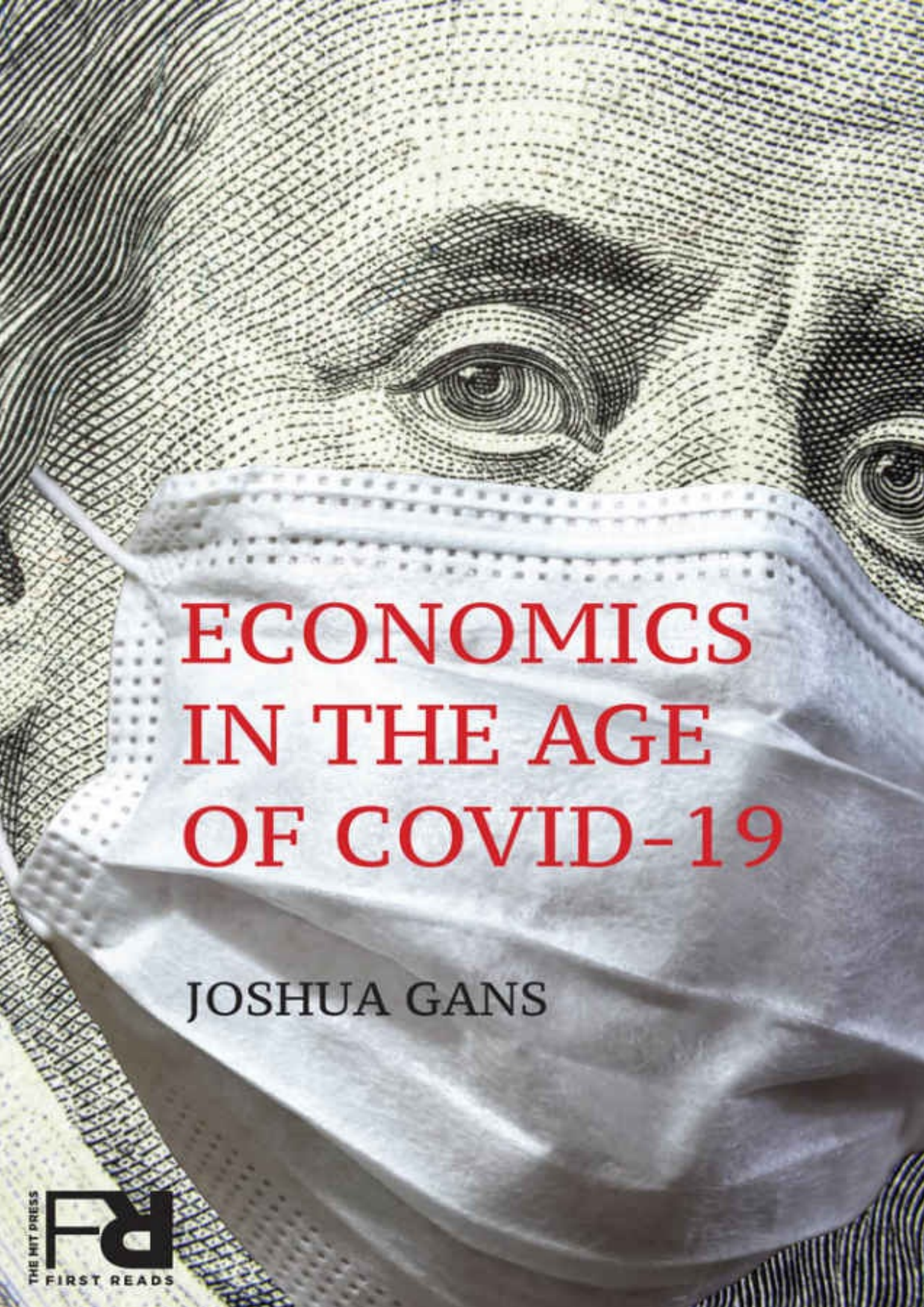
ECONOMICS
IN THE AGE
OF COVID-19
JOSHUA GANS
THE MIT PRESS
FIRST READS

Economics in the Age of COVID-19

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Preface

On September 26, 2001, *The Onion* headline read, “Not Knowing What Else to Do, Woman Bakes American-Flag Cake.”[1] That was the feeling I had at the onset of the COVID-19 pandemic in March 2020. I found myself unable to get work done and constantly obsessing over news and then data on topics that I knew very little about. I was in self-isolation, having traveled to the United States. Upon reflection, not knowing what else to do, I decided I would do what I was good at: I’d write a book. I would endeavor to explain some of the broader economic issues arising from the pandemic to a wide audience.

In this task, I was hampered by two things. First, and this is what every economist writing about this has been saying, I am not an epidemiologist. That meant I was absorbing that material as an amateur and so had to be cautious regarding my own understanding. So, I would be flying well beyond what the usual academic norms would dictate, which meant I had to be careful in making any claims. That said, my goal here was to explain the economic issues of all this, and in that task, I was very experienced. Second, things were moving fast. Policies were changing. Scientists were learning more about the virus and its disease. No one had the information to create an appropriate assessment to evaluate the reasonableness of decisions being made, although everyone (including myself) had opinions they were willing to put all over social media. But if this book was going to be relevant in a month, let alone a year’s time (as I wanted it to be), I was going to have to refrain from being judgmental. That meant that there would be no politics or even applause for what seemed like the best policies nor distain for what seemed like the worst. For readers looking for that, you will have to get that elsewhere.

In the end, what we have here is a hastily written book that no doubt leaves out citations to many who deserve it. Its purpose is to be an urgent source of clarification and a thoughtful take on the issues. In so doing, I was forecasting what we would potentially take away from this crisis and what we would want to reflect upon beyond the chaos of the first month or so. I’m hoping not to be completely wrong about all of that, but if I am, I will be the first one to call it out.

I would like to thank my family with whom I am stuck in a house writing this. They put up with my crazy idea to push out a book when I could be less socially distant, at least inside our household. I would also like to thank Scott Adams, Ajay Agrawal, Pierre Azoulay, Heski Bar-Isaac, Franceso Bova, Kevin Bryan, Eric Budish, Bruce Chapman, Ben Fine, Catherine de Fontenay, Alberto Galasso, Avi Goldfarb, Steve Hamilton, Richard Holden, Chris Joye, Stephen King, Scott Kominers, Mara Lederman, Andrew Leigh, June Ma, Tiff Macklem, Barry Nalebuff, Bob Pindyck, Eric Rasmusen, Paul Romer, Scott Stern, Alex Tabarrok, and Flavio Toxvaerd for helpful comments and discussions. A special thanks for commenters on PubPub (in particular, Patty Steele) with their many suggestions that improved the book. I would also like to thank my constant companion through this—#econtwitter—who alerted me to much of the research cited in this book. Finally, I owe a special debt to Emily Taber and the MIT Press team for acting so quickly to get this project out there.

—Joshua Gans

April 2020

1

Health before Wealth

> We know what to do to bring back our economy back to life. What we do not know how to do is to bring people back to life.
>
> —His Excellency William Addo Dankwa "Nana" Akufo-Addo, President of Ghana, March 26, 2020

Everything is awful. The virus is awful. The immediate choices are awful. The future may be even more awful.

We should have been more prepared. For almost a decade, one of the most popular apps was *Plague Inc.* (120 million downloads and counting). It showed us how diseases broke out and did their damage. When the COVID-19 outbreak hit, the app surged back to number one in China and was promptly banned in the country.[1]

In *Plague Inc.*, you play the virus and your goal is to wipe out humanity. To the extent they have a goal, that isn't the goal of most viruses. Instead, it might be survival of its genetic structure, which would end should it wipe out its hosts. But never mind; from humanity's perspective, we would want to tool up on the tactics for viruses that would lead to extinction.[2]

COVID-19 is not that species-ending virus. But it does have some of the characteristics you would employ in *Plague Inc.* if you wanted to destroy us all. An inexperienced player normally goes for a highly infectious and deadly disease. But that is not the best course of action. First, because the virus is deadly, human scientists start working extra hard to stop the plague. Second, if you kill people too quickly, you actually slow down the rate of infection. Instead, what you want to do is find a way of infecting many people preferably without any symptoms that would get the infection noticed. Then you want to ramp up the disease after each infected person has spread it around so that you overwhelm health centers before the world shuts down travel. COVID-19 fits that bill. People become infectious, many with no or just mild symptoms, but then there is a deadly movement into pneumonia, which takes some weeks of hospitalization to treat. It would do well but not necessarily win *Plague Inc*.

One thing that COVID-19 does, which was not an option for players of *Plague Inc.*, is that it impacts different demographics in different ways. While anyone appears to be able to carry the virus and infect others, those who become very sick—requiring hospitalization—tend to be the elderly. That means that in dealing with COVID-19, the costs associated with reduced economic and social activity will disproportionately fall on the young, precisely the group that is less personally impacted. That is a recipe for a virus being able to divide and conquer those who need to mount a response by creating a debate regarding whether that fight was worth it. All this means that the real game is likely to last some time.

An Awful Choice

In normal times, economists focus on the fact that we have limited resources and can do only so much. If we direct expenditures toward, say, public health, we are giving up something else. Thus, it is not surprising to see some economists reminding people of those trade-offs.

> "We put a lot of weight on saving lives," said Casey Mulligan, a University of Chicago economist who spent a year as chief economist on Mr. Trump's Council of Economic Advisers. "But it's not the only consideration. That's why we don't shut down the economy every flu season. They're ignoring the costs of what they're doing. They also have very little clue how many lives they're saving."[3]

This has the effect of causing some politicians and business leaders to embrace the notion that in dealing with a pandemic, we need to be conscious that if we push for public health, we are trading that off against a loss in economic health.

The technique of "thinking at the margin" often serves us well. This is because we can narrow the argument and think in terms of tweaking or fine tuning where we are now. In dealing with trade-offs the economist asks, If we get a little more of something, how much of something else do we have to give up? In this case, thinking at the margin would ask, If we want to open up the economy a little more during a pandemic, how many lives would that cost? However, even in normal times, there is a strong argument, recently voiced by Paul Romer,[4] that economists, at least, should stay away from trying to trade off economic costs with lives lost. Trade-offs (especially at the margin) are the economist's bread and butter. So, it really shouldn't surprise us to see this being voiced during a time of pandemic.

However, this misses a critical issue: pandemics are not the time where trade-offs at the margin are appropriate. This book is about seeing the pandemic through an economics lens. So, I am going to begin with the question of how to balance the needs of the economy with the needs of public health. The good news is that this can be done by integrating a simple epidemiological model[5] with basic economic analysis.

The starting point is to understand that at any given point in time, there is only so much we can produce. Broadly speaking, if we want to have better public health outcomes, we need to take resources from elsewhere, and so we can imagine that we get less of other stuff—which we would broadly call "the economy." What makes these trade-offs easy to grasp is that when we talk about producing some more public health, we can then think about how much less of the economy we get. Moreover, we are also confident that as we push for each extra bit of health, the more of the economy we have to give up each time. So, if our public health is poor, it is relatively "cheap" (in terms of a reduction in the economy) to get more of it. When our public health is already prioritized, pushing the system further to gain even more health is relatively "expensive" in terms of reductions to the economy. Thus, we do end up balancing and we don't have the best imaginable public health outcomes because, frankly, we have decided not to pay the price. (In the technical interlude at the end of this chapter, I put all of this discussion in graphical terms that might be familiar to an Econ 101 student—the production possibilities frontier. You can delve into that or skip as you see fit.)

One reason a pandemic is awful is because it constrains even further what we can do with our scarce resources. We can neither sustain the level of the economy we had before without a decline in public health nor vice versa. That in and of itself would not pose an issue for our

ability to fine tune. Instead, there are two factors that fundamentally mean that we can no longer fine tune and instead face a choice between prioritizing public health or the economy without the ability to balance those choices. Those two factors are (1) that a pandemic *hollows out* our ability to maintain the *same* balance between health and the economy and (2) that our choice of priority changes our options going forward; that is, they can drift.

