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Pandemic Death Traps

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Abstract

Faced with a pandemic, how does a government decide whether to shut down the economy? We develop a model in which the economy can face health shocks in two periods. The government can invest in shock mitigation but keep the economy open, or shut it down. A shutdown reduces expected deaths but weakens the ability to invest in mitigation against future health shocks. We derive conditions under which each policy is optimal. The career concerns of advisory public health experts can induce a shutdown even when not shutting down Pareto dominates. An efficient financial market predisposes countries towards shutdowns.

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"We are facing a human crisis unlike any we have experienced, and our social fabric and cohesion in under stress," Amina J. Mohammed, UN Deputy Secretary General, April 8, 2020.

I Introduction

The current Covid-19 crisis is one of the most significant events of our times. It has already caused damage that has eclipsed that by the 2007-09 financial crisis. US unemployment reached levels in the pandemic not seen since the Great Depression. Based on a survey of more than 5,800 small businesses in the U.S., Bartik, Bertrand, Cullen, Glaeser, Luca, and Stanton (2020) reported in April 2020: "...mass layoffs and closures have already occurred. In our sample, 43 percent of businesses are temporarily closed, and businesses have - on average - reduced their employee counts by 40 percent relative to January." While all nations have suffered, the distortions caused in developing economies have been even more noteworthy, as the crisis has hit the economically disadvantaged even harder than other groups. For example, it has been noted that in India, the poor were hit especially hard, and a protracted economic slowdown is likely (e.g., Dev and Sengupta, 2020), along with the potential for a worsening of gender inequality (e.g., Anbumozhi, 2020). Thus, this crisis is not only damaging the global economy but it is also exacerbating structural and distributional weaknesses in many economies.

Of course, as economists have begun to note, these consequences are substantially predicated on the policy responses. For example, while most countries almost completely shut down their economies to contain the health damage caused by the virus, Sweden never shut down. In the US, while most states shut down, six states did not. Moreover, many governments are increasing their sovereign debt to finance fiscal stimuli to cope with the crisis, which means global financial market access may also influence policy choices. This raises the research questions we address: how does a government decide whether to shut down the economy or employ lesser mitigation measures, what are the second-best distortions in this decision and how does the financial market affect these distortions?

We develop a theoretical model to address this question. Our model features a two-period production-consumption economy in which production occurs in each period and consumption occurs at the end of the second period. The economy starts with a health shock—a pandemic—hitting it. The government must decide how to respond. One policy choice is to invest in mitigation to control the mortality rate from the pandemic. Another policy choice is to shut down the economy to suppress the pandemic at the cost of economic output.

We assume that deep parameter values are such that the government always invests in mitigation provided it has the resources to do so. The government has the resources necessary for mitigation in the first period so its effective policy choices are: (i) invest in mitigation to attenuate the impact of the pandemic but keep the economy open, and (ii) invest in mitigation and shut down the economy. The government faces these same policy choices in the second period if there are enough resources to invest in mitigation. However, if it lacks these resources in the second period, its two policy choices are to do nothing or to shut down the economy without mitigation.[2] We assume that there is greater uncertainty about the number of deaths and a higher expected number of deaths if the government does not shut down the economy than if it does. That is, the deck is stacked in favor of shutting down the economy to battle the pandemic, insofar as the mortality rate is concerned. The tradeoff, however, is that shutting down the economy causes a bigger loss of economic output and hence lowers the consumption of agents in the economy relative to not shutting down.

[2]One may argue that shutting down the economy is itself a form of mitigation. This is true in our model as well in the sense that it reduces deaths from the pandemic. However, when we refer to mitigation, we are referring to a distinct set of activities like investing in therapeutics, vaccines, additional hospital capacity, and equipment like masks and ventilators.

Assuming that the government's objective is to maximize a weighted average of the lives saved and the terminal consumption of agents in the economy, we derive conditions under which mitigation without a shutdown is the optimal policy choice and conditions under which mitigation with a shutdown is the optimal policy choice. We show that there are conditions under which investing in mitigation without a shutdown in the first period leads to both fewer expected deaths over two periods and higher (terminal) consumption than investing in mitigation and shutting down the economy. The reason is that the loss of economic output due to the first-period shutdown diminishes the capacity of the economy to cope with a health shock in the second period. In some cases, this leads to an insufficient investment in second-period mitigation when the economy is hit with a pandemic again.[3] By contrast, an economy that did not shut down in the first period is able to fully invest in mitigation in the second period. Consequently, not shutting down in the first period may lead to fewer expected deaths than with a first-period shutdown.

The government's policy choices are guided by the advice it receives about the impact of its policies on the mortality rate and the economic output. We introduce public health experts in the model who advise the government on what to do based on their assessment of the mortality rates associated with different policies. The experts observe private signals that are informative about the *a priori* unknown mortality rate from mitigation without a shutdown, so it can be compared to the (presumably) known mortality rate from mitigation with a shutdown. We consider two experts with competing career concerns; a senior expert who *a priori* has greater perceived expertise and enjoys greater career prospects than a junior expert.[4] We explain later how our results change if there is only a single expert.

There are two types of uncertainties—one is about the level of the public health experts'

[3]We discuss later this is likely to be particularly germane for developing economies.

[4]We assume that in a rare pandemic, the performance of an expert is easier to evaluate against the performance of other experts rather than against an absolute benchmark. The career concerns of an expert, therefore, depend on the perception of his ability relative to the other experts. We model this by considering two experts whose career concerns arise from a tournament among the experts.

expertise (i.e., about the precision of their private signals), and the other is about whether the experts have career concerns. We derive a career-concerns equilibrium in which the public health experts' recommendations lead to a shutdown of the economy with mitigation even when their private signals indicate a low probability that this strategy will save more lives than just investing in mitigation without a shutdown. That is, the public health experts' recommendations lead to a shutdown in the first period even when their private information indicates that not shutting down is Pareto superior. We call this a "policy death trap."[5]

Although our career concerns result is obtained in a stylized manner, its intuition is quite general. A public health expert who puts most of his weight in his objective function on career concerns related to virus-related mortality will tend to unconditionally (*vis à vis* his private signal) prefer shutting down the economy, as long as he believes that a shutdown will not increase the number of deaths. This is because by shutting down, the counterfactual of not shutting down disappears, so one never finds out if that alternative would have dominated. We argue that the government or an elected official, nonetheless, follows the public health expert's recommendation, because the official cannot rule out the possibility that the expert's recommendation is informative and not tainted by career concerns.

In our base model, there is no financial market, so the government is restricted to investing capital obtained from the output available in any period. In an extension, we introduce a financial market in a very simple way. It is a mechanism for the government to borrow capital by selling (sovereign) bonds to investors outside the economy; these bonds are claims on future output. This borrowing can enable a government that has a low output at the end of the first period to fill its capital deficiency and invest in mitigation in the second period. This, in turn, makes a first-period shutdown more attractive since one potential disadvantage of the shutdown—low economic output that impedes second-period mitigation—is diminished.

[5]This result depends on the tournament structure with two public health experts who have career concerns. The same result can be obtained with only one expert who is being evaluated against an objective standard if the expert's signal is correlated with his ability and his objective/payoff is (appropriately) nonlinear in his perceived ability. See Section IV.B.

This generates the prediction that countries that are less integrated in the global financial system or face a greater cost of accessing global financial market are less likely to shut down. We also show that countries that convert labor and capital into output with higher-productivity production processes are less likely to shut down than less productive countries.

We then discuss the policy implications of our analysis. One implication is for the government to solicit input from experts whose career concerns depend *both* on the realized mortality rates *and* the economic consequences of their recommendations. Note that it is not enough for experts to simply be knowledgeable about mortality rates and economics, as their career concerns may endogenously depend predominantly on one of the two observables—realized mortality rates and economic consequences. Another is to employ multiple public health experts who all see the same data and let the government initially implement different recommendations in different geographies, with increasing reliance on the experts whose recommendations prove to be better. Both of these policy recommendations have their drawbacks. So a better alternative may be for the government to employ experts who combine expertise in both public health and economics and whose career concerns depend both on mortality rates and economic outcomes. This may require a committee of experts with diverse forms of expertise and *group* career concerns.

Our paper is related to the burgeoning literature on the economics of the Covid-19 crisis. The theoretical papers in this area have focused on the impact of the pandemic on asset prices, the mediating role of monetary policy and optimal policy responses by the government. Acemoglu, Chernozhukov, Werning, and Whinston (2020) develop a multi-risk SIR model in which hospitalization and fatality rates vary among "young", "middle-aged" and "old" people.[6] The paper finds that optimal policies that differentially target risk/age groups significantly outperform uniform policies in terms of both mortality rates and GDP impact.

[6]The SIR (Susceptible-Infectious-Recovered) class of models analyze the spread of an infection in a setting where susceptible may get infected and those who recover from infection develop immunity so the susceptible population declines over time.

Caballero and Simsek (2020) develop a model of endogenous price spirals and severe aggregate demand contractions following a large pandemic-induced supply shock. They show that when the central bank's interest rate policy is constrained, recessionary supply shocks not only feed into reduced risk tolerance of economic agents in the economy but also into further asset price and output drops. Eichenbaum, Rebelo, and Trabandt (2020) extend the SIR model to show that containment policies that reduce economic interactions among people by reducing consumption and hours worked exacerbate the consequent recession but raise welfare by reducing the death toll caused by the epidemic. Krueger, Uhlig, and Xie (2020) develop a model which shows that endogenous shifts in private consumption across sectors of the economy can act as a mitigation mechanism during the pandemic. The paper shows that the "Swedish solution" of letting the pandemic play out without shutting the economy down and allowing agents to shift their sectoral behavior on their own can substantially mitigate the economic and human costs of the Covid-19 crisis, avoiding more than 80% of the decline in output and the number of deaths within one year. Born, Dietrich, and Müller (2020) ask whether a lockdown is an effective means to limit the spread of the Covid-19 pandemic. The paper studies Sweden and uses a synthetic control technique to develop a counterfactual lockdown scenario with a "donor pool' of European countries to construct a doppelganger that behaves just like Sweden in terms of infections before the lockdown. The paper finds that infection dynamics in the doppelganger since the lockdown do not differ from the actual dynamics in Sweden. Chang and Velasco (2020) point out that the health shock, while initially triggered exogenously, is *not* entirely exogenous in that its magnitude and dynamics depend on economic policies, i.e., there are feedback loops.

Our paper shares with these papers a focus on the mortality and economic implications of different government policy choices. But we differ in that our focus is partly positive and partly normative while the focus of the existing theoretical models is primarily normative. Moreover, unlike the existing literature, we extend our base model to consider the *agency implications* of policy choices. Specifically, a novel aspect of our analysis is to highlight the distortion in policy choices that can occur due to the career concerns of public health experts who advise governments. An understanding of these distortions can guide the design of policies that can be implemented in light of these distortions. To the extent that experts in different countries put different weights on their career concerns, our model explains why different countries have followed different policies in response to the same pandemic. Another difference is that our paper highlights the role of the financial market in influencing policy choices in response to the pandemic. Specifically, a more efficient (global) financial market more strongly encourages a shutdown.

There is also an already extensive empirical literature on Covid-19. Coibion, Gorodnichenko, and Weber (2020) examine the causal impact of the crisis on household spending and macro expectations. Their survey data reveal that 50% of respondents report significant income and wealth losses. Households in U.S. counties that went into lockdown earlier expected bigger increases in their unemployment rates over the next 12 months, and the imposition of lockdowns accounts for much of the decline in employment and the reduction in consumer spending in the recent months. Baker, Farrokhnia, Meyer, Pagel, and Yannelis (2020) find similar results—households reduce spending most strongly in states with shelter-in-place orders by March 29, 2020. Kahn, Lange, and Wiczer (2020) look at job vacancy data and document that job vacancies collapsed in the second half of March 2020. In a similar vein, Barrero, Bloom, and Davis (2020) use the Survey of Business Uncertainty and document that 42% of recent layoffs will result in permanent job losses. They also conclude that policy responses like paying unemployment benefits exceeding pre-crisis wages will impede reallocation responses to the Covid-19 shock. Òscar Jordà, Singh, and Taylor (2020) use historical data going back to the 14th century and examine 15 major pandemics in which more than 100,000 people died. They find that pandemics induce labor scarcity, depress real returns and have significant macro after-effects that persist for about 40 years.

