B_{t+1}, L_t)$, we find the solution d^* to the following equation:

$$-\tilde{z}\phi'(d)(1-L_t)^\alpha(1-\mu_t^D) = (\delta+r)B_t\left[1-\kappa q_t^{\{1\}}(\mu_{t+1}(\mu_t, L_t), B_{t+1})\right].$$

   We pick the default choice in $\{d^*, 0, 1\}$ which yields the highest consumption per capita for $(\mu_t, B_t, B_{t+1}, L_t)$. Let the optimal default and social distancing choices be

$d_t^{\{1\}}(\mu_t, B_t, B_{t+1})$ and $L_t^{\{1\}}(\mu_t, B_t, B_{t+1})$.

(d) Calculate the probability of choosing each B_{t+1}:

$$\Pr^{\{1\}}(B_{t+1}|\mu_t, B_t) = \frac{\exp((W_t(\mu_t, B_t, B_{t+1}) - \overline{W}_t(\mu_t, B_t))/\rho_B)}{\sum_{\tilde{B}_{t+1}} \exp((W_t(\mu_t, B_t, \tilde{B}_{t+1}) - \overline{W}_t(\mu_t, B_t))/\rho_B)},$$

with the maximum value given by $\overline{W}_t(\mu_t, B_t) = \max_{B_{t+1}} W_t(\mu_t, B_t, B_{t+1})$.

(e) Calculate the period t's value and bond price functions, for use at $t-1$:

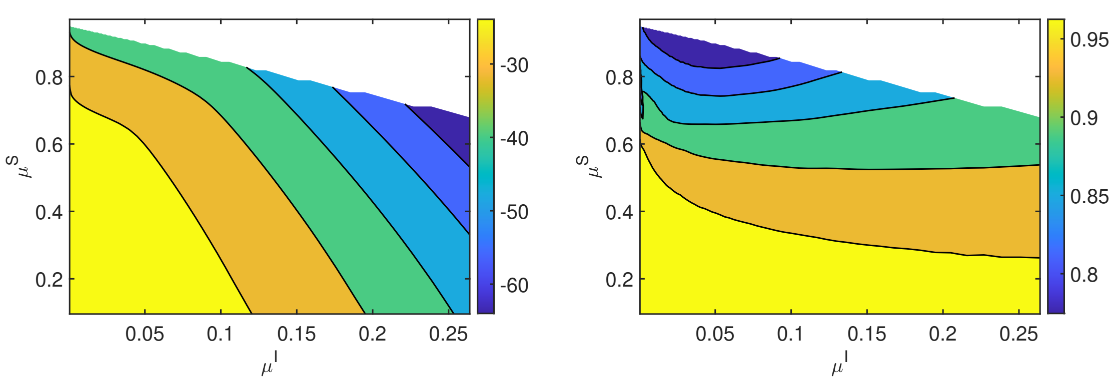
$$V_t^{\{1\}}(\mu_t, B_t) = \overline{W}_t(\mu_t, B_t) + \rho_B \log\left\{\sum_{B_{t+1}} \exp \frac{W_t(\mu_t, B_t, B_{t+1}) - \overline{W}_t(\mu_t, B_t)}{\rho_B}\right\}.$$

(f) Assign the functions with superscript $\{1\}$ to functions with superscript $\{0\}$. Go back to step 3(a) for the previous t until $t = 0$, then stop.

H Value and Policy Functions

In this appendix, we illustrate the interactions between the evolution of the epidemic and financial market conditions by plotting value and policy functions across the state space of our model. We plot policy functions in period $t = 5$, by which point the epidemic is in full swing and a large share of the population is still susceptible, but confirm that these patterns are more general in terms of timing.

Figure 6: Value Function and Bond Price Schedule



(a) Value Function (b) Bond Price Schedule

Figure 6 plots the sovereign's value function (panel (a)) and the bond price schedule (panel (b)) against the epidemic states μ_I and μ_S, with all other state variables kept constant at their equilibrium values. More infections and/or more susceptible individuals worsen welfare for the sovereign, since both are predictors of future fatalities and additional social distancing measures. Bond prices are the highest when the measure of susceptible individuals is low, when the economy has already reached "herd immunity" and the prospects of future social distancing and default are limited.