Let's begin with hollowing out. Recall that our ability to obtain our current balance of health and the economy is that we recognize that having a little more health or a little more economy is not worth the price in terms of what we give up for each. Absent other innovations—say, a vaccine or, as I will discuss later, testing—the way to achieve our previous level of public health in the face of a pandemic is to socially distance. That means that we cannot physically interact with one another, and, therefore, to a very large extent, we can no longer produce the economic outcomes we once could.

The problem is that the pandemic now changes the price of obtaining a little improvement in the economy. In order to do that, we must now give up a large degree of health as the infection rate of COVID-19 is high. Being able to have slightly larger groups of people interact or have a few workplaces open poses a potentially high risk to public health because of the way the coronavirus can spread. Put simply, the option of sacrificing a little public health for having a little more economy is no longer open to us.

This also works on the flip side. One option for dealing with a pandemic is simply to ignore it and let life go on as usual. The hope from that plan would be to maintain the economy at its previous level, see the virus spread through much of the population, hope not too many people die, and have a one- to two-year large decline in public health. This was sometimes referred to as allowing the virus to "burn through" the population. Even here the ability to fine tune is compromised. You might want to achieve a slightly lower loss of life from the pandemic but find now that the price of doing that, as even that would require a large amount of social distancing, has become very high.

Hollowing out means that you no longer want to maintain the same balance of the economy and health as you did previously. Instead, the "best" choices are to prioritize one or the other. There is a trade-off, but no longer can you dial up a little bit more of this and a little bit less of that; you either prioritize the economy or you prioritize public health. You don't want to try to do both.

One thing that can tip the balance is that you may not be able to maintain the economy at its previous level if you just let the pandemic burn through the population. This is because, like a war or natural disaster, we lose resources if we have much lower public health; that is, our workforce becomes smaller. Thus, if we let a pandemic run its course without mitigation that lowers economic activity, what happens is what I call a "dark recession." This is a recession where we see a reduction in the availability, ability, and health of the workforce as the virus spreads unabated. This causes a large reduction in economic activity.

We have some evidence that suggests that a failure to abate the spread of the virus through social distancing can make economic recovery thereafter more difficult. Economists have examined the differences in nonpharmaceutical pandemic interventions across different US cities during the flu pandemic of 1918.[6] The pandemic reduced US manufacturing by an estimated 18 percent, making it a large recession indeed. Those cities that pushed earlier and more intensively on pandemic containment ended up bouncing back and having higher economic growth thereafter, and more exposed areas had a decline in economic activity that persisted. This finding suggests that the choice between the economy and public health is not a hard one—pursuing public health can be consistent with superior long-run economic performance.

The Drift

Thus far, an analysis of what we can produce in a pandemic has shown that we face a stark choice between prioritizing public health or the economy without the ability to fine tune those trade-offs. However, epidemiological models have another implication that suggests the choice is more difficult than even that stark one. The options can *drift* depending on how we respond to the pandemic. Put simply, the longer you take to enact social distancing, the fewer options you have. This means that you can no longer achieve the existing level of health and must accept less.

This is the drift. Your ability to generate higher levels of public health during the pandemic is reduced unless you commit to holding the line on health. Importantly, if you spend too long trying to maintain the previous balance between the economy and public health, you are unable to achieve better levels of public health at all.

Importantly, the drift goes in only one direction. If you choose to prioritize the economy and maintain previous levels of economic activity, you may cut off the option of improving public health at all.[7] You no longer have the option to "buy" more public health through a reduction in economic activity. Prioritizing the economy too aggressively is like going through a one-way door. There is no exit.

Instead, holding the line on health initially is the superior way to go. It is the only direction that gives you the *option* of making a choice once you have learned more information regarding what the pandemic's effects on your options actually look like. Consequently, from an economics perspective, the fact that supporting the economy makes the decision irreversible by changing the pandemic production options means that you should be biased toward sacrificing the economy and maintaining the line on public health.

Resolve

Based on the above, economics tells us that the optimal response to a pandemic is to resolutely hold the line on health while you consider your options. It is critical to prioritize *health before wealth* until such time as you learn enough information to understand the nature of the pandemic.

Holding the line is a difficult coordination challenge. Expectations matter. To hold the line on health, you need to change the behavior of large numbers of people. It is easy to social distance when others are doing so. It is easy to practice good hygiene when you fear others around you will stigmatize you if you don't. But the flip side of this is that if you cannot achieve that convergence of expectations, you may not be able to achieve significant progress in holding a virus at bay.

This is why resolve, clarity, transparency, and other instruments that can help align expectations are so critical. When leaders downplay the magnitude of the crisis or take actions that seem to be guidelines rather than expected behavior with consequences, expectations do not converge. Instead, rather than taking actions that make sense in the public or societal interest, individuals will continue to do as they often do and pursue their own interest. They will keep businesses open and keep engaging in social life. That creates a vicious cycle that makes it harder to hold the line on health and may necessitate more costly policies by governments to contain the outbreak. The cost will be lost time and, by extension, lost lives.

Given this, you might have thought the world's population would have been better prepared to act quickly on this. However, it is harder than you think, as it requires a faith in mathematical predictions that is not easy to come by.[8] Chapter 2 is about such predictable surprises. It discusses why the mathematics of cumulative processes are so difficult to understand and make decisions on. When we look back on this, I suspect the postmortems will tell us we should have acted sooner. In reality, "sooner" was measured in days. That is a tough standard for decisions that turned out to be vastly consequential.

Phases of the Pandemic Economy

The remainder of the book is structured along the lines of various phases that arise for the economy during a pandemic. The four phases are illustrated in figure 1.1. At a high level, these steps communicate a view regarding the hoped-for endgame from the COVID-19 panic.[9] The overarching goal is to reduce the rate of infection such that the pandemic ends. This is distinct from a goal of eradicating the virus entirely (as we have done with smallpox, for instance). In other words, cases of COVID-19 may well continue for some time, but their ability to spread in an uncontrolled manner will be curtailed. Nonetheless, how precisely that endgame is achieved—that is, how a sufficient share of the population becomes immune—involves choices that will be outlined in the chapters that follow.

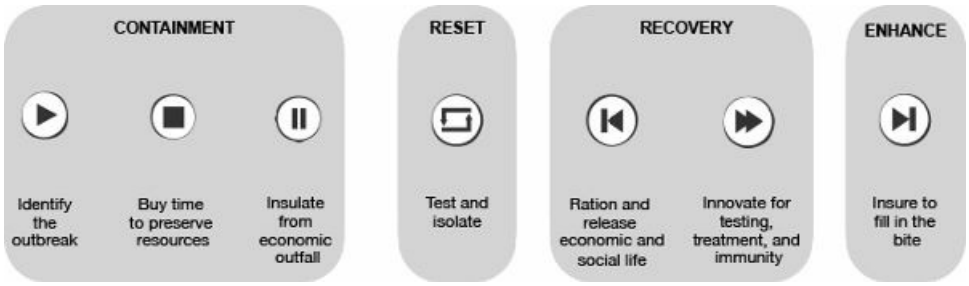

Figure 1.1
The phases of the pandemic economy.

The first phase is "containment." This involves three steps. The first, as already noted, is that the virus, outbreak, and potential pandemic have to be identified. This is the subject of chapter 2. While this is going on, the pandemic is playing itself out unabated.

Following this is a step that is designed to put the brakes on and stop the virus from spreading. This is the initial part of holding the line to learn more about the virus and to preserve potentially scarce economic resources. The decisions that must be made then are akin to those made by governments during wartime. They involve immediate sacrifice, and, as I point out in chapter 3, they require an approach to resource allocation that would, at all other times, be considered repugnant: centrally planned economies. But this is where governments, appropriately, have started to act. There are centralized and military-run operations to improve healthcare system capacity. There are price controls and subsequent rationing. And there are blanket restrictions on movement. None of these things would have been achievable under a free market regime, and all of these actions have the potential to save many lives and ultimately preserve our economy.

The costs of those decisions are very hard to fathom. Perhaps the largest contraction in economic activity since the Great Depression is taking place. And this is by choice so we could reduce the spread of COVID-19. The impact of that has been unevenly felt with growing numbers of unemployed and bankruptcies from small- and medium-sized businesses occurring. How to use government policy—both fiscal and monetary—is not simple.[10] In chapter 4, I explain that this type of recession is very different from past recessions and requires a distinct approach. The goal would be to somehow *pause* the economy so that it could be later unpaused and life could return to normal. Thus, we wouldn't let businesses fail and people lose their jobs. They need to be insulated. We need policies—in particular, loans—to keep people from breaking economic relationships either because businesses shut down or jobs are shed.

If COVID-19 is successfully contained, the next phase is to reset everything and start from scratch. A critical insight when thinking about pandemics is that the problem we face is a lack of knowledge. We do not know who is infectious and who might be safe from infection. If we have this knowledge, we can isolate the infectious until they recover and prevent the virus from spreading while maintaining much of our economic and social life.[11] In chapter 5, I describe this reset phase as a move to a testing economy. In that economy, we test widely to determine who is safe to interact with others. Then we *repeat* that until such time as a vaccine is distributed or the virus has otherwise abated. In this way, moving to a testing economy can expand our production possibilities. This is what we would have liked to do at the outset but lacked either the information or the means to do so. It highlights that the role of the containment phase is effectively to get us back to square one and have a "do over" based on better knowledge going forward.

Having reset and developed a means of testing, we will be able to begin the recovery phase from the pandemic. In chapter 6, I consider the economic issues associated with reemergence. There will be a need to prioritize who is released from isolation, as not all of the population will be designated safe for interactions. This is based on network theory, which can give us guidance as to what types of jobs, workplaces, and other factors can serve as criteria for release. In reemergence we will also face rationing of certain things—most notably, vaccine doses—and will need to consider how those scarce resources are allocated.

Chapter 7 then looks at a related but also ongoing part of the recovery: the need to rally innovation. Innovations will be needed for tests, treatments, and vaccines for COVID-19 but also for dealing with pandemics in the future. The fundamental problem is that these innovations are global public goods that we want wide distribution of, but the urgency and other factors mean that normal market-based processes of innovating are not going to succeed. Instead, I discuss various tools that might accelerate innovations, including advance market commitments to purchase the products based on innovations. These can overcome some of the incentive-dampening pressures that might otherwise emerge for innovators in this area.

Finally, having evolved from the current crisis we will reach a new phase: the future. My assumption here is that, like major crises of the past, we will want to find ways to avoid them in the future. There are opportunities for global cooperation and also to consider the differential impact of these crises and their resolution on different groups. Thus, I will end the book reflecting on these but noting that much of the work outlining that truly does lie in our future.

Technical Interlude

Readers who do not enjoy graphs are free to skip directly to chapter 2 without missing any crucial information. For economists and other graph lovers, this section will go into more detail of the hollowing-out and drift effects so critical to the economic conclusion that health should come before wealth.

The key thing to note about a pandemic (like COVID-19) is that it fundamentally changes the *production possibilities set* for the economy. A production possibilities set tells us what we can produce with the resources at hand. It does not tell us what we should or want to produce; you would need to think about preferences (in this case, social preferences) to get that. Instead, the production possibilities set focuses only on what the economy *can* do, and that is all I need to do to point out the flaws in beliefs that fine-tuning and maintaining the previous balance between health and the economy is possible.

To keep things simple, figure 1.2 is the production possibilities set during "normal" times when we have a choice between how much public health we want and how much of other stuff—which I will label "economy."

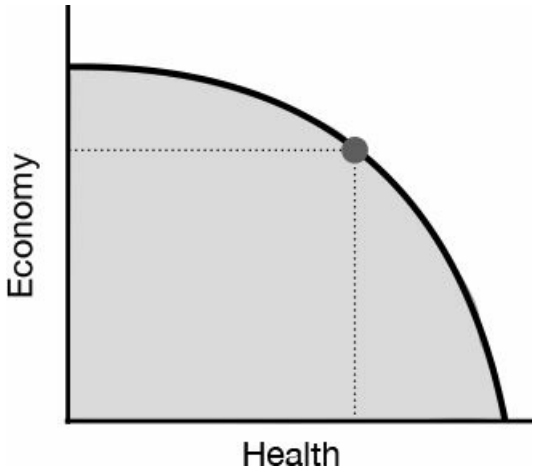

Figure 1.2

Production possibilities set in normal times.