We make assumptions in our model that are consistent with these empirical findings. Specifically, in our model, the pandemic impacts real economic output and can also generate binding labor scarcity as well as high unemployment.

Our paper is related to the extensive career concerns literature (e.g., Dewatripont, Jewitt, and Tirole, 1999, Holmstrom, 1999; and Prendergast and Stole, 1996) and especially that related to career concerns in tournaments (e.g., Goel and Thakor, 2008).

The rest of the paper is organized as follows. Section II develops the model. Section III has the analysis of the base model. Section IV analyzes the model with career concerns. Section VI discusses policy implications, along with a discussion of how the analysis speaks to emerging market policy choices. Section VII concludes. All proofs are in the Appendix.

II The Model

In this Section we describe the model, which includes a description of production, consumption, health shocks and government policy choices.

II.A Endowments and Production Technology

Consider a two-period model with the first period between dates t=0 and t=1 and the second period between dates t=1 and t=2. There are P_t people in the economy at date t. People consume only at the terminal date, t=2. This terminal consumption represents future lifetime consumption in a more general multiple-period model. The assumption of zero consumption in the first period can be relaxed without qualitatively altering the results of the paper. Production occurs in both periods.

There is one good that serves as the consumption good at t=2 and a means of production before that. The economy is endowed with initial capital supply of C_0. There is a production technology that uses capital and labor inputs at the beginning of each period and produces capital output at the end of the period. Any capital that is not invested in a period loses some value and reduces to a fraction δ of the initial value at the end of the period. Agents interact with the production technology in two ways. First, their consumption is affected by the output of the production technology. Second, agents supply the labor necessary for production. The output Y_t of the production technology in period t is given by a Leontiff production function of capital investment I_t and labor supply L_t:

$$Y_t = \beta \min(I_t, L_t), \tag{1}$$

where $\beta > 1$. We do not explicitly assign any cost to labor provision, but the output can be considered net of any cost of labor provision. While we use a Leontiff specification, our results will hold with any production function in which capital and labor are complementary.

II.B Sequence of Events

At t=0, the economy starts with capital stock C_0 and P_0 people. A health shock in the form of a pandemic hits the economy at t=0. The government decides whether to invest capital m in mitigation, which includes building up the health infrastructure to deal with the pandemic and limit its adverse impact on lives. The government also decides whether to shut down the entire economy, in addition to the mitigation investment. At t=0.5, depending on the government's two policy decisions at t=0, a fraction $\tilde{\lambda}_1$ of the population dies, thus shrinking the labor supply. At this point of time, investment in first-period production takes place.

At t=1, the output of the first-period production is realized, which then becomes the available capital stock for the second period.[7] Then with probability $\xi \in (0, 1)$, a new health shock hits the economy. The government again faces the two policy-choice decisions it faced at t=0: whether to invest m in mitigation and whether to shut down or not. Based on this decision, at t=1.5, a fraction $\tilde{\lambda}_2$ of people die, shrinking the labor supply further.[8] At this

[7]Since all consumption occurs at t=2, none of the first-period output is consumed.

[8]In many two-period models, all agents are assumed to die after consuming at the end of the second period. The deaths of the fraction $\tilde{\lambda}_2$ of people, in contrast, are pandemic-related, and occur before the consumption at t =2. The government's policies intend to minimize these deaths.

point in time, investment in second-period production takes place.

At t=2, the output of the second-period production is realized and all of it is consumed. The sequence of events is shown in *Figure* 1.

II.C Health Shock Details and Government Choices

The economy starts with P_0 people at t=0. A health shock in the form of a pandemic hits the economy at t=0.[9] A fraction $\tilde{\lambda}_1$ ($0 \leq \tilde{\lambda}_1 < 1$) of people die at t=0.5 as a result of the health shock. Thus, at t=1:

$$P_1 = (1 - \tilde{\lambda}_1)P_0 \tag{2}$$

The deaths due to the pandemic also impact the economy by causing a shrinkage in the labor supply available for production in the first period. We make the simplifying assumption that there are no births or deaths due to causes unrelated to the health shock.[10]

First-Period Policy Choices: The government coordinates how people respond to the pandemic. When the pandemic (health shock) hits, in addition to doing nothing, the government has two policy tools available to it to choose from:

1. invest in mitigation (beefing up health infrastructure, investing in testing, contact tracing, doctors, ventilators, therapeutic solutions, etc.)
2. shut down economy by placing restrictions on production

[9] We analyze the model with a deterministic health shock at t=0, i.e., the analysis is conditional on a pandemic occurring at t=0. We allow for a subsequent health shock at t=1 that is stochastic.

[10] Relaxing this assumption does not qualitatively change our results.

0	0.5	1	1.5	2
• Economy has initial capital stock of C_0 • There are P_0 people • Pandemic hits • Government chooses whether to invest m for mitigation ($M_1 = 1$) or not ($M_1 = 0$) • Government chooses whether to shut down ($S_1 = 1$) or not ($S_1 = 0$)	• A fraction $\tilde{\lambda}_1$ of people die where $\tilde{\lambda}_1$ depends on M_1 and S_1 • $P_1 = P_0(1 - \tilde{\lambda}_1)$ people survive • Labor $L_1 \leq P_1$ and investment $I_1 \leq C_0 - M_1 m$ are invested in first-period production	• First-period output is $Y_1 = \beta \min(I_1, L_1)$ if there is no shutdown • First-period output is $(1 - \gamma_1)Y_1$ if there is a shutdown • New capital stock is $C_1 = (1 - \delta)(C_0 - M_1 m - I_1) + (1 - S_1\gamma_1)Y_1$ • New health shock hits ($H = 1$) with probability ξ • If $H = 1$, government chooses whether to invest m for mitigation ($M_2 = 1$) or not ($M_2 = 0$) • If $H = 1$, government chooses whether to shut down ($S_2 = 1$) or not ($S_2 = 0$)	• If $H = 1$, a fraction $\tilde{\lambda}_2$ of people die where $\tilde{\lambda}_2$ depends on M_2 and S_2 • $P_2 = P_1(1 - H\tilde{\lambda}_2)$ survive • Labor $L_2 \leq P_2$ and investment $I_2 \leq C_1 - HM_2 m$ are invested in second-period production	• Second-period output is $Y_2 = \beta \min(I_2, L_2)$ if there is no shutdown • Second-period output is $(1 - \gamma_2)Y_2$ if there is a shutdown • New capital stock is $C_2 = (1 - \delta)(C_1 - M_2 m - I_2) + (1 - HS_2\gamma_2)Y_2$ • Everyone consumes C_2

Figure 1: Sequence of Events

Definition (Mitigation). The investment m in mitigation is a capital-consuming investment that involves the government purchasing additional medical equipment (e.g., masks, ventilators, etc.) as well as expanding hospital capacity (e.g., the U.S. government's investments in adding to the hospital capacity in New York, Los Angeles, New Orleans and other places during the 2020 pandemic), and investing in testing, therapeutics, vaccines (e.g., the U.S¿ government's "Operation Warp Speed"), surveillance, social-distancing enforcement and other measures.

Definition (Shutdown). A shutdown of the economy means limiting production and reducing economic output, as practiced by all but six U.S. states during the Covid-19 crisis.

The government can choose to employ none, one, or both of these tools in the first period to fight the pandemic.[11] The government's choice affects the number of deaths as well as the loss of economic output. The strategy of doing nothing has no initial cost but does nothing to lower the deaths from the pandemic. Mitigation lowers the number of deaths relative to the case in which the government does nothing. However, mitigation is costly and reduces the capital stock by an amount m. A shutdown may also lower the number of deaths but the restriction on production wipes out a fraction γ_1 $(0 \leq \gamma_1 \leq 1)$ of the output. Employing both mitigation and shutdown lowers deaths further relative to the case in which just a shutdown is imposed, and possibly also relative to the case in which just mitigation is implemented. However, this dual response requires both an investment in production and a loss of economic output from the production technology.

Second-Period Policy Choices: There may be a second health shock in the second period starting at t=1. This health shock occurs with probability $\xi \in (0, 1)$. Let H be the indicator variable for a health shock in the second period: $H = 1$ if there is a health shock

[11] We later assume exogenous parameters are such that the government always invests in mitigation if there is sufficient capital. That is, we make assumptions on exogenous parameters such that in the first period, the government never chooses to do nothing. However, even with these assumptions, the possibility of having insufficient capital in the second period opens up the possibility of no mitigation and no shutdown (i.e., do nothing) in the second period.

in the second period and $H = 0$ otherwise. A fraction $\tilde{\lambda}_2$ ($0 \leq \tilde{\lambda}_2 < 1$) of people die at t=1.5 due to the second health shock:

$$P_2 = (1 - H\tilde{\lambda}_2)P_1 \tag{3}$$

If there is a health shock in the second period, the government again decides whether to do nothing, invest only in mitigation, shut down the economy without investing in mitigation, or invest in mitigation and shut down the economy. Mitigation in the second period is costly—it reduces the capital stock by an amount m, which is in addition to any mitigation costs incurred in the first period. While some mitigation steps taken in the first period will continue to yield benefits in the second period, some others like producing masks, reconfiguring hospitals, testing, etc. require new investment. Although we have assumed the cost of mitigation to be the same in both periods, this assumption can be relaxed without affecting our results. A shutdown in the second period depletes a fraction γ_2 of the output from the production technology. Let M be the indicator variable for mitigation in the second period t: $M = 1$ if there is mitigation and $M = 0$ otherwise. Let S_t be the indicator variable for shutdown in period t: $S_t = 1$ if there is a shutdown in period $t \in \{1, 2\}$ and $S_t = 0$ otherwise.
Capital Stock Dynamics: We assume that the initial stock of capital is enough to meet the cost of mitigation:

$$C_0 > m. \tag{4}$$

The capital stock evolves according to the following equation:

$$C_t = (1 - \delta)(C_{t-1} - M_t m - I_t) + (1 - \gamma_t S_t)Y_t. \tag{5}$$

That is, the capital stock at the end of a period equals depreciated capital value of the stock at the beginning of period, net of any investment in mitigation or production, plus the output of the production technology, reduced by a fraction γ if there is a shutdown in the period. Government policies as well as production decisions are limited by the production technology and capital and labor constraints. The capital stock cannot be negative:

$$C_t \geq 0. \tag{6}$$

The economy starts with a positive number of people

$$P_0 > 0 \tag{7}$$

and the labor supply in each period is limited to the number of people alive in that period:

$$L_t \leq P_t. \tag{8}$$

Government Objective: The government has two objectives - reducing the number of deaths and increasing the aggregate consumption at t=2. However, sometimes these two objectives may conflict. We assume that the government maximizes a weighted average of the lives and capital stock at t=2:

$$Z = \alpha \frac{P_2}{P_0} + (1 - \alpha) \frac{C_2}{C_0}, \tag{9}$$

with $0 \leq \alpha \leq 1$. This is equivalent to maximizing a weighted average of P_2 and C_2 if P_0 and C_0 are taken as fixed. However, when comparing economies that differ in initials stocks P_0 and C_0, the tradeoff between lives and capital may depend on the abundance of people relative to capital, i.e., on which resource is scarcer. This means a given decline in capital is more costly for a more capital-constrained economy. The weight α may depend on various considerations, including the culture, political economy, and value-system of the economy.

II.D Mortality Specifications

Our first premise is that, relative to employing both mitigation and a shutdown, relying only on mitigation leads to higher uncertainty about the number of deaths due to the pandemic. We capture this by assuming that if there is a health shock in period t and the government invests in mitigation, then the fraction of people who die in that period t is:

$$\tilde{\lambda}_t(M_t = 1) = \begin{cases} \lambda_t^{MS} & \text{if } S_t = 1 \text{ (mitigation with shutdown)} \\ \tilde{\lambda}_t^M \geq \lambda_t^{MS} & \text{if } S_t = 0 \text{ (mitigation without shutdown)}, \end{cases} \tag{10}$$

That is, the number of deaths without a shutdown may be same as or more than the number of deaths with a shutdown.