Figure 7: Social Distancing (L)

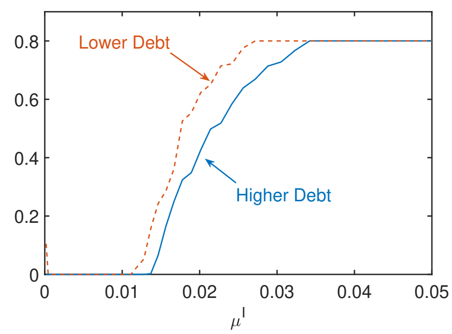
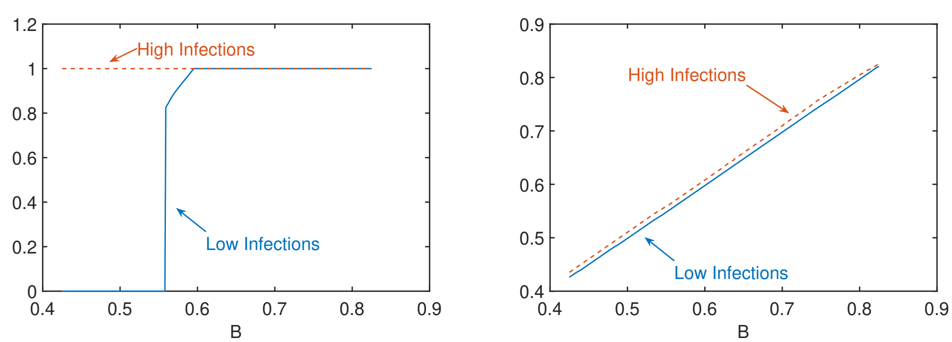


Figure 7 plots the social distancing policy against the measure of infected at the start of the period, for two different debt levels, fixing other states at their equilibrium values. "High Debt" corresponds to the equilibrium level of debt in period $t = 5$, while "Low Debt" corresponds to a debt to output ratio of 40%. More infections call for more stringent measures, but a heavier debt burden depresses incentives for social distancing, as argued in our theoretical analysis in Section 3 and the comparison between the quantitative model and its counterpart with perfect financial markets in Section 4.4.

Figure 8: Partial Default and Debt



(a) Partial Default (d)

(b) Debt Choice (B')

Figure 8 summarizes the behavior of the main economic choice variables, partial default (d) and the debt position for next period (B'). We plot these against the beginning of period debt level

(B) and compare across two cases: one with “high infections,” corresponding to the equilibrium value of μ_I, and one with “low infections,” with low but positive infections. Higher infections call for more intense default and social distancing, and thus for additional borrowing. If the initial debt level of low enough, the country may choose not to default at all, but only if infections are also not too high.

I Exogenous Social Distancing

Table 6: Exogenous Social Distancing

	Endogenous L		L Path of Perfect Fin.	
	Default Risk	Perfect Fin.	Default Risk	Perfect Fin.
Health Crisis				
Fatalities (per 100)	0.315	0.087	0.087	0.087
Length (months)	32.0	40.5	40.5	40.5
Debt Crisis				
Peak debt increase	9.9	35.3	22.5	35.3
Peak spread	5.6	—	14.1	—
Length (months)	39.0	—	72.5	—
Economic Crisis				
Cumulative output loss	32.4	35.8	65.2	35.8
... from social distancing	16.6	35.8	35.8	35.8
... from default cost	16.7	—	26.6	—
Consumption, % pre-pandemic				
2020	−7.2	−0.4	−11.1	−0.4
2021	−4.6	−0.4	−12.0	−0.4
2022	−4.8	−0.4	−4.5	−0.4
2023	−1.0	−0.4	−4.6	−0.4
2024	0.0	−0.4	−4.6	−0.4
Welfare Loss (% output)				
Country	37.4	27.2	43.4	27.2
Lenders	12.9	—	23.8	—

We have considered the joint determination of social distancing policies (L) and traditional fiscal policies such as borrowing and default. It is instructive to ask to what extent progress can be made in the study of the fiscal response to the COVID epidemic by taking social distancing as given, by fixing an exogenous path for L. To this end, in Table 6, we explore the consequences of fixing social distancing policies to those of the model with perfect financial markets, thus removing them as choice variables. The first two columns, under "Endogenous L," are our main results from Table 3, repeated here for convenience, while the last two columns report the results under the fixed L path. In this counterfactual experiment, we no longer allow economies to adapt their mitigation efforts to their financial conditions.

Qualitatively, whether or not investment in saving lives is endogenous does not alter the main takeaway on the role of default risk for the cost of managing the epidemic. Quantitatively, though, the contribution of this mechanism would be overstated. With a fixed and aggressive social distancing policy, the effect of the epidemic on consumption and output are magnified. With an endogenous L choice, the output cost of the epidemic differs by only 3% between the baseline model with default risk and the perfect financial market case. If social distancing is instead exogenously high, as in the perfect financial markets case, this difference exceeds 30%. The welfare cost of the pandemic is now 60% higher than under perfect financial markets, compared with under 37% if L is set endogenously. Overall, this finding implies that our baseline results are a conservative lower bound for the economic costs of the epidemic.