The curved black line in figure 1.2 is the production possibilities frontier (or PPF) and shows the upper limit of the combinations of the economy and health we can achieve. We can, of course, obtain lower levels of the economy and health than this, but we would try not to. If we can, we want to choose a point (like the dark gray dot) that is on the frontier which gives us a certain amount of economy and a certain amount of health.

The key feature of the textbook PPF is that the shape of the curve is concave. This means that, if you start from a very low level of health and want a bit more, you have to give up only a little bit of economy. However, if you start from a high level of health, to gain even more health, you would need to give up a larger amount of economy. This is the law of diminishing returns. Put simply, it is harder to produce more of something when you already have a lot of it.

These are not normal times. We now have a pandemic. What a pandemic does to the PPF is something like what is depicted in figure 1.3a. There are two big changes illustrated by the new line below the normal PPF. First, the pandemic PPF lies below the normal PPF. That means we can't produce as much economy or health as before. In particular, we can no longer

produce to meet the dark gray dot even if we can have the same amount of health or the same amount of economy as before. This is the logic many have when thinking of why we face a trade-off in a pandemic when we didn't before.

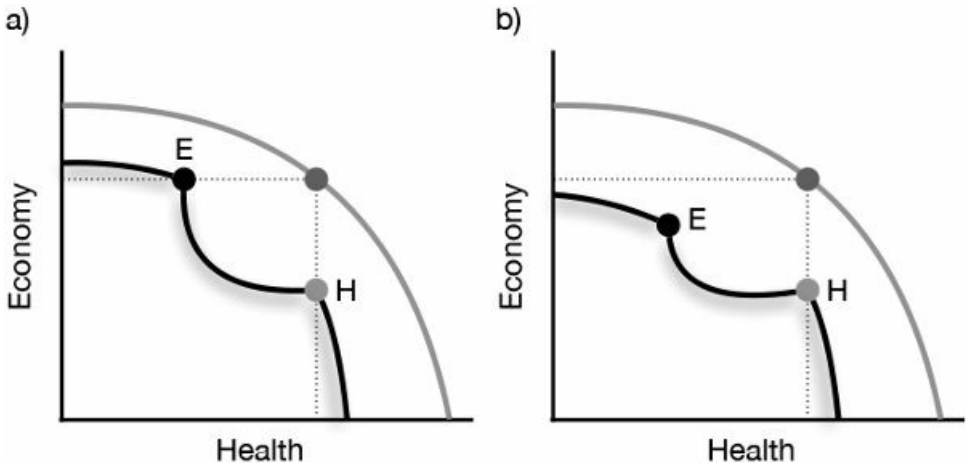

Figure 1.3
Pandemic production possibilities sets. (a) Previous levels possible. (b) Dark recession.

Second, there is a hollowing-out of the PPF. That arises out of the nature of a pandemic. To consider this, suppose that we started from our original level of the economy (at a point like E, the black dot). Then, if we want more health during a pandemic, we need to give up a lot of the economy to get it. This is the social distancing argument—we need a lot of social distancing in order to halt the spread of infectious disease, and a little bit won't have much effect. The same logic applies if we start from our original level of health (at a point like H, the light gray dot). In that situation, if we look to give up a little health for a better economy, we find that we cannot do that. Even to achieve a level of health remotely close to what we previously had, we have to employ lots of social distancing, which means that the only way to get a better economy is to give up a great deal of health. (Notice that the less virulent is the infection, the smaller the "bite" is likely to be.) The point is that if we take the epidemiologists seriously, then our usual marginal thinking about trade-offs does not work.[12]

Before moving on, it is useful to reflect on a couple of other things we learn from this approach. First, it is highly unlikely that we want to choose a point in the hollowed-out portion (say, by maintaining the previous balance between health and the economy). Doing this would leave us with lower health or economy than we could achieve at either end.[13]

Second, there is a certain logic to the idea that you might choose to give up entirely on trying to slow or contain a virus and, instead, choose a point like E where you have the economy you had before but with much lower public health (and also fewer people surviving). The logic here is that it is really, really hard to preserve public health because the economy really has to suffer. Of course, the same logic applies to a point like H. If you want to preserve public health (save lives), you have to accept that you will harm the economy in a large way. In other words, the bite forces us into a big either/or situation—that is, a choice between H and E.

Figure 1.3a as it is drawn assumes that we can achieve the same level of economic performance even if we have low public health. That is potentially very unrealistic. If we let a pandemic run its course without mitigation, that lowers economic activity and leads to a "dark recession" as depicted in figure 1.3b. If this is the case, you can see that a point like E will be far less desirable than H.

The drift can also be represented using PPFs. This is done in figure 1.4. Figure 1.4a shows

what happens if you do not hold the line on public health to keep it at its previous levels. You will see that option no longer is viable and lies outside the moving pandemic PPF. Figure 1.4b shows what happens if you try to maintain the previous economy level and delay too long on social distancing. In this case, the PPF has a cliff and it is no longer possible to control the pandemic after a time.

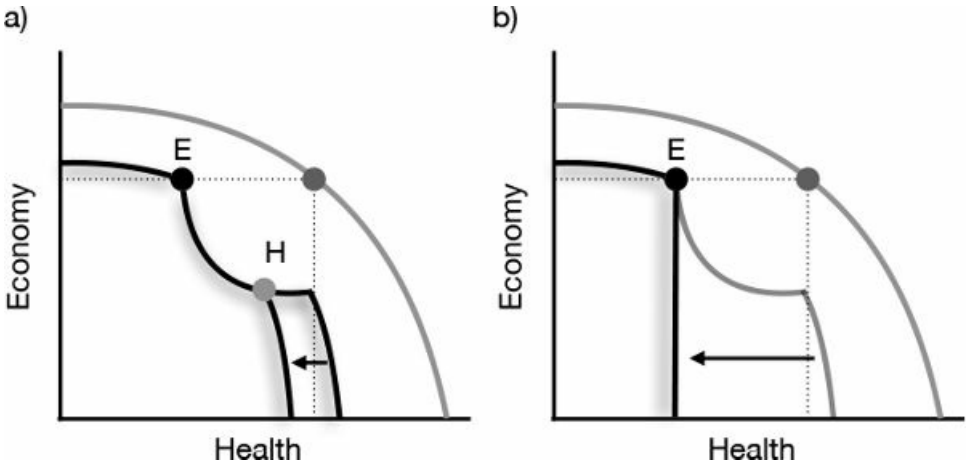

Figure 1.4

The drift. (a) The PPF moves. (b) The cliff.

There are two final things worth demonstrating using the pandemic PPFs. First, figure 1.5 shows what happens if you hold the line on public health but do not institute the type of macroeconomic policy "life support" mechanisms that allow you to pause the economy. As will be discussed in chapter 4, introducing those mechanisms can improve the economy along with maintaining public health as you move from a point, like B, within the PPF to the frontier itself.

The economist Eric Budish observed that it is very important to consider the correct mindset when thinking about how to reach the frontier.[14] In particular, if you have a mindset that focuses solely on reducing the infection rate as quickly as possible, this will not necessarily get you to the frontier. Instead, that frontier involves targeting an infection rate that stops the pandemic[15] but, otherwise, picking allowable activities that reflect both their value for the economy and their risk in terms of public health.

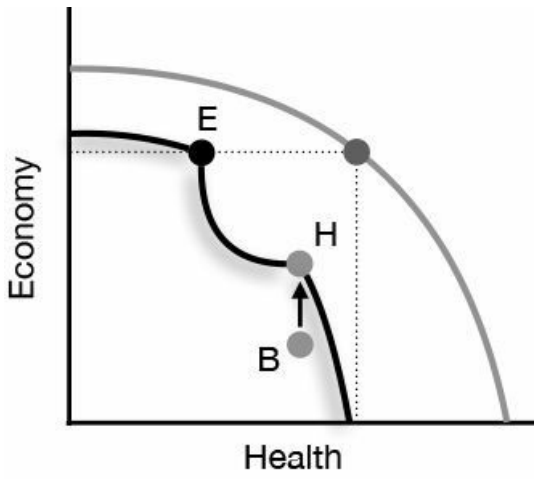

Figure 1.5

Supportive macroeconomic policy.

Second, there are some innovations and investments that can be made that will improve the pandemic PPF. In chapter 5, I describe the use of tests to make interacting physically safe again. This has the effect—shown in figure 1.6—of expanding the production possibilities set. This makes H more desirable. However, it is useful to note that such innovations and investments are of no value if you decide to move to a point like E. Thus, the key reason you may want to hold the line on health is to provide breathing space for the reset phase to be prepared for and then conducted.

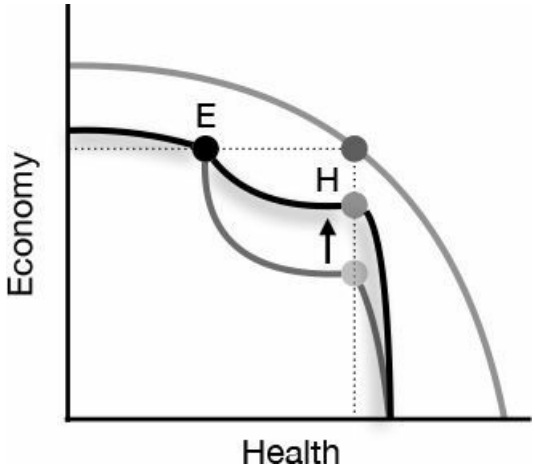

Figure 1.6
Impact of testing.

Key Points

1. The way in which COVID-19 propagates through the population means that there is a stark choice between maintaining economic activity and public health.
2. If governments choose not to hold the line on public health, there is no going back. It is, therefore, economically sensible to prioritize public health during a pandemic in order to learn more about the ways in which the pandemic can be managed.
3. In dealing with the pandemic, because of delays in taking action, governments must first contain the outbreak in order to then put themselves in a position to reset and conduct recovery policies—such as testing and tracing and innovations in treatment and prevention—in order to bring the crisis to a resolution.
4. Attention must then turn to developing institutions and global coordinated responses to deal with future pandemics in a more timely and effective manner than is currently being done for COVID-19.

2

Predictable Surprises

It starts with a grain of rice on a chessboard. This is grain one. The craftsperson makes an offer to the monarch. “I have made this beautiful chessboard and I will give it to you for some more rice. I have placed a grain on the first square. I want you to add grains to each of the remaining squares in turn, doubling each time. Two on the next one. Four on the one after that and so on until all 64 squares have been covered.” The monarch feels they can spot a good deal and so accepts the offer.[1]

Suffice it to say, it was not a good deal, and accepting it would surely bankrupt the monarch’s land. The reason why it is bad is that it is very clear what is going on and only a lack of willingness to do the math would allow you to think otherwise. Put simply, the total amount of rice being asked for was not some mystery. It was the solution to this equation:

$$1 + 2 + 4 + \ldots + 9{,}233{,}372{,}036{,}854{,}775{,}808 = 18{,}446{,}744{,}073{,}709{,}551{,}615$$

That, it turns out, is a lot of rice. If you laid the grains end to end you would go from the Earth to Alpha Centauri and back twice.[2] Ultimately, there isn’t enough rice in the world, let alone the land, to pay out the contract. I’m no lawyer, so I have no idea what the outcome of this would have been had it ended up in the courts.

Obviously, this fable isn’t about contract law; it is about our ability to use mathematics to understand the world around us. If you base your decisions on what you can see with little effort, then you might miss the underlying processes at work. Alternatively, if you understand the underlying processes and see them to their ultimate conclusion, you will make a better decision. Those conclusions may be surprising, but, paradoxically, they are predictable.

The COVID-19 pandemic came as a predictable surprise to most people. While the mathematics are not as clear as the rice and the chessboard, they were present, and the same disconnect between what you could see immediately and what the math told you about where this was heading was there. The tough challenge was how to make some very costly decisions based on the mathematics alone.

The Degree of the Problem

Pandemics are better than a rice/chessboard process in a very important way: once the first grain of rice is placed, there are ways to stop the process before square 64 is reached. The key to any mitigation strategy that modifies the mathematics of that process is a willingness make that break.