Assumption 1. *With investment in mitigation in period t, the fraction of deaths without a shutdown is equal to or exceeds the fraction of deaths with a shutdown with probabilities π_t^M and $1 - \pi_t^M$, respectively. Specifically,*

$$\tilde{\lambda}_t^M = \begin{cases} \lambda_t^{MS} & \textit{with probability } \pi_t^M \in (0, 1) \\ \lambda_t^{MH} > \lambda_t^{MS} & \textit{with probability } 1 - \pi_t^M. \end{cases} \tag{11}$$

The idea behind (11) is that the issue of whether a shutdown with mitigation saves more lives than mitigation only is still unsettled empirically; see our discussion in the Introduction. The specification in (11) captures the *ex ante* uncertainty about whether a shutdown will save more lives than mitigation without a shutdown—in one state of the world it does, and in another state it does not. On an *expected value* basis, however, a shutdown with mitigation saves more lives than mitigation only without a shutdown. *Thus, a shutdown with mitigation is assumed to lead to both less uncertainty and fewer expected deaths than mitigation alone.*

If a health shock is experienced in period t and the government does not invest in mitigation, then the fraction of people who die in that period t is:

$$\tilde{\lambda}_t(M_t = 0) = \begin{cases} \lambda_t^S & \text{if } S_t = 1 \text{ (shutdown without mitigation)} \\ \tilde{\lambda}_t^N \geq \lambda_t^S & \text{if } S_t = 0 \text{ (do nothing),} \end{cases} \tag{12}$$

Again, the number of deaths without a shutdown may be the same as or more than the number of deaths with a shutdown.

Assumption 2. *With no investment in mitigation in period t, the fraction of deaths without a shutdown is equal to or exceeds the fraction of deaths with a shutdown with probabilities π_t^N and $1 - \pi_t^N$, respectively. Specifically,*

$$\tilde{\lambda}_t^N = \begin{cases} \lambda_t^S & \textit{with probability } \pi_t^N \in (0, 1) \\ \lambda_t^H > \lambda_t^S & \textit{with probability } 1 - \pi_t^N. \end{cases} \tag{13}$$

Our second premise is that mitigation saves lives regardless of whether there is a shutdown. If there is no shutdown, the fraction of deaths without mitigation exceeds the fraction of deaths with mitigation in first-order-stochastic-dominance sense.

$$\mathbb{P}[\tilde{\lambda}_t^M < x] \geq \mathbb{P}[\tilde{\lambda}_t^N < x] \quad \forall x \tag{14}$$

where $\mathbb{P}[x]$ indicates probability of event x. If there is a shutdown, the fraction of deaths without mitigation exceeds the fraction of deaths with mitigation.

$$\lambda_t^{MS} < \lambda_t^S. \tag{15}$$

III Analysis

We analyze the impact of government policies on lives lost and on economic output. We first consider the impact of government policies in the second period, taking first-period outcomes as given.

III.A Second-Period Choices and Outcomes

Consider t=1.5, after the government has responded to the health shock, if any, at t=1 and any resulting loss of life has already been realized. The number of people alive is given by,

$$P_2(H, M_2, S_2) = \begin{cases} P_1 & \text{if } H = 0 \text{ (no health shock)}, \\ (1-\lambda_2^{MS})P_1 & \text{if } H = 1, M_2 = 1, S_2 = 1 \text{ (health shock, mitigation, shutdown)}, \\ (1-\tilde{\lambda}_2^{M})P_1 & \text{if } H = 1, M_2 = 1, S_2 = 0 \text{ (health shock, mitigation, no shutdown)}, \\ (1-\lambda_2^{Nl})P_1 & \text{if } H = 1, M_2 = 0, S_2 = 1 \text{ (health shock, no mitigation, shutdown)}, \\ (1-\tilde{\lambda}_2^{N})P_1 & \text{if } H = 1, M_2 = 0, S_2 = 0 \text{ (health shock, no mitigation, no shutdown)}. \end{cases} \tag{16}$$

The second-period capital stock is obtained from (5) and (1) as:

$$C_2(M_2, S_2, I_2, L_2) = (1-\delta)(C_1 - M_2 m - I_2) + (1 - \gamma_2 S_2)\beta \min(I_2, L_2) \tag{17}$$

Investment I_2 and labor supply L_2 are chosen to maximize this capital stock subject to $I_2 \geq 0$, $C_1 \geq M_2 m + I_2$ and $L_2 \leq P_2$. Assuming non-negative capital and labor availability ((6), (7)), both capital investment and labor investment are chosen to be the minimum of the available capital stock and the labor supply. That is, which resource constraint is binding determines the investment of capital and labor:

$$I_2 = L_2 = \min(C_1 - M_2 m, P_2). \tag{18}$$

The resulting capital stock at t=2 is:

$$C_2(M_2, S_2) = (1-\delta)(C_1 - M_2 m) + ((1-\gamma_2 S_2)\beta + \delta - 1)\min(C_1 - M_2 m, P_2). \tag{19}$$

We now consider how policies at t=1 affect the number of lives (16) and the capital stock (19) at t=2, assuming optimal investment in production technology at t=1.5.

1 No Health Shock in the Second Period

If there is no health shock in the second period ($H = 0$), there will be no mitigation ($M_2 = 0$) or shutdown ($S_2 = 0$) as these measures are costly but provide no benefit. The number of people alive at t=2 is

$$P_2(H = 0) = P_1 \tag{20}$$

and the capital stock at t=2 is

$$C_2(H = 0) = (1-\delta)C_1 + (\beta + \delta - 1)\min(C_1, P_1). \tag{21}$$

2 Health Shock in the Second Period with Sufficient Capital for Mitigation

If there is a health shock in the second period ($H = 1$) and there is sufficient capital for mitigation ($C_1 \geq m$), then as we indicated earlier, the government can do nothing, mitigate without a shutdown, shut down without mitigation, or mitigate with a shutdown. We consider each in turn.

If the government does nothing, the expected number of people alive at t=2 is:

$$\mathbb{E}[P_2(H = 1, M_2 = 0, S_2 = 0)] = (1 - \mathbb{E}[\tilde{\lambda}_2^N])P_1. \tag{22}$$

and the expected capital stock at t=2 is:

$$\mathbb{E}[C_2(H=1, M_2=0, S_2=0)] = (1-\delta)C_1 + (\beta+\delta-1)\mathbb{E}[\min(C_1, (1-\tilde{\lambda}_2^N)P_1]. \tag{23}$$

If the government invests in mitigation but does not shut down, the expected number of people alive at t=2 is:

$$\mathbb{E}[P_2(H=1, M_2=1, S_2=0)] = (1-\mathbb{E}[\tilde{\lambda}_2^M])P_1, \tag{24}$$

and the expected capital stock at t=2 is:

$$\mathbb{E}[C_2(H=1, M_2=1, S_2=0)] = \\ (1-\delta)(C_1-m) + (\beta+\delta-1)\mathbb{E}[\min(C_1-m, (1-\tilde{\lambda}_2^M)P_1)]. \tag{25}$$

If the government imposes a shutdown but does not invest in mitigation, the number of people alive at t=2 is:

$$P_2(H=1, M_2=0, S_2=1) = (1-\lambda_2^{Nl})P_1, \tag{26}$$

and the capital stock at t=2 is:

$$C_2(H=1, M_2=0, S_2=1) = (1-\delta)C_1 + ((1-\gamma_2)\beta+\delta-1)\min(C_1, (1-\lambda_2^{Nl})P_1). \tag{27}$$

If the government invests in mitigation and also imposes a shutdown, the number of people alive at t=2 is:

$$P_2(H=1, M_2=1, S_2=1) = (1-\lambda_2^{MS})P_1, \tag{28}$$

and the capital stock at t=2 is:

$$C_2(H=1, M_2=1, S_2=1) = (1-\delta)(C_1-m) + ((1-\gamma_2)\beta + \delta - 1)\min(C_1 - m, (1-\lambda_2^{MS})P_1). \tag{29}$$

The government's policy choice depends on the weights it places on saving lives and on increasing economic output. If saving lives at t=2 is the sole objective of the government and the capital stock used for consumption at t=2 is ignored, the government invests in mitigation and also imposes a shutdown because λ_2^{MS} is less than λ_2^{Nl}, $\mathbb{E}[\tilde{\lambda}_2^M]$, and $\mathbb{E}[\tilde{\lambda}_2^N]$.

If the government's objective is solely to maximize the capital stock at t=2 and the production process is capital-constrained, doing nothing maximizes the capital stock. The reason is that saving lives does not increase the output of the production technology. On the contrary, both mitigation and shutdown reduce the capital stock. The investment in mitigation directly reduces the capital stock, whereas a shutdown reduces the output from the production process. Therefore, the government chooses to do nothing.

The choice of policy is less obvious in an economy that is labor-constrained. The reason is that saving lives preserves the labor supply and leads to a higher capital output through the production process. The overall effect of investment in mitigation and/or a shutdown depends on a comparison of the number of lives saved through these strategies, the costs of these strategies, and the abundance of the capital stock relative to the labor supply.

Finally, these same tradeoffs govern the government's policy choice if the government places positive weight on saving lives and also on increasing output.

Proposition 1. *Suppose there is sufficient capital for mitigation in the second period ($C_1 > m$). Then, given a health shock in the second period:*

1. *The government is more likely to do nothing in the second period if it places a lower weight on lives. That is, if doing nothing maximizes the government's objective with*

$\alpha = \hat{\alpha}$, then, doing nothing also maximizes the government's objective with $\alpha < \hat{\alpha}$,

2. *The government is more likely to employ both mitigation and shutdown in the second period if it places a bigger weight on lives. That is, if investment in mitigation and imposing a shutdown maximizes the government's objective with $\alpha = \hat{\alpha}$, then, investment in mitigation and imposing a shutdown also maximizes the government's objective with $\alpha > \hat{\alpha}$,*

3. *The government is more likely to invest in mitigation in the second period if there is a larger capital stock in the economy. That is, if given a specific capital stock $C_1 = \hat{C}_1$, the government prefers mitigation to doing nothing, or mitigation and a shutdown to a shutdown without mitigation, then it also does so for capital stock $C_1 > \hat{C}_1$.*

Proposition 1 shows that the government's policy response to a health shock in the second period depends on the weights that the government places on saving lives and capital as well as the abundance of capital relative to people. A government that places a sufficiently high weight on preserving capital chooses to do nothing in response to the health shock while a government that places a sufficiently high weight on saving lives invests in mitigation, provided it has the resources to do so, and also shuts down the economy. Since mitigation saves lives but diminishes the capital stock, holding fixed the weights placed on saving lives and preserving capital, a government is more likely to invest in mitigation if the economy has more capital.

3 Health Shock in the Second Period with Insufficient Capital for Mitigation

If there is a health shock in the second period ($H = 1$) and there is not enough capital for mitigation ($C_1 < m$), the government is unable to invest in mitigation and its only choice is to shut down or not, i.e., doing nothing now becomes a possible choice. It follows from Proposition 1 that the government will do nothing if its weight on lives α is below a threshold value and will shut down if it places a greater weight on saving lives. The inability to invest in mitigation thus constrains the government's policy choices. We now have:

Lemma 1. *The number of lives and the capital stock at the end of the second period are increasing in the capital stock at the end of the firs period and also increasing in the number of lives at the end of the first period.*

Lemma 1 links government's first-period policies and the second-period outcomes. The result shows that a higher capital stock at the end of the first period increases not only the capital stock at the end of the second period but also the lives saved during the second period. The intuition is that having a sufficiently high stock of capital is necessary for the government to be able to invest in mitigation in the second period if there is a health shock in the second period. This means that even if a government is solely interested in maximizing lives saved over the two periods, it should still consider the implications of its first period policies on the capital stock at the end of the first period.

III.B First-Period Choices and Outcomes

We now consider the government's choice of response to a health shock in the first period. The government chooses a response to the health shock at t=0, and the impact of the shock in terms of the loss of life and the loss of economic output is realized at t=0.5. While choosing a policy in the first period, the government anticipates its policy choices and their outcomes in the second period in case there is another health shock in the second period.

To keep the analysis simple, we focus on the government's decision to shut down the economy and make the following assumption for the rest of the paper.

Assumption 3. *The exogenous parameters are such that the government always prefers to invest in mitigation if there is sufficient capital stock to invest in mitigation.*

Assumption 3 holds, for instance, if the fraction of deaths in the absence of mitigation (λ_t^S or λ_t^H) is sufficiently high relative to the cost of mitigation (m). Under this assumption, if there is enough capital for mitigation, the government considers only two strategies: mitigation without shutdown and mitigation with shutdown.

The number of lives L_1 and the capital stock C_1 at the end of the first period depend on the government's response. Based on Lemma 1, the government's objective is increasing in the stock of capital and also in the number of lives at the end of the first period. Shutting down the economy may save lives, but at the expense of lower economic output. Thus, the government faces a tradeoff between saving lives and enhancing the capital stock at the end of the first period. However, this tradeoff cannot be the sole determinant of the government's policy choice because the eventual goal is related to the number of lives and capital stock at the end of the *second period*. The following proposition highlights a potential problem with a policy driven solely by outcomes at the end of the first period.

Proposition 2. *There is a non-empty set of exogenous parameter values such that the expected number of people alive at the end of the second period and the expected consumption at the end of the second period are both lower if there is a shutdown in the first period than if there is no shutdown in the first period.*

A shutdown in the first period may reduce the expected number of deaths in the first period, but it does so at the expense of a reduced capital stock. Proposition 2 shows that under some parametric assumptions, this capital-stock effect leads to a first-period shutdown actually elevating the number of deaths in the second period. The intuition is that the loss of economic output due to a shutdown in the first period weakens the economy by shrinking the stock of capital available. For some parameter values, the economy is left with insufficient capital to invest in mitigation in response to a health shock in the second period. Thus, notwithstanding the lives saved by a shutdown in the first period, the inability to invest in second-period mitigation can cause the total loss of lives across the two periods to be greater with a first-period shutdown than without. Of course, no investment in mitigation is needed if the economy does not experience another health shock in the second period. In this case, a shutdown in the first period is expected to save more lives across the two periods. Whether a first-period shutdown results in fewer or more deaths over the two periods then depends on the probability of a health shock in the second period. For some deep parameter values, including a large enough probability of a health shock in the second period, *not* shutting down in the first period may lead to fewer expected deaths than with a first-period shutdown. It also leads to greater expected capital if the economic output lost due to a shutdown is sufficiently high. This result is more likely to hold in economies that are capital-constrained. It may be particularly applicable to emerging market economies.

IV Analysis with Career Concerns and Policy Implications

Every government we know relied on the advice of epidemiologists and other health care experts to guide its policy decisions. Like any other agent in the economy, a health care expert has career concerns, likely related to the desire for enhanced professional prestige and visibility. We now capture this by examining how career concerns of advisers and decisionmakers may influence the government's policies in a pandemic. We assume that a health shock hits the economy in the face of a pandemic at t=0 and the government invests in mitigation. We focus on the advice health-care experts offer about whether the government should impose a shutdown or not in the first period, and how the government acts on it.

A fraction λ^l of people die if these is a shutdown (we do not use subscripts for time and for mitigation as we simplify the main model in Section II by suppressing the mitigation decision and considering only the first period). There is uncertainty about the fraction $\tilde{\lambda}$ of people that die if there is no shutdown. The common belief is that with probability π, the fraction of deaths without a shutdown equals λ^l and with probability $1-\pi$, the fraction of deaths without a shutdown equals $\lambda^h > \lambda^l$.

The government relies on reports by experts to determine whether to impose a shutdown or not. The basic premise is that when the government imposes a shutdown, the expert's prediction about deaths in the absence of a shutdown cannot be evaluated because the counterfactual disappears. However, if there is no shutdown, a comparison of the actual number of deaths with the expert's prediction is used to update beliefs about his ability. Thus, not shutting down exposes the expert to greater uncertainty about the posterior assessments of his ability and the resulting career prospects. An expert's report may be influenced by this uncertainty about his career concerns if the expert competes with other experts. We consider two experts that have career concerns arising from a tournament in which they compete to be considered the more talented expert.

IV.A Experts and Government Objective

Experts: There are two experts whose recommendations guide the government's policies. One of these is considered the senior expert and the other is considered the junior expert. We refer to these two with subscripts s and j, respectively. The type τ_i of expert $i \in s, j$ can be talented (T) or untalented (U). It is common knowledge at $t=0$ that the senior expert is talented with probability p_s, the junior expert is talented with probability p_j, and τ_s and τ_j are independently distributed. At t=0, expert i observes a private signal x_i about λ^l. The signal can be good (g) or bad (b). The signal of a talented expert perfectly reveals $\tilde{\lambda}$:

$$\text{If } \tau_i = T, \qquad x_i = \begin{cases} g & \text{if } \tilde{\lambda} = \lambda^l \\ b & \text{if } \tilde{\lambda} = \lambda^h, \end{cases} \tag{30}$$

The signal of an untalented expert is uninformative about $\tilde{\lambda}$:

$$\text{If } \tau_i = U \text{ and } \tilde{\lambda} = \lambda^l, \qquad x_i = \begin{cases} g & \text{with probability } \pi \\ b & \text{with probability } 1-\pi \end{cases}$$
$$\text{If } \tau_i = U \text{ and } \tilde{\lambda} = \lambda^h, \qquad x_i = \begin{cases} g & \text{with probability } \pi \\ b & \text{with probability } 1-\pi \end{cases} \tag{31}$$

The two signals are independent of each other, conditional on $\tilde{\lambda}$. The two experts simultaneously announce their recommendations about whether to shut down or not. Without loss of generality, we consider the recommendation by expert i, y_i to be a report of his signal x_i. Based on the two reports, the government updates its beliefs about $\tilde{\lambda}$, the fraction of deaths in the absence of a shutdown. Let θ be the posterior probability that $\tilde{\lambda} = \lambda^l$.

Government Objective: In this single-period model, the government's objective depends on the number of lives P_1 and capital C_1 at the end of the period. The government's objective (9) is increasing in both P_1 and C_1 (Lemma 1). Thus, the government maximizes:

$$Z \equiv f(P_1, C_1), \tag{32}$$

where f is a continuous function, increasing in both arguments. The value of the government's objective function with a shutdown is

$$f((1-\lambda^l)P_0, \beta(1-\gamma_1)C_0) \tag{33}$$

and without a shutdown, it is

$$\theta f((1-\lambda^l)P_0, \beta C_0) + (1-\theta) f((1-\lambda^h)P_0, \beta C_0). \tag{34}$$

The government imposes a shutdown if and only if the value of the objective function with a shutdown exceeds the expected value of its objective function without a shutdown:

$$\theta < \theta^* \equiv \frac{f((1-\lambda^l)P_0, \beta(1-\gamma_1)C_0) - f((1-\lambda^h)P_0, \beta C_0)}{f((1-\lambda^l)P_0, \beta C_0) - f((1-\lambda^h)P_0, \beta C_0)} \tag{35}$$

If we assume that f is concave in both arguments, that is the marginal value of number of people (amount of capital) decreases as the number of people (amount of capital) increases, then θ^* is increasing in C_0 and decreasing in P_0. That is, countries with a greater stock of capital relative to people are more likely to impose a shutdown. Heterogeneity in θ^* across nations can be a source of heterogeneity in policy choices.

First-Best: We now consider the first-best equilibrium in which the government can directly observe the experts' signals. Based on the signals x_s and x_j, the government updates its beliefs about the probability that $\tilde{\lambda} = \lambda_l$. Since each expert's signal is more likely to be good if $\tilde{\lambda} = \lambda_l$, a good signal increases the posterior probability θ that $\tilde{\lambda} = \lambda_l$ while a bad signal decreases $\tilde{\lambda} = \lambda_l$. We assume that the experts' signals are useful in the sense that the government will impose a shutdown if both experts' signals are bad, and will not impose a shutdown if both experts' signals are good. We make the following assumption to handle the case in which the two signals differ.

Assumption 4. *The posterior probability that a shutdown does not save additional lives ($\tilde{\lambda} = \lambda_l$) exceeds θ^* if the senior expert's signal is good and the junior expert's signal is bad, but is less than θ^* if the senior expert's signal is bad and the junior expert's signal is good. That is,*

$$\theta(x_s = b, x_j = g) < \theta^* < \theta(x_s = g, x_j = b). \tag{36}$$

Given the above parametric assumption, the first-best equilibrium involves the government imposing a shutdown whenever the senior expert's signal is bad but not imposing it if the senior expert's signal is good.

IV.B Second Best with Career Concerns

We now assume that each expert's signal is private and that the experts may be motivated by career concerns. The probability that the senior expert is talented and the probability that the junior expert is talented are updated at t=1 based on the experts' reports of their signals and the fraction of deaths observed. The expert who is considered to be talented with a higher probability at t=1 is then made the senior expert. We assume that the experts have career concerns. That is, expert i maximizes an objective that is a weighted average of the government's objective Z and the probability of being appointed senior expert at t=1:

$$(1-c)Z + cB\mathbb{1}(\mathbb{P}[\tau_i = T] > \mathbb{P}[\tau_j = T]),$$

where τ_j is type of the other expert, $B > 0$ is the benefit of being appointed a senior expert, and c is the weight the expert attaches to this benefit.[12] The weight c may reflect societal values as well as the expert's personal preferences. We call c the strength of an expert's career concerns and assume that the value of c is the expert's private information. The government knows the probability distribution of c. To simplify the analysis, we assume that with probability μ an expert's objective is completely driven by career concerns ($c = 1$), while with probability $1 - \mu$ the expert has no career concerns ($c = 0$). We assume that the incidence of career concerns is independent across the two experts, and that each expert privately knows whether he is driven by career concerns, whereas others share the common prior belief that the probability of this is μ.

We first note that if $\mu = 0$, the two experts share the government's objective function. In this case, both experts reveal their signals truthfully to the government and the first-best equilibrium is attained in which the government imposes a shutdown only if the senior expert's signal is good. Now, we consider the case where the experts may have career

[12] B could stem from a variety of sources—enhanced professional prestige, greater media visibility, higher compensation, etc.

concerns and their reports, y_s and y_j, may differ from their respective signals, x_s and x_j.

Proposition 3. *If the probability, μ, that experts have career concerns is positive, then it is not a Nash Equilibrium for both the experts to always report their private signals truthfully. If the government expects the experts to always report their private signals truthfully, then a senior expert with career concerns reports a bad signal after privately observing a good signal.*

The intuition is that a senior expert with career concerns prefers to "play it safe" by recommending a shutdown rather than taking a chance by not recommending a shutdown. Even if the senior expert's private signal indicates that a shutdown will not save additional lives, there is a nonzero probability of *additional* deaths if there is no shutdown.[13] Thus, if a shutdown is not imposed, there is a positive probability that the senior expert is revealed to be untalented and loses the benefits of being a senior expert. However, if there is a shutdown, the counterfactual is never observed and the career concerns of the senior expert are not threatened.

Proposition 4. *There exists a non-empty set of exogenous parameters such that there is a Nash equilibrium in which experts with career concerns always report a bad signal, experts without career concerns report their signals truthfully, the government imposes a shutdown if the senior expert reports a bad signal, and appoints the expert with a higher posterior probability of being talented as the senior expert at t=1. In this equilibrium, the government imposes a shutdown when it would not impose a shutdown in the first-best equilibrium.*

The intuition for Proposition 4 is that a senior expert with career concerns wants to maintain his reputation as the expert with a higher probability of being talented. He recommends a shutdown regardless of his private signal because if a shutdown is not imposed, the outcome in terms of the number of deaths may reveal him to be untalented. Interestingly, the junior expert with career concerns also recommends a shutdown regardless of his private

[13]This is because the signal is informative but noisy.

signal. The reason is that if there is a shutdown, the number of deaths in the counterfactual is not observed and the junior expert continues to be considered talented with a lower probability than the senior expert. The only situation in which the junior expert is promoted to be the senior expert at $t = 1$ is when the senior expert is proven wrong. This happens when the senior expert (without career concerns) reports a good signal and there is no shutdown. The junior expert can distinguish himself from the senior expert in this case by reporting a bad signal, regardless of his private signal, and if the number of deaths ends up being high, the assessed ability of the junior expert will now be higher than the senior expert's. While the government recognizes that the recommendations of experts with career concerns are uninformative, as long as there is a sufficiently high probability that the senior expert does not have career concerns and consequently that his report is informative, the government follows the senior expert's recommendation.