Before getting to that, it is worthwhile to review the mathematics. When a person contracts an infectious virus, they can pass it to others by contact. This isn't true of all viruses nor of all infectious diseases, but, at the time of writing, this is the most plausible infection path for the novel coronavirus. Sometime in November 2019, someone contracted the virus and began passing it on to others. The question was: How many others? The question pertains not only to that person but, more important, to any random person who might carry the virus.

In epidemiology this has a number, R_0, or the basic reproduction number. R_0 is the expected number of people one infectious person is likely to infect with a particular virus at the outset.[3] In the past, with enough knowledge, R_0 for other viruses or infectious diseases could be measured. Absent any interventions, the critical threshold number is 1. If each infected person infects at most one other person, then the total number of infections might rise initially but will progress very slowly, and, because eventually you are meeting more and more people who have had the virus and are, hopefully, immune, the infection rate will die off fairly quickly. For an $R_0 > 1$, an epidemic is possible, with a much higher share of the population likely to become infected. This is why the number-one goal in pandemic management is to create conditions so that the basic reproduction number is moved to less than 1.

The most infectious disease in modern times was measles, with an R_0 between 12 and 18.[4] This is because it could spread in the air. The usual influenza we experience each year is between 0.9 and 2.1. Some years are good, while others are bad. The SARS outbreak was between 2 and 5, while Ebola, which is transmitted via bodily fluids, was between 1.5 and 2.5. You can see both significant variation but also significant ranges of uncertainty. For Ebola, this was likely related to population density. At the time of writing, COVID-19 has an estimated R_0 between 1.4 and 3.9. It is for this reason that many predicted that, left unchecked, 70 percent of all people would eventually contract the virus.

The Human Equation

The interesting thing about R_0 is that it is not just a biological number—that is, related to how a virus can move and bind itself to others—but also a social number.[5] If a hermit contracts the measles, then R_0 is 0. If a partygoer gets it, R_0 is much higher. The estimates of R_0 are averages, which is a guide to decision-making but not what you want to know. In principle, you want to know everyone's specific R_0 and you likely want to draw your attention to reducing the R_0s of those who are at the top of this list.

Rather than individual R_0s, the best we can hope for are group R_0s. For instance, children move about, keep personal hygiene, and live their lives in a very different way from other beings. As any parent with young kids knows, there are years in which your house turns into the town from Albert Camus, *The Plague*, sans any widespread epidemic. This is why, in many countries, the first step in social distancing was to shut down schools. This wasn't because children are especially at risk—they aren't, thank goodness—but because they are "vectors"—an identifiable group known to have potentially high R_0s. The same is true of college students. If most students stayed at college, they were likely to be strong vectors for infection because they spend their days going from numerous gatherings of a hundred people or more before bringing it all back to others in their dorms. By contrast, office workplaces are potentially lower-risk.

The epidemiological models consider who might interact with whom when they try to predict the spread of an infection, but those assumptions are "hard-wired" into their models. Economists (and other social scientists) typically shy away from predictions based on such hard-wired behavior. Instead, when considering how people might interact with one another, they look to their choices. People do not blindly react to pandemics and continue to go about their daily business. Nor do they hide out for the duration. What they do is balance the risk of interactions as the pandemic progresses, based on information they have at hand. In other words, what epidemiological models can miss is that humans change their behavior over time, and this can impact the mathematics of the infection.

The research that integrates economics into epidemiology is very much nascent. However, from the work that has been done to date, some important insights can be drawn. First of all, we can expect that when people are concerned about the costs of being infected, they won't necessarily need to be told to socially distance themselves from others.[6] In particular, as the infection rate starts to climb, more people will reduce their economic activity, which has the effect of moderating the spread of any virus. During the 2009 H1N1 epidemic, people in the United States reduced their time spent among others,[7] and similarly in Mexico, although there the behavior differed among different socioeconomic groups, with poorer groups adjusting less.[8]

Second, it is possible that the behavioral response to a pandemic can cause the peak infection level to be lower than what might otherwise emerge from a standard epidemiological model.[9] This is because, as the infection rate increases, people will perceive greater risk from interacting with others. While that reduces the infection rate, this back and forth will slice the top off the peak but spread the length of the pandemic further; that is, it will "flatten the curve" (discussed in more detail in chapter 3).

This has another important implication that can test our usual epidemic intuition. If a virus is more virulent (that is, can be more easily passed between people), the usual prediction is that a larger share of the population will become infected (as R_0 is relatively high). However, once the human element is taken into account, this could go the other way. If it was known

that a virus was particularly virulent, people would fear going out and would socially distance. The more virulent it is, the more people will self-isolate to avoid others. This could well mean that virulent outbreaks have a *lower* total number infected than less virulent ones. This is, of course, just a theoretical possibility at this stage, but there is anecdotal evidence in the COVID-19 outbreak that certain groups—particularly, younger people who have less to fear from the consequences of being infected—do not practice social distancing as much as others.[10]

While people might reduce their social interactions out of fear, it is important to emphasize that this may still be too little relative to what we might all agree would be in the collective interest. That is because people take into account their own fear in refraining from social interactions but not the impact those actions might have on others. In other words, fear is not necessarily enough, and governments may have to take heavy-handed actions to influence R_0.[11]

The good news is that policy actions designed to change the behavior of many can have an impact. This was starkly demonstrated in a comparative study of the Philadelphia and St. Louis responses to the flu pandemic of 1918.[12] As figure 2.1 (drawn from that study) demonstrates, St. Louis had a milder and prolonged epidemic compared with Philadelphia, which had the majority of cases in just one month. The difference between the two was that Philadelphia held a parade of returning soldiers from World War I, while St. Louis, armed with the same health warnings, closed schools and even churches and banned gatherings of more than 20 people. As network economist Matthew Jackson notes, being able to reduce the number of highly connected clusters within a network of social relationships can dramatically reduce R_0.[13]

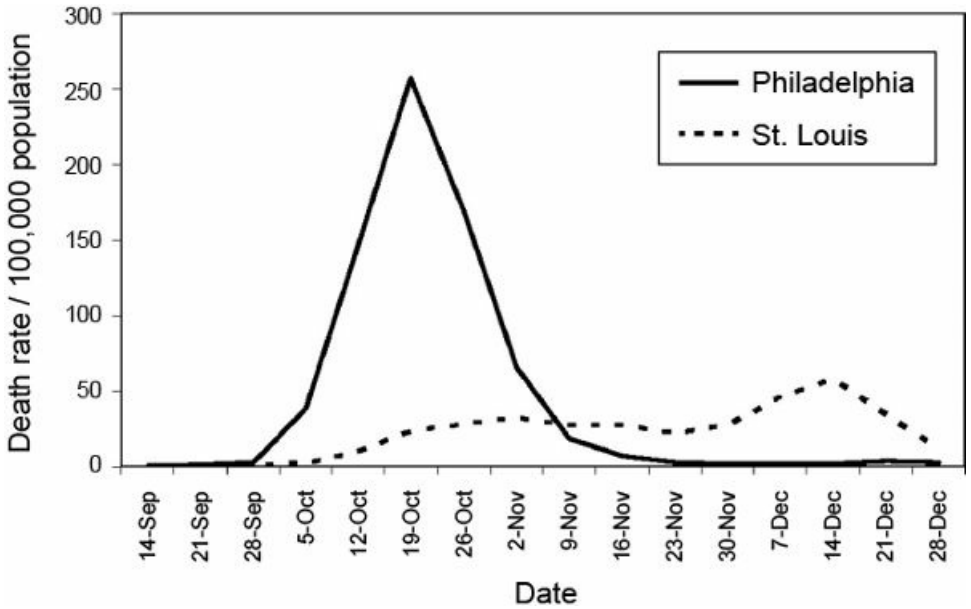

Figure 2.1

Pandemic of 1918. *Source:* Richard J. Hatchett, Carter E. Mecher, and Marc Lipsitch, "Public Health Interventions and Epidemic Intensity during the 1918 Influenza Pandemic," *Proceedings of the National Academy of Sciences* 104, no. 18 (May 2007): 7582–7587 (doi: 10.1073/ pnas.0610941104).

While we understand the general science behind disease transmission, the mix of biological and social factors for each new disease means that we have broad ranges for R_0 and scant details about what any particular measure might do to the spread of the virus. That said, we know that if we shut everything down, then we can minimize any given R_0. In doing so,

we maximize the R_0 within a given household, but the idea is to keep the spread between households at a minimum. How much we want to do this depends both on the degree of the problem—how high R_0 would otherwise be—and on the costs of becoming infected versus the costs associated with trying to reduce R_0.

Willingness to Act

This leads us to the costs. The potential health costs of COVID-19 are of primary interest. As I apply my economist filter to what I understand of the biomedical properties here, I see those health costs (in terms of likely medical care) in four groups. The first are the people who contract the virus but have no important symptoms. They create no health costs at all. The second are people who contract the virus and have symptoms akin to a severe flu. The health costs here are primarily in terms of lost ability to work and function. The third are those who have severe enough symptoms to require hospitalization with the obvious associated costs. The final category is those for whom COVID-19 proves to be fatal. Early estimates from China suggested that 81 percent of those who tested positive for COVID-19 were in the first two categories. Of the remainder, 14 percent were severe, and 5 percent were critical. The remaining 2.3 percent had died.[14]

The problem we face is that the mix of people in the third and fourth category potentially depends critically on the ability of the healthcare system to manage their infections and resulting consequences. Economizing on this dimension is the focus of policymakers in minimizing the health costs associated with COVID-19.

There are two ways to achieve this. The first would be to ensure there was sufficient capacity in the healthcare system to handle cases when they are at their most intense. That will be the subject of chapter 3. The second is to reduce the intensity of critical COVID-19 cases at any point in time. In other words, that means taking actions to reduce R_0.

Let's consider ways of reducing R_0 in terms of their costs. The least costly ways are good health practices. This includes thorough hand washing and regular cleaning of surfaces. These are the types of things that occur within hospitals that become of high value during a pandemic. There are also a related set of protocols for the operation of healthcare facilities themselves so as to protect healthcare workers. Not surprisingly, these were the first set of measures that were enacted in most countries.

The second set of actions was to limit the spread of the virus across national boundaries. The logic here is that, if the virus has not infected significant numbers of a country's population (and in the case of COVID-19 that would have to be a very small number), then by limiting travel between countries, the virus might be kept out. Some countries, notably Taiwan, did this very quickly, while most others did it in a somewhat ad hoc way. For instance, the United States closed travel to any foreign nationals coming from China but not their own citizens. In March 2020, Israel took the unusual step, at the time, of requiring any person coming in to self-quarantine for two weeks and using cell phones to track infractions. At the time of writing, it is safe to say that the ability to contain the spread across national boundaries was limited. Obviously, restricting travel would start to impact negatively on certain industries, especially tourism, hotels, and airlines.

The third set of actions came under a catchall term of "social distancing." Initially, this involved cancelling large gatherings. In Australia this was 500 people initially, while at a similar time Austria banned gatherings of more than five people (which might have given pause to households with four or more children). This, however, led to more extreme actions such as canceling school, college classes, instituting work-from-home practices, and eventually closing restaurants and bars. Finally, in some jurisdictions there were orders to "shelter in place" (including China, Italy, and parts of the United States).

The first two measures—hygiene and travel restrictions—are disruptive, potentially very disruptive. However, they pale in comparison to the costs associated with social distancing.

To achieve social distancing in a manner that would prevent the healthcare system from exceeding capacity requires a reduction in economic activity that would plunge any economy into an immediate recession. This is why there is a reduction in economic activity if you choose to hold the line on health. How to handle that is the subject of chapter 4. Nonetheless, however you cut it, the costs are significant, perhaps of the order of 10 to 20 percent of GDP of any country. And this is just the economic cost. You are also asking much of the population to remain at home. Thanks to the Internet, in many places it has never been more comfortable to do this. Nonetheless, it is unknown just how long such social distancing can last.