This analysis also explains the role that having *two* experts plays in the model. If there is only one expert being evaluated against an objective benchmark, the results depend on the form of career concerns and informational structure. If the expert's objective is to maximize his expected perceived ability and if there is no correlation between expert's signal and ability, then it is an equilibrium for the expert to truthfully report the private signal. This equilibrium may not exist under two scenarios. The first is that there is a correlation between the agent's signal and ability. For example, a higher ability expert is more likely to recognize the severity of the pandemic and observe a signal of high mortality. The second is that the agent's objective is a nonlinear function of perceived ability. Our model of a tournament between two experts effectively results in a winner-take-all payoff, a special case of an objective that is nonlinear in his perceived ability and can prevent truthful reporting by the expert.

This proposition indicates that the recommendations of public health experts depend on whether they have career concerns. Thus, cross-country in the career concerns of public health experts will lead to heterogeneous policy choices as well.

V Pandemic with a Global Financial Market

We now consider how existence of a global financial market can impact a government's response to a pandemic. A global financial market allows one country to borrow capital from another country or lend capital to another country in the second period. We assume that the debt market is competitive so all debt transactions between countries will take place at a market clearing real interest rate r. We extend the main model by assuming that there are multiple countries and each country's government determines the policy of that country. We simplify the model by assuming that each country invests in mitigation in the first period and by suppressing shutdowns in the second period. We assume that if there is a health shock in a country in the second period, its government may invest in mitigation if it has the necessary resources. The costs and benefits of mitigation are exogenously specified. We focus on the question of whether governments impose shutdowns in the first period. We start with the case in which global financial markets do not exist and then examine how the existence of a global financial market affects government policies.

V.A Policy Choices and Government Objective

Policy Choices: There is a continuum of atomistic countries with unit mass. The country index i ranges from 0 to 1. Each country experiences a health shock at $t = 0$. If country i shuts down the economy in the first period ($S_1^i = 1$), its capital at $t = 1$ is $c^i = \hat{c}^i$ and the number of lives is $P^i = \hat{P}^i$. If country i does not shut down the economy ($S_1^i = 0$), its capital at $t = 1$ is $c^i = (1 + \kappa^i)\hat{c}^i$ and the number of lives is $P^i = (1 - \lambda)\hat{P}^i$.[14]

Government Objective: Each government maximizes the number of lives and capital at the end of the first period. Specifically, we assume that the government places a weight μ on the number of lives and a weight η on capital. If a health shock hits the country in the

[14]In the main model, we assumed that production output is diminished from a shutdown while uninvested capital is not. As a simplification, we assume that a shutdown diminishes total capital.

second period ($H^i = 1$), there is a loss of lives. The government can invest in mitigation to reduce the loss of life. If the government spends $m^i \geq 0$ per person on mitigation, the fraction of lives lost equals $\rho(m^i)$ where $\rho(0) < 1$, $\rho > 0$, $\rho' < 0$, and $\rho'' > 0$[15]. Thus, the government of country i maximizes the expected value of the objective

$$Z^i \equiv \mu P^i(1 - H^i \rho(m^i)) + \eta(c^i - P^i m^i) \tag{37}$$

subject to the financial constraint $m^i \leq c^i/P^i$ in the absence of a global financial market. We focus on the case in which no country shuts down in the first period, we make the following assumption and then show that it is optimal for each country to not shut down.

Assumption 5. *(a) The saving of lives from a shutdown is valued more by the government than the loss of capital from the shutdown:*

$$\mu \hat{P}^i \lambda > \eta \hat{c}^i \kappa^i.$$

(b) The government has enough capital to choose the optimal level of mitigation investment in the second-period in the absence of a first-period shutdown but not with a first-period shutdown:

$$\frac{\hat{c}^i}{\hat{P}^i} < m^* < \frac{(1+\kappa^i)\hat{c}^i}{(1-\lambda)\hat{P}^i}$$

where

$$m^* = \arg\min_m (\mu\rho(m) + \eta m).$$

(c) The cost of insufficient capital for mitigation in a shutdown is sufficiently high:

$$\xi \hat{P}^i(\mu\rho(\frac{\hat{c}^i}{\hat{P}^i}) + \eta\frac{\hat{c}^i}{\hat{P}^i}) - \xi(1-\lambda)\hat{P}^i(\mu\rho(m^*) + \eta m^*) > \mu\hat{P}^i\lambda - \eta\hat{c}^i\kappa^i$$

[15]Unlike the main model, where the investment required for mitigation is fixed and the government chooses whether to mitigate or not, to avoid nonconvexity, we assume each government can choose how much to investment in mitigation

Under these parametric assumptions, the increase in the value of the objective function due to the saving of lives in a shutdown exceeds the decrease in the objective function from a reduction in capital, making a shutdown appealing. Thus, ignoring the second-period consequences, there is a predilection towards a shutdown. However, a shutdown also constrains mitigation investment in case of a second-period health shock, and the cost of this constraint is so large that each government chooses not to shut down.

Lemma 2. *No government imposes a shutdown in the first period if a global financial market does not exist.*

We will now use this "benchmark" case to examine whether a global financial market makes a shutdown more attractive. We are not suggesting that it is always optimal for governments to not shut down in the first period if there is no global financial market. Rather we want to focus on the deep parameter values for which this is true in order to have a benchmark that will then allow us to show that, even in this case, the advice of the public health experts may be to shut down.

V.B Global Financial Market

We now assume that countries can borrow and lend capital at the beginning of the second period ($t = 1$) in a global financial market. Each debt is structured to be repaid at a future time when the borrowing country is assumed to have enough capital to repay the debt. Each country chooses its demand and supply taking the interest rate as given. Let D^i be the net debt raised by country i. The government of country i maximizes the expected value of the objective

$$Z^i \equiv \mu P^i(1 - H^i\rho(m^i)) + \eta(c^i - P^i m^i - rD^i) \tag{38}$$

subject to the financial constraint $m^i \leq (c^i + D^i)/P^i$. The interest rate is determined by the market clearing condition: $\int_i D^i \mathrm{d}i = 0$.

A prerequisite to value-enhancing transactions in global financial markets is heterogeneity in countries. Countries may differ in their ex ante characteristics or in ex post outcomes. We first assume all countries are identical but some countries may experience a health shock in the second period while others do not. Specifically, we assume that not all countries experience a health shock in the second period:

$$\text{Probability}\left(\int_i \xi^i \mathrm{d}i = 1\right) = 0 \tag{39}$$

We now show that a global financial market relaxes the financial constraints that limit countries' ability to invest in mitigation in the second period and has the effect of inducing some countries to shut down their economies in the first period.

Proposition 5. *When countries can access a global financial market, there can not be an equilibrium in which no country shuts down in the first period. In any subgame perfect equilibrium, there is a positive mass of countries that shut down in the first period with a positive probability.*

The above proposition shows that a global financial market opens up opportunities for international debt and can relax the financial constraints on countries experiencing a second health shock. Countries that do not shut down in the first period or do not experience a health shock in the second period are not financially constrained and would lend to the countries that are financially constrained. Financially-constrained countries will borrow to invest optimally in mitigation provided the interest rate is not too high. The interest rate itself depends on the relative proportions of financially-constrained and unconstrained countries as well as their respective credit demand and credit supply functions. If there is a sufficiently large proportion of countries that do not shut down in the first period or do not experience a health shock in the second period, the interest rate is low and the financially constrained countries can overcome their financial constraints with borrowing. Anticipating this, at least some countries choose to shut down in the first period to save lives.

The equilibrium consists of one of three possibilities: (i) all countries shut down with a positive probability less than one; (ii) a "mixed" outcome in which some countries shut down with probability one and others never shut down, and (iii) a combination of (i) and (ii). A special case of (i) is when all countries shut down with probability one. This is possible if the second health shock hits a small proportion of countries and these countries can borrow from the countries which do not experience a second-period health shock.

The predisposition to shut down when a country can access a global financial market suggests another source of variation in countries' policy responses. Countries with lower integration with the global financial market or facing a higher marginal cost of funds are less likely to impose a shutdown than countries with better access to a global financial market.

We now assume that some countries are more productive than others. Specifically, there is a positive mass of high-productivity countries with $\kappa^i = \kappa^H$ and a positive mass of the remaining low-productivity countries with $\kappa^i = \kappa^L < \kappa^H$. The countries are identical otherwise with $\hat{c}^i = \hat{c}$ and $\hat{P}^i = \hat{P}$ for all i.

Proposition 6. *In any subgame perfect equilibrium, either all low-productivity countries shut down with probability one or all high-productivity countries shut down with probability zero.*

The above proposition shows that low-productivity countries are more likely to shut down than high-productivity countries. This is because the latter expect to lose more from shutting down their more productive production technology than do the former. This result assumes that the countries are otherwise identical. However, countries which differ in productivity may also differ in other characteristics, so an empirical test of this result must control for variations in characteristics other than productivity.

VI Discussion and Policy Implications

VI.A Governance during Pandemic

Our analysis shows that the career concerns of public health officials may bias their recommendations in addressing a health pandemic. While career concerns have been extensively studied in private organizations, public officials are no less susceptible to career concerns. For example, Bertrand, Burgess, Chawla, and Xu (2019) use a nationwide survey and data on elite civil servants in India to show that the career incentive of reaching the top of a public organization is a powerful determinant of bureaucrat performance. Career concerns among public officials are likely to prevail in developed economies as well as in emerging markets. Wilson (1991) finds that performance-based financial incentives are weak and the performance objectives are less well defined in U.S. public agencies than in the private sector. Thus, career concerns can play a significant role in shaping the incentives of public officials.

As we mentioned in the Introduction, our analysis has the implication that the government's policy choice should be predicated not only on the input of public health experts, but also those who care about economic outcomes. To the extent that career concerns are ubiquitous, there are two ways for the government to formulate a policy. One is to solicit input from public health experts and from economists who can assess the economic consequences of different policy choices. The government can then determine how to combine these recommendations with some sort of weighting scheme. Even if this solution does not eliminate the career concerns of public health experts, economists' input about economic consequences can help the government balance the dual objectives of saving lives and preserving economic output. Moreover, if this policy results in a positive probability that the senior health experts' recommendation to shut down the economy is overruled, it may moderate the impact that public health experts' career concerns have on their recommendations.

Another way for the government to overcome the bias in public health experts' recommendations is to employ those who combine public health expertise with economics expertise. These experts will then have career concerns that reflect both public health and economic consequences. There are some costs of such an arrangement. First, incentivizing effort provision from experts with diffuse expertise is costly (see Dewatripont et al., 1999). Second, even when experts have expertise in both public health and economics, differences in the measurability of their expertise or career concerns may lead each expert to focus predominantly on public health or economics (see Tirole, 1994; Goel, Nanda, and Narayanan, 2004). Despite these inefficiencies, during a pandemic that poses both a health crisis and an economic crisis, the broad expertise of such experts can be valuable in reaching nuanced approaches that balance conflicting goals (for example, see Acemoglu et al., 2020) rather than corner solutions that focus on one crisis and ignore the other.

This assumes, of course, that the government decisionmaker herself does not have career concerns. But this is an unrealistic assumption. In democracies, the President or the Prime Minister is an elected politician who also has career concerns. It is likely that these career concerns will be more heavily weighted either in favor of saving lives or in favor of conserving economic output. This means that even with public health experts and economics experts advising the government, public choices are likely to be biased in favor of shutdowns in countries where the head of the government's career concerns are skewed towards saving lives and against shutdowns in countries where the career concerns of the head of the government are more heavily tied to economic production.

These policy choices are likely to be biased towards a shutdown, partly due to the belief that a shutdown will save more lives than not shutting down; this is also the assumption in our model. However, one should recognize that since the shutdowns in the Covid-19 pandemic were unprecedented, there was no historical evidence to back up this belief—it was merely an assumption. It is only now that a serious examination of counterfactuals is emerging, and it is showing that the validity of this assumption is far from settled (see, for example, Born et al., 2020).

VI.B Emerging Markets

Our analysis also has implications for emerging market economies like India and Brazil. Compared to developed economies like the US, emerging market economies are more likely to be capital constrained and less likely to be labor constrained. This means that our assumption that an economy that shuts down in the first period will have insufficient resources for mitigation should a second pandemic hit in the second period is more likely to apply to emerging market economies. Moreover, such economies are also likely to have less resources to invest in fiscal stimuli, so the economic damage done by a shutdown may be greater in these economies than in developed economies. This appears to be the case in India, for example, which has suffered substantial economic damage from its shutdown.

An implication of our analysis is that for emerging market economies, it may be even more important that both public health experts and economics experts have their advice reflected in the policy choices of the government, and a greater weight should perhaps be placed on capital preservation than the weight placed by developed economies.

VI.C Voluntary Shutdown

The case for shutting down economy during a pandemic should be based on a comparison of the effectiveness of the consequent shutdown in reducing the spread of infection and consequent saving of lives with the loss of economic output due to the shutdown. This tradeoff is likely to vary across economies, industries, and businesses. In the absence of a shutdown, private organizations can evaluate the tradeoff and choose the degree to which they suspend operations. An approach that allows businesses to voluntarily shut down allows businesses to make more informed decisions that result in lower economic loss than a government-imposed blanket shutdown, while suppressing the spread of the infection. An argument against allowing businesses to make these decisions is that the private goals of businesses differ from social goals and that the businesses will not take into account the health externalities their actions impose on others. However, to the extent businesses depend on and care about the health concerns and economic concerns of consumers, employees and other stakeholders, their interests may be closely aligned with social objectives. These complex interactions are worthy of further research.

VII Conclusion

In this paper we have presented a simple two-period model of a production-consumption economy that can suffer stochastic health shocks in the form of pandemics. The government is faced with a choice from a set of four policy choices in response to the pandemic: do nothing, invest in mitigation only, shut down the economy without mitigation, and invest in mitigation and also shut down the economy. What the government finds optimal to do in each period depends on the weights it puts on mortality rates and the economic output that is eventually consumed by agents in the economy.

We establish sufficient conditions under which a shutdown of the economy with an investment in mitigation can lead to both lower consumption and a higher mortality rate than investing in mitigation without shutting down the economy. Then, instead of assuming a faceless decisionmaking body called "the government," we introduce two public-health experts who advise the government on the optimal policy choice during an epidemic, based on their privately-observed, noisy but informative signals. The informativeness of their signals depends on their respective expertise. There is uncertainty about the expertise of each expert, as well as about whether the experts have career concerns. Each expert acts to influence the likelihood that his expertise is evaluated to be higher than that of the other expert. In this case, we show that truthful reporting of their signals by the two experts is *not* a Nash equilibrium. If the experts are expected to be truthful, then, even when the deep parameter values are such that mitigation without a shutdown leads to fewer deaths, the expert with the greater perceived expertise recommends a shutdown with mitigation. We discuss the policy implications of this result in the Introduction and Section VI.

We also show that a more developed financial market tends to incline governments toward shutting down in the first period. This is because with a better-developed market, the government has a higher probability of borrowing in the second period against its terminal output. This softens the impact of a lower first-period economic output due to a shutdown, making a shutdown more attractive. An implication is that countries with costlier access to the global financial market are less likely to shut down. High-productivity countries are also less likely to shut down than low-productivity countries.

Our analysis has not considered numerous complications that may be useful for future research. For example, not shutting down the economy in the first period may facilitate the development of herd immunity that leads to *lower* deaths in the second period without a shutdown than with a shutdown. Alternatively, *not* shutting down the economy in the first period could lead to peak-load problems that cause the health system of the economy to crash. A third extension would be to introduce deaths from *non-Covid-19* causes that could be higher with a shutdown than without, so that *total deaths*—Covid-related and non-Covid—may be higher with a shutdown, leading to a "corner" policy solution. These extensions require making calls that need to be based on empirical evidence not available yet.

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APPENDIX

Proof of Proposition 1: For the proof of part (1), consider $\alpha < \hat{\alpha}$. Then, the government's objective is

$$Z = \alpha P_2 + (1-\alpha)C_2 = \frac{1-\alpha}{1-\hat{\alpha}}\left(\hat{\alpha}P_2 + (1-\hat{\alpha})C_2\right) + \left(\alpha - \frac{(1-\alpha)\hat{\alpha}}{1-\hat{\alpha}}\right)P_2.$$

The first term on the right is maximized with the policy of doing nothing by the definition of $\hat{\alpha}$. The second term is a negative multiple of the number of lives, and the number of lives is minimized by doing nothing.

For the proof of part (2), consider $\alpha > \hat{\alpha}$. Then, the government's objective is

$$Z = \alpha P_2 + (1-\alpha)C_2 = \frac{1-\alpha}{1-\hat{\alpha}}\left(\hat{\alpha}P_2 + (1-\hat{\alpha})C_2\right) + \left(\alpha - \frac{(1-\alpha)\hat{\alpha}}{1-\hat{\alpha}}\right)P_2.$$

The first term on the right is maximized with investment in mitigation and imposing a shutdown by the definition of $\hat{\alpha}$. The second term is a positive multiple of the number of lives and is maximized with an investment in mitigation and imposing a shutdown.

For the proof of part (3), the difference in the government's objective with a policy of mitigation (but no shutdown) over doing nothing is obtained from (22), (23), (24) and (25) as:

$$\begin{aligned}
&\mathbb{E}[Z(H=1, M_2=1, S_2=0)] - \mathbb{E}[Z(H=1, M_2=0, S_2=0)] \\
&= (\alpha\left(\mathbb{E}[\tilde{\lambda}_2^N] - \mathbb{E}[\tilde{\lambda}_2^M]\right)P_1 - (1-\alpha)(1-\delta)m \\
&+ (1-\alpha)(\beta+\delta-1)\left(\mathbb{E}[\min(C_1 - m, (1-\tilde{\lambda}_2^M)P_1] - \mathbb{E}[\min(C_1, (1-\tilde{\lambda}_2^N)P_1]\right).
\end{aligned}$$

The derivative of the above expression with respect to C_1 is:

$$
\begin{aligned}
&(1-\alpha)(\beta+\delta-1)\left(\mathbb{P}[(1-\tilde{\lambda}_2^M)P_1 > C_1 - m] - \mathbb{P}[(1-\tilde{\lambda}_2^N)P_1 > C_1]\right) \\
&\geq (1-\alpha)(\beta+\delta-1)\left(\mathbb{P}[(1-\tilde{\lambda}_2^M)P_1 > C_1] - \mathbb{P}[(1-\tilde{\lambda}_2^N)P_1 > C_1]\right) \\
&\geq (1-\alpha)(\beta+\delta-1)\left(\mathbb{P}[\tilde{\lambda}_2^M < 1 - C_1/P_1] - \mathbb{P}[\tilde{\lambda}_2^N > 1 - C_1/P_1]\right) > 0.
\end{aligned}
$$

The last inequality follows from (14). □

Proof of Lemma 1: The result is obvious if there is no health shock in the second period. We show that it holds even if there is a health shock in the second period. We first consider the effect of C_1 on $\mathbb{E}[C_2]$ and $\mathbb{E}[P_2]$. From equations (20)-(29), it is clear that for all possible combinations of H, M_2, and S_2, $\mathbb{E}[P_2(H, M_2, S_2)]$ is independent of C_1 and $\mathbb{E}[C_2(H, M_2, S_2)]$ is strictly increasing in C_1. That is,

$$
\begin{aligned}
&\mathbb{E}[P_2(H, M_2, S_2) \mid P_1, C_1^1] = \mathbb{E}[P_2(H, M_2, S_2) \mid P_1, C_1^2] \quad \forall P_1, C_1^1, C_1^2 \text{ and} \\
&C_1^1 > C_1^2 \iff \mathbb{E}[C_2(H, M_2, S_2) \mid P_1, C_1^1] > \mathbb{E}[C_2(H, M_2, S_2) \mid P_1, C_1^2] \quad \forall P_1.
\end{aligned}
$$

Suppose the government response M_2^* and S_2^* results in lives P_2 and capital stock C_2 at the end of period 2 when the capital is C_1^1 and there are P_1 people at the end of period 1. Then with capital stock $C_1^2 > C_1^1$ at the end of period 1:

$$
\max_{M_2, S_2} \mathbb{E}[P_2(H, M_2, S_2) \mid P_1, C_1^2] \geq \mathbb{E}[P_2(H, M_2^*, S_2^*) \mid P_1, C_1^2] = \mathbb{E}[P_2(H, M_2^*, S_2^*) \mid P_1, C_1^1]
$$

and

$$
\max_{M_2, S_2} \mathbb{E}[C_2(H, M_2, S_2) \mid P_1, C_1^2] \geq \mathbb{E}[C_2(H, M_2^*, S_2^*) \mid P_1, C_1^2] > \mathbb{E}[C_2(H, M_2^*, S_2^*) \mid P_1, C_1^1].
$$

We now consider the effect of P_1 on $\mathbb{E}[C_2]$ and $\mathbb{E}[P_2]$. From equations (20)-(29), it is clear that for all possible combinations of H, M_2, and S_2, $\mathbb{E}[P_2(H, M_2, S_2)]$ are strictly increasing in C_1 and $\mathbb{E}[C_2(H, M_2, S_2)]$ is weakly increasing in P_1. That is,

$$
\begin{aligned}
&P_1^1 > P_1^2 \Longleftrightarrow \mathbb{E}[P_2(H, M_2, S_2) \mid P_1^1, C_1] > \mathbb{E}[P_2(H, M_2, S_2) \mid P_1^2, C_1] \quad \forall C_1 \text{ and} \\
&P_1^1 > P_1^2 \Longrightarrow \mathbb{E}[C_2(H, M_2, S_2) \mid P_1^1, C_1] \geq \mathbb{E}[C_2(H, M_2, S_2) \mid P_1^2, C_1] \quad \forall C_1.
\end{aligned}
$$

Suppose the government response M_2^* and S_2^* results in lives P_2 and capital stock C_2 at the end of period 2 when the capital is C_1 and there are P_1^1 people at the end of period 1. Then with $P_1^2 > P_1^1$ people at the end of period 1:

$$
\max_{M_2, S_2} \mathbb{E}[P_2(H, M_2, S_2) \mid P_1^2, C_1] \geq \mathbb{E}[P_2(H, M_2^*, S_2^*) \mid P_1^2, C_1] > \mathbb{E}[P_2(H, M_2^*, S_2^*) \mid P_1^1, C_1]
$$

and

$$
\max_{M_2, S_2} \mathbb{E}[C_2(H, M_2, S_2) \mid P_1^2, C_1] \geq \mathbb{E}[C_2(H, M_2^*, S_2^*) \mid P_1^2, C_1] \geq \mathbb{E}[C_2(H, M_2^*, S_2^*) \mid P_1^1, C_1].
$$

□

Proof of Proposition 2: We provide a series of sufficient conditions for the result to hold. These conditions are restrictions on the exogenous parameters. We assume $\gamma_2 = 0$ so that a health shock always results in a shutdown in the second period. This condition can be relaxed but simplifies the proof.