So herein lies the basic trade-off. We want to reduce R_0, as it is very costly to have a high number of sick people at one time. The reason we have to do this is because of the limited healthcare system capacity. If R_0 is too high, healthcare capacity becomes quickly overwhelmed and doctors have to engage in triage, which in the context of COVID-19 often means choosing who will live and who will die. This outcome has to be balanced against the significant economic cost associated with spreading infections over time. To be effective, social distancing has to go the distance. But with every week or month of low economic activity, the costs rise.

If that weren't a tough enough trade-off, it is actually worse than that. Whether or not people can develop immunity from COVID-19 is still an open scientific question, but let's assume that it is more likely to be true than not. If you reduce R_0 too far, initially, then most of the population does not become infected and that means that once you stop policies such as social distancing, the virus can emerge once more, and we all have to do this again. It is a reasonable assumption that we want to intervene only once.

The reason there is a cost to this is that you are actually more socially useful if you get the virus and recover and thus are no longer a possible carrier. That means that other people and society do not have to fear interactions with you. In other words, achieving "herd immunity" is an investment in the future. It is like a vaccine, but, alas, you have to actually get the virus rather than an injection. For an understandably short time, the British response to the pandemic, reflecting this idea, was to embrace the idea of "taking one for the team." That said, a week in bed is one thing; dying is another. How you conduct this policy without getting significant people in the latter category is hard to see.

How Will I Know?

Thus, governments face a real quandary: When should social distancing be instituted and how intensive should it be? The problem is that there is uncertainty. When a virus first appears, we know soon after what its R_0 is likely to be. But we don't know immediately. In a situation like COVID-19 where many infected people are asymptomatic, that information can be even harder to get.

We also know that time can be of the essence. For COVID-19, wait a day to act and you might have 40 percent more cases 21 days later than if you acted immediately.[15] As time goes on, that 40 percent becomes a very large number. The more limited your information, the harder it is to act and achieve results. So, for a country where the outbreak commences, choosing when to socially distance is a very difficult choice. Moreover, given that today's travel possibilities can lead to transmission out of a country very quickly, placing the onus of that decision on the country of origin may not be enough. In the case of COVID-19, it was more than a month before China started to impose travel restrictions.[16] In retrospect, the price to be paid by the world was very high. However, what we were asking China to do was to pay a price themselves. These types of decisions are rarely pursued optimally. Moreover, for countries that could observe outbreaks elsewhere and failed to act quickly, even in terms of their own self-interest, excuses could run out.

The point of this is to demonstrate just how hard it is to pull the trigger on measures to reduce R_0 when an outbreak has just begun. There is uncertainty, and, moreover, the costs of actions are felt disproportionately. However, the notion that delaying a day or two will have much in the way of real benefits is a false comfort. If you choose to shut down your economy on Wednesday rather than Tuesday, a day's work and economic activity is lost. But that is peanuts relative to the costs associated with a shutdown at all. The takeaway, therefore, is that if you *know* you are going to shut down the country eventually, there are huge returns to doing it quickly.

One reason to delay is to gather more information. If you will learn by Wednesday that you could safely keep schools open, you might do well to continue to keep them open on Tuesday. What is more, it may be that shutting down early causes you to miss that critical information altogether. Thus, while "the drift" told us that if we do not hold the line on health, we may take away options we could use, it is nonetheless true that we can learn about different ways of containing the virus based on the actions we take.[17]

Delaying a decision in order to gather more information has a value in economics called the *real option value*. Suppose you need to consider when to shut down the economy for a month or more. You know that will have potential costs, but those costs are like an investment in terms of the benefits associated with reducing R_0. The decision to shut down will be the same on Tuesday versus Wednesday unless you learn something in the interim. Suppose you are predisposed to shut down on Tuesday, but there is more information to be accumulated.[18] Should you wait?

It turns out the answer depends on the type of information you are expecting to receive. As noted by Ben Bernanke, chair of the Federal Reserve during the 2008 financial crisis, if you are expecting news that will justify and reinforce the decision you were already predisposed to make on Tuesday, there is no reason to wait.[19] That information will not change your mind. Instead, the reason to wait is if you receive news that will convince you not to shut down. The only information that gives you an option value of waiting to pull the trigger is news that would cause you to remove your finger from the trigger entirely.

As I write this, it is hard to imagine the information governments were expecting to receive that would have caused them *not* to act on some type of social distancing. If there was hope, it was not articulated nor in the data. Thus, we are left to speculate. My speculation is that waiting was driven by receiving political news rather than scientific or economic news. Governments may have decided not to shut down if they found that a large proportion of the population would resist those efforts. In many cases, this is why governments implored citizens to engage in social distancing in the hope that they could achieve a reduction in R_0 without stronger measures. Those stronger measures included legal requirements to stay at home, which could potentially then be enforced with penalties associated with violations.

In summary, it is important to realize that acting decisively is very challenging. It is more challenging depending on the style of government, the transparency of information, and the competence of the decision makers. In the end, most governments eventually made strong moves to reduce R_0, and they did so in a manner that, on reflection, was relatively fast compared with decisions of far less consequence. In retrospect, with situations like this, we may always conclude that governments should have acted earlier. The future question that I have yet to hear a good answer for is: What changes are necessary so that it is possible for decisive action to be taken when it needs to be?

Key Points

1. The mathematics of pandemics means that when the basic reproduction number (R_0) is greater than one, the outbreak will not naturally end until a large fraction of the population has immunity.
2. The exponential properties associated with infectious outbreaks, like COVID-19, mean that delay in actions—such as social distancing and identifying who is infected and isolating them—can be very costly in terms of much higher numbers of infections.
3. People will, if given the information, engage in some social distancing in order to mitigate their own risk of infection. However, in making those choices, they neglect the impact they may have on others becoming infected. Thus, governments need to act to ensure that such practices actually take place at a sufficient level.
4. The timing of when to act is a very difficult decision because, in the case of a pandemic, many of its properties are not known at the outset, while the costs of suppression are very high.

3

A War Footing

"It is not easy for a free community to organize for war," wrote John Maynard Keynes in 1940.[1] He was commenting on something very obvious: people do not like to be told what to do. Keynes was frustrated by the inability of political leaders to lucidly explain to the public what needed to be done. Resources had to be allocated to the war effort, and, after that, a clear statement of how the remainder would be shared among the public had to be made. Instead, politicians were glossing over both issues with superlatives and no clear plan. Writing, as I am in March 2020, as politicians announce today what they claimed was unthinkable just yesterday (and I mean that literally), I understand where Keynes is coming from even if the magnitude of the problem seems comfortably lower.

Keynes was particularly concerned that the decisions that needed to be made were numerous and interrelated with one another.

> Is it better that the War Office should have a large reserve of uniforms in stock or that the cloth should be exported to increase the Treasury's reserve of foreign currency? Is it better to employ our shipyards to build warships or merchant-men? Is it better that a 20-year-old agricultural worker should be left on the farm or taken into the army?

He pointed out the obvious. A start was to think about which margin to fix—the standard of civilian life or the war effort—leaving the other as the residual. This had to be decided one way or the other. In our present conundrum, when asked, people would surely say that we should fight the pandemic first and adjust the rest. The fact that, in 1940, Keynes was pointing out that it was not obvious what Britain had decided should give us pause.

It is for this reason that having a clear and resolved approach to holding the line on health is warranted. Absent a clear resolve to place public health first, we end up at a point where we have the opportunity to improve the economy and public health. But when political leaders give in to the temptation to try to achieve both too early, they have failed to contain the virus and, thus, have chosen a lower point with regard to public health. That situation calls for strong measures to move back to what might be possible.

It is a striking fact that even the most market-loving, capitalist nations quickly abandoned the decentralized process of allocating resources in the face of World War II. No one expected the military to use markets to decide where to deploy troops and equipment, but the fact that the rest of the economy moved to a war footing in this way is useful to reflect on. In particular, for the most part, even though they may have flirted for a day with relying on strong advice to citizens, governments in the COVID-19 pandemic realized that was insufficient to their ends and ended up with strict and, in some cases, very strictly enforced policies. More authoritarian regimes were a little quicker to act initially, but the lag could be measured in days for most countries.

Why Central Coordination?

Economists claim that markets are the most efficient way of allocating resources and solving the age-old problem of who gets what if there isn't enough to go around. Markets are quite amazing in this regard, and every economist has their moment of wonder that markets work. The following is by Thomas Schelling:

> Most people, whether they drive their own taxis or manage continent-wide airlines, are expected to know very little about the whole economy and the way it works. They know the prices of the things they buy and sell, the interest rates at which they lend and borrow, and something about the pertinent alternatives to the ways they are currently earning their living or running their business or spending their money. The dairy farmer doesn't need to know how many people eat butter and how far away they are, how many other people raise cows, how many babies drink milk, or whether more money is spent on beer than on milk. What he needs to know is the prices of different feeds, the characteristics of different cows, the different prices farmers are getting for milk according to its butter fat content, the relative costs of hired labor and electrical machinery, and what his net earnings might be if he sold his cows and raised pigs instead or sold his farm and took the best job for which he's qualified in some city he is willing to live in.
>
> Somehow all of the activities seem to get coordinated. There's a taxi to get you to the airport. There's butter and cheese for lunch on the airplane. There are refineries to make the airplane fuel and trucks to transport it, cement for the runways, electricity for the escalators, and, most important of all, passengers who want to fly where the airplanes are going.[2]

It is a miracle and we should appreciate it as such. The problem is that it doesn't always get the job done.

When the job to be done is urgent and resources need to be reallocated quickly, the system can gum up. The issue is not markets per se but the problems of relying on a decentralized process whereby everyone allocates the resources they control on the basis of their own information and preferences. Indeed, the problem we face in a time of war (or pandemic) is that resources, currently controlled by individuals, all need to be applied to a new end, and the task of convincing everyone to choose to do so is unlikely to work out well.

This notion was captured in a 1990 paper by economists Patrick Bolton and Joe Farrell.[3] Imagine a situation where we need one factory to produce face masks and another to produce ventilators, but we don't know which will be able to do each task at the lowest cost. In a market economy, each factory owner might look at the situation and try to work out what to do. One option is that they both jump in and start producing the product they think they will provide most efficiently. They retool for that purpose, but there is a chance that they will end up both choosing the same thing and we will end up with too many face masks and too few ventilators or vice versa. Another option is to wait and see what the other factory chooses to do and then do the opposite. But in this world, we have both factories waiting to see what happens and there is a consequent delay. In other words, decentralization either will not get the job done or will cause it to be delayed.

The alternative is for someone to choose who does what. This is the role of central

coordination. This prevents both duplication and delay but opens up another problem: the government may make the wrong choice. The factories may end up producing both goods at a higher cost than otherwise. At times of crisis, however, we do not let the perfect be the enemy of the good and so comfortably resort to centralized resource allocation and bear the potential productive inefficiency.[4]

There are three areas where in the COVID-19 pandemic, market processes have been abandoned in favor of centralized coordination and control. These include the mobilization of resources to dramatically expand healthcare system capacity, the institution of price controls for certain important goods and services, and the use of blanket restrictions on movement of people. Each of these will be discussed in turn.

Surfing the Curve

The initial responses from governments to the pandemic were to institute progressively strong forms of social distancing in the hope of reducing R_0 (the number of people infected people themselves infect). Those responses had the goal of what came to be known as "flattening the curve." In a scenario where this needs to be done once, this involved a scenario such as depicted in figure 3.1. The task was not so much to reduce the total number who became infected but to spread them out over time to economize on healthcare system resources.

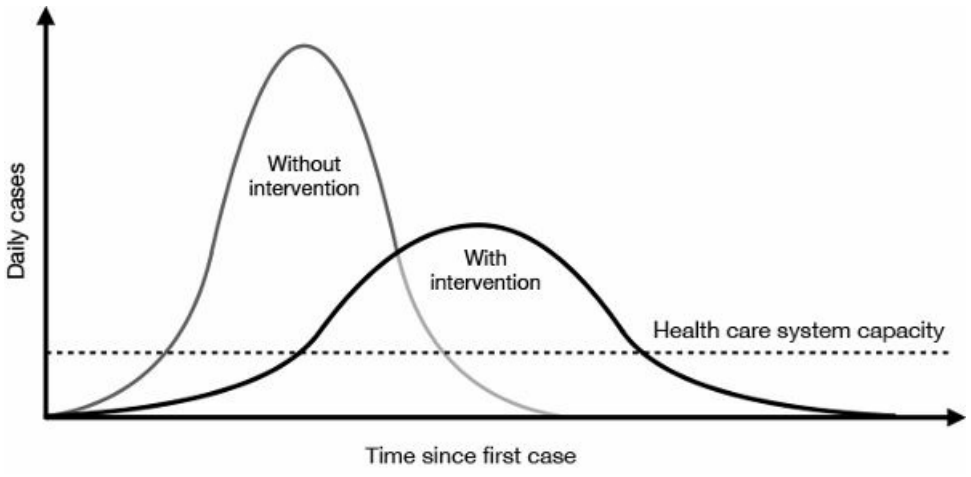

Figure 3.1
Flattening the curve.

The problem is determining how flat we need to go. The flatter the goal, the harder it is to achieve and, moreover, the greater are the consequent costs of prolonged economic harm, social isolation, and the possibilities that there could be a subsequent reemergence of the pandemic, causing us to do it over again.

The healthcare system capacity is likely much lower than the diagram is showing beyond what flattening the curve can actually achieve. This differs by country. Japan has 13 beds per 1,000 people, while the United States has fewer than three beds per 1,000. And this is just one statistic. There are large national differences in key inputs such as ICU beds, ventilators, hospital protective equipment, and healthcare workers. Nonetheless, in most cases, it is clear that policies aimed at reducing R_0 have happened too late to prevent healthcare system capacity from being reached. In Italy, doctors are having to make heart-breaking triage decisions to determine which patients would get scarce resources. From an economics perspective, the demand on healthcare resources was going to far outstrip supply. What is more, there was no prospect or desire to use higher prices to deal with the shortage. As Keynes noted for World War II, a plan for rationing was required but no plan was being formulated.

Given this, it is somewhat surprising that more has not been done to dramatically increase the capacity of the healthcare system. It is a policy option that both reduces the cost of overwhelmed capacity and reduces the amount of flatness of the curve and its associated costs. In March 2020, calls are being made for more ventilators and other equipment.[5] Most countries had not done what China had done earlier in Wuhan by building entirely new hospitals in just over a week. Everyone marveled at this. I heard: "Wow, we can't do that." And this was mostly from the healthcare industry whose basic message for years was how

hard it was to provide more. They have had expansion beaten out of them by years of a scarcity mindset.

While flattening the curve can take place and reduce the required capacity expansion, what is required is to surf the curve (see figure 3.2). In this situation, healthcare system capacity would be temporarily expanded so as to cover the unflattened portion of the curve.

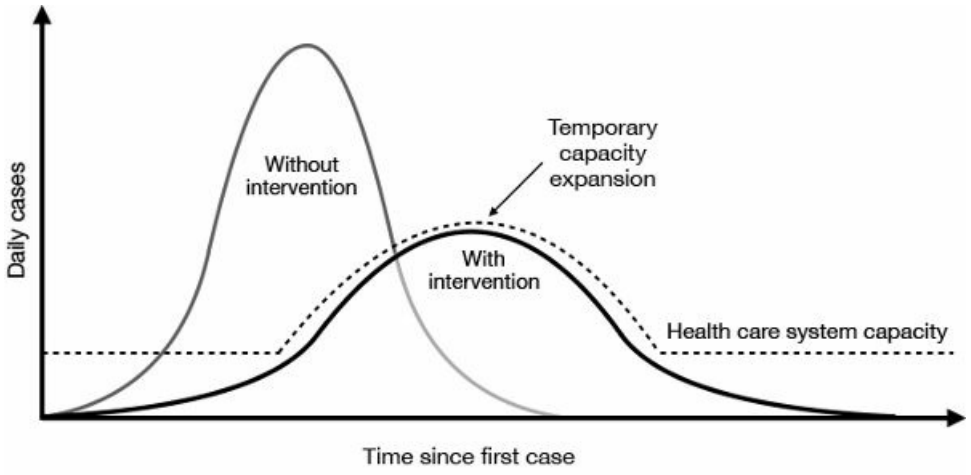

Figure 3.2
Surfing the curve.

Building out that capacity requires a new mindset and requires it quickly. The nature of the problem was obvious on the ground. The following are the words of Dr. Daniel Horn (a physician at Massachusetts General Hospital in Boston):

> In the face of a global shortage, American industries can step up and quickly produce ventilators. All week, I have been receiving text messages and emails that say things like "By the way, my company makes parts for G.E. ventilators. We just got a big order that we are pushing through as fast as we can." The General Motors chief executive, Mary T. Barra, announced that G.M. was working closely with Ventec Life Systems, one of a few ventilator companies based in the U.S., to rapidly scale up production of their critically important respiratory products. My colleagues at the nation's top hospitals are getting phone calls from tech leaders asking for ventilator specs.
>
> Such stories give me hope. But we need the federal government, too.… We need a plan.[6]

Sound familiar? This is precisely the coordination problem as outlined by Bolton and Farrell. Hospitals alone cannot procure what they need. Some factories can make some parts better than others. And then there is the issue of which hospitals to send them to. There has been little information present, and, in the United States, despite having the powers to do so, no central action has been taken.

This has highlighted the need for a war-like resource allocation mindset. Someone is needed to take control, and, when it came to fast and rapid capacity of healthcare, most countries have an obvious candidate: the military. Mobile Army Surgical Hospitals (or MASH), as portrayed in the TV show, are a part of the armed forces; they just had to be moved to civilian ends. In some countries, this happened with the military preparing and/or building facilities, for example, in Switzerland, Colombia, the Netherlands, Italy, and France.

The United States has also redirected hospital ships to California and New York to handle patients with other conditions who might be pushed out of those systems.

The numbers involved, however, suggest that a more comprehensive and aggressive solution is likely to be required: not only military provision but also a means of diverting manufacturing effort to the cause. Much of this has been lying idle due to social distancing. The need is for a centralized process to unlock that potential and ensure timely provision. In World War II, businesses quickly retooled for military production. The same is required now. Moreover, there will likely be a need for additional healthcare workers. This too could be a mobilization effort (perhaps even supported by conscription). The good news is that those resources are idle. The better news is that, unlike in wartime, no one will be asked to kill others.

Price Controls

Hand sanitizer and toilet paper went first. Hand sanitizer made sense. It was a genuine surge in demand as people expected to use more, much more, of it and were advised to do so. Toilet paper came as a surprise. The lack of it was not just due to a surge in demand but was said to be a result of hoarding. But why? As Justin Wolfers argued, showing that economists were unafraid to tell it like it is, "[o]nce they have more toilet paper, people aren't going to poo more."[7] He saw it like a bank run. People saw that toilet paper supplies were dwindling and bought more because they were concerned about supplies down the track. This created a run on the product just like a bank run. As it turned out, some toilet paper (even if it wasn't the good stuff) was back in the store after the initial rush before people found that they didn't have a square to spare.[8]

Hand sanitizer and other products that might be subject to real shortages are another matter. One story involved a couple of entrepreneurs who bought up a huge supply of hand sanitizer right after the first US death on March 1.[9] They had intended to sell their stock of 17,700 bottles at a large markup on Amazon. Before they could do so, Amazon cracked down, preventing them and others from selling the items that were in high demand. eBay followed suit. In the end, the bottles were donated to hospitals.

Price gouging is given an ugly name because, of course, it is associated with people taking advantage of shortages in times of crisis to make a profit. At normal times, economists usually like to let prices rise because they signal to others were demand is high and there are profitable opportunities to produce more. In other words, they are part of a market process for resource allocation. When we outlaw or otherwise try to provide a cap on prices, what we are doing is accepting a shortage.

As John Kenneth Galbraith, who headed up the US World War II office of price controls, noted, this is an acceptance of a "disequilibrium system" where demand persistently outstrips supply. This meant that items subject to controls needed to be rationed. As Galbraith noted, the outrage at this process tended to involve surprising items (just as we saw with toilet paper):

> [F]or some reason ceilings on fur coats inspired them to special anger. On several occasions I found myself contending with new colleagues (and once with a new administrator) who were enthusiastic about dropping price controls on fur coats. When they saw that this action would put a premium on high-priced coat manufacture, would draw materials ("trim") away from cheaper lines, they soon reversed themselves. In doing so they adopted a position entirely consistent with a broad theoretical pattern for allocating resources and equalizing incentives. Of the existence of any such theoretical pattern they were totally unaware.[10]

Given this, it is instructive to consider why we happily resort to price controls in times of crisis. The reason is that it may well do a better job at resource allocation. According to research by Piotr Dworczak, Scott Kominers, and Mohammad Akbarpour,[11] whom we want to get hand sanitizer can be different from whom the market will allocate it to. In that case, the social value of who has sanitizer is unrelated to wealth. Thus, had the price gougers got their way, only the wealthy would have got their hands on it and, in the process, protected themselves and the people they interacted with from infection.[12] But those are the very people

who have the best access to healthcare, who don’t live in more densely populated neighborhoods, or who can easily work from home. What makes more social sense is for the poorer members of the community to be allocated the hand sanitizer. Price controls give them a fighting chance. What might even be better is directly allocating hand sanitizer supply according to where it can have the greatest impact.[13]

Restrictions on Movement

We need to keep infected people isolated because one infected person can have the same impact as that of a mass shooter. Here is the calculation. If the R_0 for COVID-19 is 2, then an infected person will cause two others to be infected. But it obscures the magnitude of the problem. Those two people will infect two more people, and so on. After 10 rounds of this, that adds up to 1,024. (If R_0 = 3, it is 59,049!) If 1 percent of those people die from the disease, one infected person has been responsible for 10 deaths. Suffice it to say, that puts mass shootings in perspective. It is no surprise we want to keep infected people isolated.

The problem is how to do that. For starters, you have to know you are infected, and with COVID-19, as was already explained in chapter 1, the majority of infected people are unaware of it. Moreover, once you do know it, using claims (such as I have just done) that you might be responsible for between 10 and 600 deaths means that being infected carries a social stigma. Laura Derksen and Joep van Oosterhout found this when examining the spread of AIDS in Africa.[14] They found that when people were asked to opt for testing or AIDS-related care, there were few takers because people feared the stigma of being seen to be concerned that they may have the disease. People have to be generally and publicly knowledgeable about the social benefits of these actions, otherwise they might choose to cover up symptoms fearing discrimination. If refusing to go out is seen as a cover, that may be a problem.

Ordinarily, if you were going to restrict movement of people, you would try to target the individuals both at risk and who are likely to be people with a higher individual R_0. For COVID-19, some physicians wondered if a more targeted approach could be achieved. For instance, as those over the age of 70 were more likely to require the higher end of health costs (including death) associated with the virus, would it be better to isolate them and leave the rest of the population to circulate?[15] Doing this would greatly mitigate the economic costs from a broader policy.

The problem with targeting is that there are real doubts it would work. If a large proportion of those under 70 still become sick and need hospitalization, resources could still be overwhelmed. Moreover, with large numbers of infected younger people, we lack the people to support the elderly being isolated. As Alex Tabarrok agues, there are internal contradictions that may well render it impossible for a more “surgical” approach to social distancing.[16]

Targeted policies are also hard to enforce. When there are restrictions on movement, it is very easy for the authorities to see whether people are moving or not. In their absence it is harder to tell and can require more resources.[17] For these reasons, to deal with the costs associated with COVID-19 transmission, governments have opted for blanket policies akin to martial law in wartime or other times of emergency. These may be supported by penalties for violations but nothing like the type of taxes that economists would otherwise recommend so that exceptions can be made at the discretion of individual decision makers willing to bear a taxation cost. Instead, a heavy-handed approach is used without much room for nuance.