First consider the case that there is investment in mitigation but no shutdown in the first period. The number of people alive at t=1 in this case is

$$
P_1(M_1 = 1, S_1 = 0) = \begin{cases} (1 - \lambda_1^{MS}) P_0 & \text{with probability } \pi_1^M, \\ (1 - \lambda_1^{MH}) P_0 & \text{with probability } 1 - \pi_1^M. \end{cases} \tag{40}
$$

The capital stock at t=1 is

$$\begin{aligned} C_1(M_1 = 1, S_1 = 0) &= (1-\delta)(C_0 - m) + (\beta + \delta - 1)\min(C_0 - m, P_1(M_1 = 1, S_1 = 0)) \\ &= (1-\delta)(C_0 - m) + (\beta + \delta - 1)P_1(M_1 = 1, S_1 = 0), \end{aligned} \tag{41}$$

under the assumption

$$\textit{Parametric Restriction:} \quad C_0 \geq \frac{(1-\lambda_1^{Ml})P_0}{1-\delta}. \tag{42}$$

With probability $1-\xi$ there is no health shock at t=1, and the number of people alive at t=2 is

$$P_2(M_1 = 1, S_1 = 0, H = 0) = P_1(M_1 = 1, S_1 = 0). \tag{43}$$

With probability ξ, there is a health shock at t=1. Assuming there is enough capital stock for mitigation in the second period (parametric condition to follow) and the government will invest in mitigation and impose a shutdown. The number of people alive at t=2 is

$$P_2(M_1 = 1, S_1 = 0, H = 1) = (1-\lambda_2^{MS})P_1(M_1 = 1, S_1 = 0). \tag{44}$$

Next, consider the case that there is investment in mitigation and a shutdown in the first period. The number of people alive at t=1 in this case is

$$P_1(M_1 = 1, S_1 = 1) = (1-\lambda_1^{MS})P_0, \tag{45}$$

and the capital stock at t=1 is

$$
\begin{aligned}
C_1(M_1 = 1, S_1 = 1) = (1-\delta)(C_0 - m) + ((1-\gamma_1)\beta + \delta - 1) \min(C_0 - m, P_1(M_1 = 1, S_1 = 1)) \\
= (1-\delta)(C_0 - m) + ((1-\gamma_1)\beta + \delta - 1) P_1(M_1 = 1, S_1 = 1), \qquad (46)
\end{aligned}
$$

using (42). The term $1-\gamma_1$ captures the depletion of the capital stock due to shutdown. We assume that capital stock is insufficient for mitigation in the second period:

$$
\textit{Parametric Restriction}: \quad C_0 \leq \frac{m - ((1-\gamma_1)\beta + \delta - 1)(1-\lambda_1^{MS})P_0}{1-\delta} + m. \qquad (47)
$$

If there is no health shock at t=1, the number of people alive at t=2 is

$$
P_2(M_1 = 1, S_1 = 1, H = 0) = P_1(M_1 = 1, S_1 = 1). \qquad (48)
$$

If there is a health shock at t=1, the government cannot invest in mitigation but still imposes a shutdown, and the number of people alive at t=2 is

$$
P_2(M_1 = 1, S_1 = 1, H = 1) = (1-\lambda_2^{Nl})P_1(M_1 = 1, S_1 = 1). \qquad (49)
$$

Using (40), (43), (44), (45), (48), and (49), the expected number of people alive at t=2 without a shutdown in the first-period exceeds the expected number of people alive at t=2 with a shutdown in the first-period if

$$
(1-\xi\lambda_2^{MS})\left(1 - \pi_1^M \lambda_1^{MS} - (1-\pi_1^M)\lambda_1^{MH}\right) \geq (1-\xi\lambda_2^{Nl})(1-\lambda_1^{MS}) \qquad (50)
$$

which holds if we assume

$$\textit{Parametric Restriction}: \quad 1 \geq \xi \geq \frac{(1-\pi_1^M)(\lambda_1^{MH}-\lambda_1^{MS})}{\lambda_2^{Nl}(1-\lambda_1^{MS})-\lambda_2^{MS}(1-\pi_1^M\lambda_1^{MS}-(1-\pi_1^M)\lambda_1^{MH})}. \tag{51}$$

We now compare the expected capital stock at t=2 under the two scenarios - no shutdown in the first period and a shutdown in the first period. A shutdown in the first period may save more lives at the expense of a diminished capital stock. If there is no further health shock in the second period, these two effects of the first-period shutdown have opposing effects on production in the second period. As a result, the capital stock with a shutdown may be higher or lower than without a shutdown. It is sufficient to show that, conditional on a second health shock, under some parametric restrictions, the capital stock at the end of the second period is lower if there is a first-period shutdown at t=1 than if there is no shutdown at t=1. The desired result then follows with a large enough probability of a health shock.

Suppose there is no shutdown in the first period and there is a health shock in the second period. Using (29), the value of the capital stock at t=2 is

$$C_2(M_1=1,S_1=0,H=1)=(1-\delta)(C_1-m)+(\beta+\delta-1)\min(C_1-m,(1-\lambda_2^{MS})P_1). \tag{52}$$

We assume that production is labor-constrained:

$$C_1-m \geq (1-\lambda_2^{MS})P_1 \tag{53}$$

Using (40) and (41), the following condition is sufficient for this assumption.

$$\textit{Parametric Restriction}: \quad C_0 \geq \frac{(2-\beta-\delta-\lambda_2^{MS})(1-\lambda_1^{MS})P_0+m}{1-\delta}+m. \tag{54}$$

Substituting (53) in (52), we get

$$C_2(M_1 = 1, S_1 = 0, H = 1) \geq \beta(1 - \lambda_2^{MS})P_1$$

Substituting (40), we get

$$\mathbb{E}[C_2 \mid M_1 = 1, S_1 = 0, H = 1] \geq \beta(1 - \lambda_2^{MS}) \left(1 - \pi_1^M \lambda_1^{MS} - (1 - \pi_1^M)\lambda_1^{MH}\right) P_0. \tag{55}$$

Now consider the case of a shutdown in the first period followed by another health shock in the second period. As already discussed, the government does not invest in mitigation in the second period but imposes a shutdown. Using (27), the value of the capital stock at t=2 is

$$C_2(M_1 = 1, S_1 = 1, H = 1) = (1 - \delta)C_1 + (\beta + \delta - 1)\min(C_1, (1 - \lambda_2^{Nl})P_1). \tag{56}$$

We assume that depletion of capital from the first-period shutdown causes production to be capital-constrained:

$$C_1 \leq (1 - \lambda_2^{Nl})P_1 \tag{57}$$

Using (45) and (46), the following condition is sufficient for this assumption.

$$\textit{Parametric Restriction:} \quad C_0 \leq \frac{\left(2 - (1 - \gamma_1)\beta - \delta - \lambda_2^{Nl}\right)(1 - \lambda_1^{MS})P_0}{1 - \delta} + m. \tag{58}$$

Substituting (58) in (57), we get

$$C_2(M_1 = 1, S_1 = 1, H = 1) \leq \beta(1 - \lambda_2^{Nl})P_1 \tag{59}$$

Substituting (45), we get

$$\mathbb{E}[C_2 \mid M_1 = 1, S_1 = 1, H = 1] \leq \beta(1 - \lambda_2^{Nl})(1 - \lambda_1^{MS})P_0. \tag{60}$$

From (51), it follows that

$$(1 - \lambda_2^{MS}) \left(1 - \pi_1^M \lambda_1^{MS} - (1 - \pi_1^M)\lambda_1^{MH}\right) \geq (1 - \lambda_2^{Nl})(1 - \lambda_1^{MS}).$$

Combining this inequality with (55) and (60), we get

$$\mathbb{E}[C_2 \mid M_1 = 1, S_1 = 0, H = 1] \geq \mathbb{E}[C_2 \mid M_1 = 1, S_1 = 1, H = 1]$$

The parametric restriction (47) holds if $\lambda_1^{Mh} - \lambda_1^{Ml}$ is small or if π_1^M is high. This is true if if the difference between the expected number of deaths with a shutdown and without a shutdown is small in the first period when the government invests in mitigation. Parametric restrictions (54) and (58) hold if the initial stock of capital is not too high (in which case the government can always invest in mitigation in the second-period) and not too low (in which case the government can never invest in mitigation in the second-period). A non-empty range for initial capital stock exists if (42), (54), and (58) are consistent. A sufficient condition for this is:

$$\frac{\left\{(1 - \gamma_1)\beta + \delta + \lambda_2^{Nl} - 1\right\}(1 - \lambda_1^{Ml})P_0}{1 - \delta} < m < (\gamma_1\beta + \lambda_2^{Ml} - \lambda_2^{Nl})(1 - \lambda_1^{Ml})P_0. \tag{61}$$

That is, the production technology creates high surplus without a shutdown but most of that surplus is dissipated with a shutdown. The interpretation of the first inequality is that the economic output created from the production technology in the case of a shutdown is insufficient to allow for investment in mitigation in the second period. The interpretation of the second inequality is that the investment in mitigation is less than the impact of a first-period shutdown on the capital stock (through the parameter combination $\gamma_1\beta$) and on lives lost in the second period if the government cannot invest in mitigation (through the parameter combination $\lambda_2^{Ml} - \lambda_2^{Nl}$). The two inequalities are consistent if γ_1 is sufficiently high and β is sufficiently high.

As an example, all the parametric restrictions are satisfied if $C_0 = 4/3$, $P_0 = 0.9$, $m = 0.5$, $\lambda_1^{MS} = 0.1$, $\lambda_1^{MH} = 0.2$, $\lambda_1^{S} = 0.8$, $\lambda_1^{H} = 0.9$, $\lambda_2^{MS} = 0.1$, $\lambda_2^{MH} = 0.2$, $\lambda_2^{Nl} = 0.2$, $\lambda_2^{H} = 0.3$, $\pi_1^M = 0.4$, $\beta = 1.5$, $\delta = 0.1$, $\gamma_1 = 0.65$, $\gamma_2 = 0$, and $\xi = 0.65$. □

Proof of Proposition 3: Suppose there is a Nash Equilibrium in which the two experts truthfully report their signals, regardless of whether they have career concerns or not. If both experts report a bad signal, there is a shutdown. The government's posterior probability that $\tau_s = T$ is

$$\frac{(1-\pi)p_s(p_j + (1-p_j)(1-\pi))}{\pi((1-p_s)\pi)((1-p_j)\pi) + (1-\pi)(p_s + (1-p_s)(1-\pi))(p_j + (1-p_j)(1-\pi))}$$

and the government's posterior probability that $\tau_j = T$ is

$$\frac{(1-\pi)(p_s + (1-p_s)(1-\pi))p_j}{\pi((1-p_s)\pi)((1-p_j)\pi) + (1-\pi)(p_s + (1-p_s)(1-\pi))(p_j + (1-p_j)(1-\pi))}.$$

A comparison of the previous two expressions shows that the senior expert continues to be considered talented with a higher probability and continues as senior expert at t=1.

If both experts report a good signal, there is no shutdown. If the number of deaths is low ($\tilde{\lambda} = \lambda^l$), the government's posterior probability that $\tau_s = T$ is

$$\frac{p_s}{p_s + (1-p_s)\pi} \tag{62}$$

and the government's posterior probability that $\tau_j = T$ is

$$\frac{p_j}{p_j + (1 - p_j)\pi}. \tag{63}$$

Again, a comparison of the previous two expressions shows that the senior expert continues to be considered talented with a higher probability and continues as senior expert at t=1.

If following reports of good signals by both experts and following no shutdown, the number of deaths is high ($\tilde{\lambda} = \lambda^h$), both experts are considered untalented ($\tau_s = \tau_j = U$). We assume that either expert may get the title of senior expert with a positive probability.

If the senior expert reports a bad signal but the junior expert reports a good signal, there is a shutdown. The government's posterior probability that $\tau_s = T$ is

$$\frac{(1 - \pi)p_s(1 - p_j)\pi}{\pi((1 - p_s)(1 - \pi))(p_j + (1 - p_j)\pi) + (1 - \pi)(p_s + (1 - p_s)(1 - \pi))((1 - p_j)\pi)}$$

and the government's posterior probability that $\tau_j = T$ is

$$\frac{\pi(1 - p_s)(1 - \pi)p_j}{\pi((1 - p_s)(1 - \pi))(p_j + (1 - p_j)\pi) + (1 - \pi)(p_s + (1 - p_s)(1 - \pi))((1 - p_j)\pi)}$$

Again, a comparison of the previous two expressions shows that the senior expert continues to be considered talented with a higher probability and continues as senior expert at t=1.

If the senior expert reports a good signal but the junior expert reports a bad signal, there is no shutdown. In this case, if the number of deaths is low ($\tilde{\lambda} = \lambda^l$), the junior expert is inferred to be untalented and the senior expert retains his title at t=1. If, however, the number of deaths is high ($\tilde{\lambda} = \lambda^h$), the senior expert is inferred to be untalented and loses the title of the senior expert at t=1.