At the time of writing, the length of time for social distancing has been of the order of a few weeks. What remains unknown is precisely how long it both needs to and can last. I leave that as an open question that may already be answered by the time you read this book.[18]

Key Points

1. Pandemics require resolve and quick action to control while minimizing public health and the eventual economic impact. The urgency and need for coordination imply that governments need to adopt policies and allocate resources akin to times of war. This means a suspension of free market forces in favor of command and control approaches.
2. If social distancing aimed at “flattening the curve” is too late, the goal of that policy —to prevent healthcare systems from reaching capacity—will not be achieved. In that situation, governments will need to rapidly expand capacity using wartime protocols such as redirecting private manufacturing facilities to produce medical equipment and using the military to expand hospital capacity.
3. There is a need for price controls on products that have a role in reducing the spread of the infection, as market prices will not allocate those products where there are shortages in an optimal manner.
4. Restrictions on movement will need to be imposed and enforced to ensure proper social distancing in containing COVID-19. Targeted quarantines have high risks associated with them that may undermine their effectiveness unless information about those specifically infected is widely available.

4

This Time It Really Is Different

Recessions are not normally thought of as normal. But *normal* recessions tend to follow a certain pattern. First, they are preceded by a boom—a sustained period of high growth. Second, this boom gives the financial sector the confidence to innovate in various new ways of managing risk. Too often, however, these are not really new innovations per se but, instead—it is not a stretch to suggest—are just new ways of rationalizing the taking of risk and spreading it around. Third, some people start worrying about whether these new innovations are really innovations but are instead just more risk taking. Those worries are often dismissed by those in the mainstream who point out that, while that may have been the case in the past, *this time it really is different*, and the financial markets have found a party that will last forever. Fourth, something happens that starts to suggest this isn't a party anymore. Like Wile E. Coyote, the market realizes they are over a cliff and the party ends in a crash as if gravity is a force that can be defied without self-awareness. And, finally, this leads to a freeze in liquidity—that is, everyone not wanting to do anything but hold onto whatever money they have—which curtails investment, harms the cash flow of businesses, causes bankruptcies, and puts people out of work. The end result of this is an economic mess that the government and central banks try to solve by providing liquidity that went missing and by spending where others stopped, and, after a long period of time (at least for the unemployed), the economy starts up again and there is a boom. Repeat.

Given the regularity of the normal recession narrative, you may wonder how people could think there was something else going on. In hindsight, it all looks like a familiar pattern. At the time, however, there are people who think otherwise. They may class themselves as mavericks who will finally buck a historical trend, or it may be that they are a generation who didn't live through it before nor have taken or paid attention during their Macroeconomics 101 classes. But it is precisely because no one is really sure who believes what that during the actual cycle, there is uncertainty and noise. Indeed, financial markets have confidence issues all of the time and often manage to act like a recession is coming even when it does not emerge. That is, a financial crisis always precedes a recession, but there are financial crises that also happen without broader "real world" consequences. Such uncertainty is why governments and central banks can be (somewhat) excused when they don't quite see a recession coming and perhaps act when it is too late.

The COVID-19 pandemic is a real crisis and not a financial crisis born of years of naked hubris on the part of relatively few people. Instead, it has elements of a natural disaster and, surprisingly, as explained below, a national holiday. At the time of this writing, the COVID-19 recession is more of the latter than the former and the hope is to keep it that way. Either way, it is very different from previous recessions—we don't need hindsight to understand what its causes are. We know exactly what happened. Economic activity is falling because of COVID-19, both its (potential) impact and our policies designed to protect our health from it. From the perspective of economic policy, that yielded something unprecedented: virtually all economists—regardless of how confident or not they were in the economic role of the government—agreed on what we had to do about it.[1] We needed to ensure that people got paid or, at the very least, continued to act as if they were going to be paid.

Before explaining why this is so, it is useful to reflect on the natural disaster recession that, in many respects, we are trying to avoid. Such recessions have occurred in the past and they are the worst.

Dark Recessions

Economic activity is usually measured by exchange—that is, people pay money for services and things and one person's purchases becomes another's pay. The more we do this, the higher our incomes are. Recessions are a reduction in economic activity. As a consequence, we end up with lower incomes and lower expenditure. As expenditures tend to make us more happy than not, our economic well-being is harmed by recessions.

There are two distinct ways that we can see a reduction in economic activity. First, we can decide that we want to spend less on things. If we do that, then businesses find their demand and sales will drop off; they will be less profitable and, not surprisingly, will want to scale back what they do. Fewer payments mean fewer people are paid. Second, something terrible can befall our ability to produce things that people will buy. If that happens, then, regardless of how much they may want those things, there will be shortages. If there are fewer people around to be paid, there will be fewer payments. Dark recessions are recessions of the second variety.

Natural disasters are a clear cause of dark recessions. A flood, hurricane, or earthquake can hit a region and, in the process, cost lives and destroy productive assets—in particular, buildings and equipment but also infrastructure. Ultimately, we produce things by supplying capital and labor. Natural disasters reduce the availability of both, and, depending on its severity, it can take months or years to restore them. If there is a silver lining here, we can ensure people get paid quickly by employing them in the cleanup and rebuilding process. From the perspective of our national accounts, disaster in reality doesn't always look like a disaster for the GDP.

The same loss in productive factors arises after wars. During wars there is another story as resources are reallocated to war efforts. Once again, this is a situation where a seeming expansion in economic activity underlies a tragedy.

A pandemic has the elements of a natural disaster except that it is purely focused on people. The fear is that a large share of the population will become sick and a relatively large share might die. From an economic perspective, that means that temporarily, and potentially permanently, we will have fewer workers to produce stuff. We will have a recession or worse but without the potential increase in economic activity that might be generated by rebuilding.

The past is some guide to this. The only global, widespread pandemic that has happened during times where we kept some economic data is the flu of 1918.[2] The problem, of course, is that pandemic was hot off the heels of World War I, although it was precisely the end of that war and the returning soldiers that led to it being a global event. This made it hard to disentangle what was due to the war and what was due to the pandemic.

Economists Robert Barro, Jose Ursua, and Joanna Weng have looked at the impact of the 1918 influenza pandemic and have calculated that it likely resulted in the deaths of 2 percent of the world's population over a two-year period.[3] That put it in a class of disasters akin to the world wars and the Great Depression where there were greater than 10 percent declines in real per capita consumption in an adjacent year. Nonetheless, it is hard to separate the pandemic from the war.

To tease this out, the economists noted that World War I had different intensities of combat both on and away from a country's own soil and that there were some differences in how the pandemic spread across countries. They concluded that, in the United States, the fatality rate of 0.5 percent likely led to a decrease in GDP of 1.5 percent (2 percent for consumption) but that there was a corresponding decline through 1921 that caused a 6 percent decrease in GDP

(7 percent for consumption) in that year alone. In other words, these were declines similar to the Great Recession of 2008–2009.

Could we be facing a dark recession that is worse than this? It is hard to say. On the "bright" side, unlike 1918, most of those becoming seriously ill are not of working age. On the "dark" side, we have more complex and integrated supply chains where an outbreak in a particular workplace or region can cause widespread disruptions. Even completely ignoring the horrific loss in life and uncertainty, a dark recession is very significant and something we want to work very hard to prevent.

The Recession We "Want"

A dark recession could come later. At the beginning of the outbreak, we have policies being enacted that are generating an immediate recession. This is the recession we want so as to prevent the catastrophic outcomes we really don't want. But that doesn't mean it isn't without costs. It is, as former Obama economic advisor Austan Goolsbee said, a "now problem" that we want to "prevent forever damage."[4]

Small businesses are worried about both now and the future. The majority of countries are pursuing social distancing in response to the pandemic, which means that those businesses have found that, all of a sudden, their customers have disappeared and with them the payments they make. What hasn't disappeared are lots of bills. If you are a restaurant owner, you can scale back purchases of food and you could also lay off employees. In both cases, there is the specter of supply chain disruption, which is what many economic policymakers immediately worried about. But what those businesses cannot do is easily stop paying rent, loan repayments, utilities, and other costs that do not vary much (or at all) with customer volume.

Here is what normally happens if a business loses its customers. They scale back expenses, and then, if it continues, they are unable to pay for those other items and so go out of business. This is part of the ebb and flow of the economy and a reason for businesses to work hard to keep their customers coming. On the other side, there is little tolerance for unpaid bills because those suppliers — say, a landlord or a bank — have their own businesses to manage. This is why we measure economic activity by the volume of payments that are made between people in a year (as we do for GDP and its relatives). We are richer when we pay each other more and are poorer otherwise.

This time it really is different. We know exactly why businesses have seen their customers disappear—the pandemic response of social distancing, whether enforced or otherwise, wants to ensure that people do not congregate even if that is the way economic activity takes place. Moreover, we know that, ideally, we want people to go straight back to their economic activity afterward. In other words, in a normal recession we don't want to go back to business as usual because that likely caused the problem. In a pandemic, we do.

This may seem like a tough task, but we should take solace that we choose to have recessions all of the time and it just works out. This may seem like a surprising statement, but consider what happens on December 25 in many countries. On that day, economic activity declines at levels that would make the Great Depression seem like a picnic. Apart from some people who would really like Chinese food, this does not appear to have significant economic costs. You may want to work that day or you may want to buy something, but you will have difficulty finding others reciprocate in the transaction. Hence, payments stop and, with that, economic activity.

If we measured GDP changes daily rather than monthly or quarterly, this may show up in our economic mindset. The same is true of our "weekly recession" that occurs in we call "the weekend." Once again, we appear to agree that no one is transacting as much on Saturdays or Sundays (or Fridays in some places), and even if you want to, you cannot engage in some forms of economic activity. It's a regular recession and one that we appear to want just to give everyone a break.

This is the reason why pandemic-induced social distancing that causes a recession is a little like a national holiday. We have agreed not to engage in economic activity, so we should not be surprised when our usual measures of such activity show a decline.

Herein lies our potential mistake: treating this recession like a normal recession when it is not. People are not getting paid and resources are lying idle. But that is what makes a recession and not the normal state of affairs. If we layer on the concern that the usual way of measuring economic activity is sending us bad signals, which is what happens in a normal recession, then we have a problem.[5]

It shouldn't be that way. Instead, we have to do what we do on weekends and holidays. We need to stop time.

The Pause

"Stopping time" is a lovely turn of phrase that I can attribute to Scott Ellison, who was quoted on the Marginal Revolution blog with this proposal:[6]

> I propose temporarily stopping time. This means that today's date, Tuesday, March 17th, 2020, will remain the current date until further notice. This also means that everything that happens in time (e.g. mortgage due dates, payrolls, travel bookings, stock market trading, contractor gigs, concerts, sporting events) will be paused. It also means that all of these events remain on the books, and will continue as planned once time is resumed.

He notes that most do this every fall when we all agree that time will be paused one hour and pretend that we deserved more sleep. The problem, however, is that much of the economy needs to actually keep running—some more intensively than before—which means that just calling a time-out won't do the trick.

The principle, though, is a useful one. Without something different, a business that finds itself in trouble will have to shut down. Shutdowns are costly precisely because it is hard to get started again. Our hypothetical restaurant owner would have to find a new place, secure new capital, and make new investments, all before hiring people and opening up. It is like hitting the eject button and removing the CD from the player. Instead (and you can anticipate a tortured metaphor here), what the restaurant owner wants to do is hit the pause button. They want their business to stay where it is but to stop playing.[7]

One obvious solution is for the private sector to be able to do this for themselves. Sure, our restaurant owner's landlord could evict them because they are no longer able to pay rent. But the landlord could also not do that. They could realize—because it is plainly obvious—that the restaurant is a viable business in the middle of a hiccup and so agree to suspend rent payments. In actuality, they may not be technically losing out from this choice because (1) they are unlikely to find any other renter in the meantime and (2) they won't have to look for another renter beyond that.

This is all well and good if the landlord has the power to make such decisions. However, behind many landlords are banks that have provided them with mortgages. They have provided loans to many property owners and may struggle to work out who is really participating in the pause. Thus, they may choose to foreclose on the landlords. If we could all see what was going on, maybe we could coordinate the pause without help. However, because that is risky and the pause button needs to be hit urgently, governments can help coordinate that just as they do with daylight savings time.