Considering all possible cases, whenever the senior expert reports a bad signal, he retains the title of senior expert at t=1. However, if the senior expert reports a good signal, regardless of his actual signal, there is a positive probability that he may lose the title at t=1. If the senior expert is driven by career concerns ($c = 1$), reporting a bad signal dominates reporting a good signal. Therefore, a senior expert with career concerns reports a bad signal when his signal is good. □

Proof of Proposition 4: We first show that each expert's equilibrium strategy is incentive compatible taking the other expert's and the government's equilibrium strategies as given. Then, we show that the government's strategy is incentive compatible if the government updates its beliefs using Bayes rule, taking the experts' equilibrium strategies as given. First consider the senior expert without career concerns ($c = 0$). The expert shares the government's objective function. Since the government imposes a shutdown if and only if he reports a bad signal, and the expert also prefers a shutdown if and only if his signal is bad (see Assumption 4), it is incentive compatible for the expert to truthfully report his signal.

Now consider the senior expert with career concerns ($c = 1$) who is concerned with retaining the title of senior expert at t=1. If both experts report a bad signal, there is a shutdown. The joint probability of the two reports and $\tau_s = T$ is

$$p_s \left[\pi\mu \left\{ (1-\mu)(1-p_j)(1-\mu) + \mu \right\} + (1-\pi) \left\{ p_j + (1-p_j)(1-\pi) + (1-p_j)\pi\mu \right\} \right].$$

The joint probability of the two reports and $\tau_j = T$ is

$$p_j \left[\pi \left\{ (1-\mu)(1-p_s)(1-\mu) + \mu \right\} + (1-\pi) \left\{ p_s + (1-p_s)(1-\pi) + (1-p_s)\pi\mu \right\} \right].$$

Comparing the previous two expressions, the probability that $\tau_s = T$ exceeds the probability that $\tau_j = T$ and the senior expert continues as senior expert at t=1

If both experts report a good signal, there is no shutdown. If the number of deaths is low ($\tilde{\lambda} = \lambda^l$), the joint probability of both reports of good signals, low number of deaths and senior expert being talented is

$$\pi p_s(1-\mu)(1-\mu)\{p_j+(1-p_j)\pi\}. \tag{64}$$

The joint probability of both reports of good signals, low number of deaths and junior expert being talented is

$$\pi(1-\mu)\{p_s+(1-p_s)\pi\}(1-\mu)p_j. \tag{65}$$

A comparison of the previous two expressions shows that the senior expert continues to be considered talented with a higher probability and continues as senior expert at t=1.

If following reports of good signals by both experts and following no shutdown, the number of deaths is high ($\tilde{\lambda}=\lambda^h$), both experts are revealed to be untalented ($\tau_s=\tau_j=U$). We assume that either expert may get the title of senior expert with a positive probability.

If the senior expert reports a bad signal but the junior expert reports a good signal, there is a shutdown. The joint probability of the two reports and the senior expert being talented is

$$p_s\left[\pi\mu(1-\mu)\left\{p_j+(1-p_j)\pi\right\}+(1-\pi)(1-\mu)(1-p_j)\pi\right].$$

The joint probability of the two reports and the junior expert being talented is

$$p_j\pi\left[\left\{p_s+(1-p_s)\pi\right\}\mu+(1-p_s)(1-\pi)\right](1-\mu).$$

Again, a comparison of the previous two expressions shows that the senior expert continues to be considered talented with a higher probability and continues as senior expert at t=1.

If the senior expert reports a good signal but the junior expert reports a bad signal, there is no shutdown. In this case, if the number of deaths is low ($\tilde{\lambda}=\lambda^l$), the joint probability of the two reports and the senior expert being talented is

$$p_s\pi(1-\mu)\left[(1-p_j)(1-\pi)+\mu\left\{p_j+(1-p_j)\pi\right\}\right].$$

The joint probability of the two reports and the junior expert being talented is

$$p_j\pi(1-\mu)\left\{p_s+(1-p_s)\pi\right\}\mu.$$

Again, a comparison of the previous two expressions shows that the senior expert continues to be considered talented with a higher probability and continues as senior expert at t=1.

If, however, the number of deaths is high ($\tilde{\lambda}=\lambda^h$), the senior expert is inferred to be untalented and loses the title of the senior expert at t=1.

Considering all possible cases, for a senior expert with career concerns, reporting a bad signal is a dominant strategy.

Now, consider the junior expert without career concerns ($c=0$) who wants to maximize the government's objective Z. His equilibrium strategy of truthful reporting is incentive compatible because the government's decision to shut down or not depends only on the senior expert's report.

The junior expert with career concerns ($c=1$) wants to maximize the probability of being appointed the senior expert at t=1. Following a discussion of various cases above, if the senior expert reports a bad signal, there is a shutdown and the senior expert retains his title at t=1 regardless of the junior expert's report. If the senior expert reports a good signal, there is no shutdown, and the number of deaths is low ($\tilde{\lambda}=\lambda^h$), again the senior expert retains his title regardless of the junior expert's report. If however, the senior expert reports a good signal, there is no shutdown, and deaths are high ($\tilde{\lambda}=\lambda^h$), the junior expert gets the senior expert's title at t=1 with a probability between 0 and 1 if he reported a good signal as well but with probability 1 if he reported a bad signal. Thus, reporting a bad signal is a dominant strategy for the junior expert with career concerns.

To show that the government's proposed equilibrium strategy is incentive compatible, it suffices to show that

$$\theta(y_s = b, y_j = g) < \theta^* < \theta(y_s = g, y_j = b). \tag{66}$$

Using beliefs about equilibrium strategies and Bayes rule,

$$\frac{\theta(y_s = b, y_j = g)}{1 - \theta(y_s = b, y_j = g)} = \tag{67}$$

$$\frac{\pi \left[(1-p_s)(1-\pi) + \mu \left\{p_s + (1-p_s)\pi\right\}\right](1-\mu)\left\{p_j + (1-p_j)\pi\right\}}{(1-\pi)\left\{p_s + (1-p_s)(1-\pi) + \mu(1-p_s)\pi\right\}(1-\mu)(1-p_j)\pi} \tag{68}$$

and

$$\frac{\theta(y_s = g, y_j = b)}{1 - \theta(y_s = g, y_j = b)} = \tag{69}$$

$$\frac{\pi(1-\mu)\left\{p_s + (1-p_s)\pi\right\}\left[(1-p_j)(1-\pi) + \mu\left\{p_j + (1-p_j)\pi\right\}\right]}{(1-\pi)(1-\mu)(1-p_s)\pi\left\{p_j + (1-p_j)(1-\pi) + \mu(1-p_j)\pi\right\}}. \tag{70}$$

Notice that (66) follows from Assumption 4, (68), and (70) if $\mu = 0$. From continuity of f and therefore, of θ^*, if μ is sufficiently small, (66) holds and the government's equilibrium strategy is incentive-compatible.

If the senior expert observes a good signal, the government does not impose a shutdown in the first-best equilibrium but if the senior expert has career concerns, he reports a bad signal and the government imposes a shutdown. □

Proof of Lemma 2: If country i shuts down in the first period, the expected value of its government's objective is

$$\mu\hat{P}^i + \eta\hat{c}^i - \xi\hat{P}^i \min_{m^i \leq \frac{\hat{c}^i}{\hat{P}^i}} (\mu\rho(m^i) + \eta m^i) = \mu\hat{P}^i + \eta\hat{c}^i - \xi\hat{P}^i(\mu\rho(\frac{\hat{c}^i}{\hat{P}^i}) + \eta\frac{\hat{c}^i}{\hat{P}^i}). \tag{71}$$

where the equality follows from Assumption 5(b). If country i does not shut down in the first period, the expected value of its government's objective is

$$\mu(1-\lambda)\hat{P}^i + \eta(1+\kappa^i)\hat{c}^i - \xi(1-\lambda)\hat{P}^i \min_{m^i \leq \frac{(1+\kappa^i)\hat{c}^i}{(1-\lambda)\hat{P}^i}} (\mu\rho(m^i) + \eta m^i)$$

$$= \mu(1-\lambda)\hat{P}^i + \eta(1+\kappa^i)\hat{c}^i - \xi(1-\lambda)\hat{P}^i(\mu\rho(m^*) + \eta m^*). \tag{72}$$

where the equality follows from Assumption 5(b). Assumption 5(c) guarantees that this expected payoff exceeds the expected payoff with a shutdown. □

Proof of Proposition 5: For each country, there is a unique choice of second-period debt and investment in mitigation that maximizes the expected value of its objective (38) given interest rate r. The debt D^i raised by country i is non-increasing in interest rate r so there is a unique market clearing rate. Thus, second-period outcome is a deterministic and continuous function of (P^i, C^i, H^i) for all countries. Further, since P^i and C^i depend on whether country i shuts down or not in the first period, the expected payoff of each country is a continuous function of the probabilities with which different countries shut down. The strategy space (probabilities of shutdowns) is compact so a Nash equilibrium exists in mixed strategies. Since we assume each country maximizes the expected value of its objective (38), the equilibrium is subgame perfect.

We now show that there is a positive mass of countries that shut down with a positive probability. Suppose this is not true. Then, there is a set $mathcal I$ of countries with unit mass that shut down with probability zero. From Assumption 5(b), each of these countries have second-period capital in excess of m^* and are indifferent to lending m^* (that is, choosing debt $-m^*$) if the interest rate r is zero. This means any country can borrow $m^(*)$ at $r = 0$. Given this, we will shows that the equilibrium strategy of country $i \in \mathcal{I}$ to never shut down is not incentive compatible. Country i's expected payoff in absence of a shutdown is given by (72) and its expected payoff with a shutdown is given by

$$\mu \hat{P}^i + \eta \hat{c}^i - \xi \left\{ \hat{P}^i \min_{m^i \leq \frac{\hat{c}^i + D^i}{\hat{P}^i}} (\mu\rho(m^i) + \eta m^i) - rD^i \right\} = \mu \hat{P}^i + \eta \hat{c}^i - \xi \hat{P}^i (\mu\rho(m^*) + \eta m^*). \tag{73}$$

where the equality follows from Assumption 5(b) and the fact that country i can borrow up to m^* at rate $r = 0$. Using Assumption 5(a), the expected value of the objective in (73) exceeds the expected value of the objective in (72). This rules out the proposed equilibrium. □

Proof of Proposition 6: Country i's payoff if all other countries follow their equilibrium strategy and country i shuts down in the first period is given by

$$\mu \hat{P} + \eta \hat{c} - \xi \left\{ \hat{P} \min_{D, m \leq \frac{\hat{c} + D}{\hat{P}}} (\mu\rho(m) + \eta m) - rD^i \right\}. \tag{74}$$

This payoff is the same for all countries but is conditional on interest rate r. Since each country is atomistic and doesn't impact r, the equilibrium probability distribution of r is same for all countries and therefore, the expected payoff from shutting down in the first period is same for all countries.

A more productive country's payoff if all other countries follow their equilibrium strategy and that country does not shut down in the first period is given by

$$\mu(1-\lambda)\hat{P} + \eta(1+\kappa^H)\hat{c} - \xi(1-\lambda)\hat{P} \min_{D, m \leq \frac{(1+\kappa^H)\hat{c}}{(1-\lambda)\hat{P}}} (\mu\rho(m) + \eta m). \tag{75}$$

A less productive country's payoff if all other countries follow their equilibrium strategy and that country does not shut down in the first period is given by

$$\mu(1-\lambda)\hat{P} + \eta(1+\kappa^L)\hat{c} - \xi(1-\lambda)\hat{P} \min_{D, m \leq \frac{(1+\kappa^L)\hat{c}}{(1-\lambda)\hat{P}}} (\mu\rho(m) + \eta m). \tag{76}$$

Suppose there is a less productive country i that does not shut down with probability one in equilibrium. Then, its expected payoff from shutting down must be less than or equal to its expected payoff from not shutting down. That is, the expected value of (74) must be less than or equal to the expected value of (76). It follows that the expected value of (74) must be less than the expected value of (75) (since (76) is less than (75) for each value of r). That is, the expected payoff of any more productive country from shutting down is less than its expected payoff from not shutting down. All more productive countries must then shut down with probability zero in equilibrium. $\square$