This is not specific to rent or mortgage payments by small businesses. The services that comprise their fixed costs extend well beyond that. The popular fresh fast food chain in Boston, Clover Food Lab, put out a plea in March 2020 for tech companies to not require payments for three months.[8] Its founder, Ayr Muir, wrote:

> I'm hours and hours into painstakingly reaching out to the HUGE number of services Clover uses to operate. For all it's the same thing. (1) We want to use these services as soon as we re-open, (2) we DON'T want to lose all our data and set-up all over again, (3) We CAN'T pay while we have no revenues coming in.

Some companies responded to Muir's plea, but the majority did not. For companies that have otherwise very high margins, a pause would be a sensible response compared with pushing businesses off their services and making them pay the costs—in time and otherwise—of setting up again. The difference between these Big Tech companies and landlords is that it is highly likely they won't face any costs from offering a pause.

All of these considerations apply beyond small business. There are employees who face consequences in terms of paying ongoing household expenses should they find themselves unemployed. So, while we cannot necessarily expect them to be paid while not working for an extended period of time, the pause notion surely equally applies to them with respect to their rent, mortgage, debt, and utility payments.[9]

How to Pause

For once, it didn't take governments long to realize the nature of the problem. Through March 2020 they ordered lenders and landlords to hit the pause button on foreclosures and evictions for a month or two.[10] French President Emmanuel Macron was more strident and suspended utility payments and rent for small businesses, promising that "no business would be allowed to fail."[11] The US government pushed back its annual tax payment deadline from April 15 to July 15 and allowed student loan payments to be stopped without penalty. But perhaps no country opted to "freeze" their economy quicker than Denmark. In mid-March 2020, they opted to pay 75 percent of all salaries of potentially laid off workers (earning up to $52,000 a year), guarantee 70 percent of new bank loans to companies, and cover the fixed expenses of small businesses. The total cost was 13 percent of their usual GDP.[12] If the United States did the same thing, it would be $2.5 trillion.

Halting consequences and payments is a very direct way of pausing the economy and making sure that the temporary harm is not baked into the recovery. In other cases, the government tried to provide money to achieve the same thing. In Canada and the United Kingdom this included wage subsidies when businesses keep employees and delayed tax payments that businesses make on their behalf.

Perhaps the most radical proposal came from French economists Emmanuel Saez and Gabrielle Zucman, who argued that governments should become "payers of the last resort."[13] If a business was facing shutdown, the government would come in and pay for employees and for fixed-cost payments such as rent, utilities, and interest. In other words, they would have governments pay for businesses to pause. They suggested that unemployment payments could simply be made as if workers have lost their jobs, to provide an easy route to such payments. They would also allow self-employed or gig economy workers to report themselves as idle to be eligible for such payments. For businesses, if they are part of lockdowns for more extreme social distancing, they would report their costs, be reimbursed, and then any misreporting would be worked out later.

Is it better to stop bill payments or to pay them? Stopping certain bill payments is straightforward and easy to enforce. The problem, of course, is that it is not clear we are allocating the burden of preventing a recession equitably. In fact, when the dust settles, that won't be the case. The problem is that, at the moment the policy needs to be introduced, there is no easy way of knowing this. This suggests that there may be some political fallout or economic recompense to be hashed out postcrisis. That uncertainty may actually cause some short-term problems to become long-term ones.

By contrast, paying bills can circumvent this by, in principle, sharing the burden at the outset. For instance, you could make sure that the hit to workers in terms of lost income was proportionate to the likely loss in capital returns. This is done by paying part of the invoiced amount of bills and wages. The challenge with this is that it requires some verification (eventually) of what those bills might have been and, in the meantime, a process of getting those payments to where they are needed. In other words, neither of these options is cleanup free.[14]

An Alternative: Income-Contingent Loans

The problem with both stopping bill payments or paying them is that each becomes more difficult the longer the initial pandemic recession lasts. What is more, we do not actually have a good sense of how much more difficult these would become. In other words, they are really temporary emergency measures.

One measure that has the potential to last longer is government or private loans with a government guarantee. At the time of writing, various government support loans are being contemplated. As Sendhil Mullainathan wrote:

> During the 2008 crisis, the government understood this principle well. It bailed out large financial firms for much the same reason: They were facing temporary shocks that, without intervention, would unnecessarily become permanent ones. Whatever else one may feel about those bailouts, that economic logic was sound. Those investments yielded healthy profits for the government.[15]

The same logic of using loans has also been considered for some of the more hard-hit industries, including travel and hospitality. Loans are a way of allowing bills to be paid without having to sort out what bills and how much because whoever takes out a loan is still responsible for repayments.

However, it may also be the case, given the absence of revenue or wages, that full loans may be not be financially possible. In this regard, there is a debate regarding whether governments should step in and handle some of the short-term payments to give debtors financial breathing space or to provide support to reduce the loan principal. The rationale for the latter is that it reduces the future debt overhang of businesses and others, assisting them in getting back on their feet.

A careful study by Peter Ganong and Pascal Noel showed that if your goal is to prevent temporary issues becoming long-term ones, it is better to provide short-term help.[16] Using the differential impact of certain programs offered during the financial crisis of 2008–2009, they were able to measure the impact of reducing long-term obligations (a direct improvement to wealth) versus reducing short-term payments (assisting liquidity). As it turned out, the former did nothing for borrowers who were already underwater, while the latter significantly reduced default rates. This study strongly suggests that we want to help borrowers with government-backed assistance for loan repayments rather than assistance paid directly to lenders to reduce loan principals.

Of course, providing this assistance to people directly can make it hard to tailor it to individual circumstances as well as to ensure that the repayment of any assistance is not onerous. As it turns out, however, an innovative Australian debt scheme used for higher education tuition could be readily applied. Australian universities are (mostly) public but still charge tuition to students. The rationale for that is that while education has public benefits, when you have an education you are the main financial beneficiary and so should be responsible for some of the costs. Thus, in the 1990s, the left-wing Labor government ended two decades of free tuition and put in its place an income-contingent loan.

The idea was this. You want to ensure that student loans are automatic and not onerous to administer. Thus, when tuition was charged, students could opt not to pay it immediately but, instead, incur a debt to the government. However, what you did not want is the repayment of

those loans to depend too much on career paths. After all, a lawyer or doctor may be able to earn more than a high school teacher, so you don't want the latter to have debt repayments that presumed too high an income. The scheme instead gave students a slightly higher marginal tax rate until their loan principal (plus modest interest) was repaid. Thus, the high-income professionals would, by virtue of their higher income, be required to pay more sooner than those with lower income.

Higher education was a natural candidate for this type of loan, but in 2004, my economist colleague Stephen King and I proposed a similar arrangement for housing.[17] We suggested that when there were temporary shocks to someone's income as might arise should they lose employment, then rather than evicting or foreclosing on them (as would be their initial worry), the government would step in and cover those housing-related payments for a time. A debt would accrue, but, as for students, it would only be repaid through the tax system, when people had income again. This would both provide stability for households when there were economic shocks and also, by providing financial breathing space, make lending or offering housing to people who might be more exposed to such shocks a better proposition for lenders and landlords.

There is little reason that such a scheme could not be enacted to cover short-term expenses associated with a pandemic recession. Presumably, only those who believed that they could pause their economic activity would avail themselves of this loan, but then they could spread the burden over time. It would provide liquidity but at the same time ensure that those who received payments were responsible for them somewhat in proportion to their benefits.

The Final Stimulus

In many respects, the previous discussion is a somewhat optimistic one. It assumes governments can implement policies that pause the economy and that actually work. Since it has never been done before, economists have no idea whether it will be enough. Conceptually, it is a strong proposal. In reality, as with all of these things, there are consequences we cannot predict.

Bound up in the US approach to macroeconomic support in the United States is a program to send a stimulus of $1,200 (in the form of tax rebates) to every citizen as restrictions were put in place. This was done after 9/11 and also during the 2008 financial crisis. The idea then, as now, is to restore consumer confidence and spending. With COVID-19 or any pandemic, as the recession is not normal, one must wonder if such direct stimulus is appropriate. The worry is that, while this cash may support those people who have loan and other immediate obligations, with social distancing policies in place, the money may not be consumed but instead saved. Saving can be beneficial if there is a need for liquidity, but in this case, that was already being provided by aggressive actions from central banks.

The determination of when a direct stimulus is likely to be required is part of the effort to restart the economy as social distancing is no longer required. Thus, we might be concerned that directing policy toward a stimulus prematurely might hamper that option arising later and might detract from the decidedly not-normal task of pausing the economy at the outset of the crisis.

Key Points

1. The worst economic outcome from COVID-19 is a dark recession where there are insufficient workers available to restore economic activity to its previous level.
2. To prevent this, we need to engineer a recession that would accompany social distancing to contain the outbreak. In doing this, the key objective is to be able to preserve job matches and prevent businesses from closing so that economic activity can be restarted again.
3. This requires payments, subsidies, and loan guarantees that can ensure that people's short-term disruptions are not translated into long-term breakups that would require a lengthy period of time to overcome. One way of doing this would be to institutionalize loans by the government that could be paid back through taxes when incomes (or business revenue) is restored.
4. Following the crisis, there will likely be a need for the usual macroeconomic policies to stimulate and accelerate the recovery.

5

The Testing Economy

The cows were not safe. They were mad. But what made them unsafe was that anyone consuming them may well become mad. That is what the United Kingdom discovered in the 1990s. It was found that cattle affected by bovine spongiform encephalopathy (or BSE) could cause a variant of Creutzfeldt-Jakob disease in humans. That disease would mentally impair its victims and eventually take their lives. As of 2013, 177 people in the United Kingdom had died. Not surprisingly, no one wanted to consume cattle that might have BSE.

The reaction of the United States to cases of BSE is instructive. In 2003, a cow imported to the United States from Canada was found to have BSE. Imports were banned. In Canada, cattle prices fell by a half and retail beef prices by 14 percent. Canada's annual beef export revenues to the United States fell by two thirds. At the time, Canadian beef made up three quarters of US beef imports, so this imposed costs on both countries, with losses estimated in the billions.[1] When, later in 2003, an infected cow was discovered in Washington State, the trade bans fell on the other foot.

As internal bans were neither palatable or practical, the US Department of Agriculture (or USDA) ramped up testing. It favored what was argued to be a less accurate "rapid" immunologic test (with results delivered in hours rather than weeks). The cost of these tests was about $200 million, but the positive impact on reviving the US beef export industry was far in excess of this.

This chapter is about the value of testing and how it can improve the functioning of markets when there are infectious diseases. The BSE example indicates the value of testing for the beef trade and has strong lessons in the wake of COVID-19 for how the testing of humans can make it safe for people to interact with one another. But before getting to the meat (!) of the issue, there was one more twist in the USDA's handling of BSE testing. Having successfully demonstrated the economic value of tests, the USDA promptly banned them.

You read that right. The USDA forbade cattle exporters from paying for the tests themselves for their own livestock. A producer of black Angus beef for sale to Japan, Creekstone Farms Premium Beef, wanted to use the USDA's approved rapid test as part of its production and marketing efforts. The reasons were obvious. It was commercially lucrative to provide that information to customers. However, the USDA claimed that using the test was for "surveillance" purposes and was concerned that if some producers tested their cattle, this would imply that the cattle of others was unsafe. Cattle trade associations feared that this would lead to an unravelling, necessitating all producers to incur the costs of testing.

Creekstone sued the USDA and, initially, prevailed.[2] The USDA's position wasn't ludicrous as a matter of economics. Many economists had been concerned that in some markets, particularly higher education, there may be undue costs to signaling and that there may be a social rationale for banning such contests.[3] (For instance, students spending enormous effort to get into a slightly higher-ranked college even though the learning outcomes were the same.) However, in this situation, the Court realized that there was a customer who was particularly sensitive about certification of quality and that in the absence of a threat to public safety, there was no reason to prevent a business's right to use tests to assist in their marketing. The only rationale for prohibiting the use of the test would be if the tests were uninformative. They weren't. In other words, the tests could not simultaneously be

effective in identifying a safety concern and ineffective in certifying product quality. The USDA appealed and the US Court of Appeals reversed the decision and returned to the USDA the power to regulate BSE test kits, which it exercised. Private testing was banned.

A Lack of Knowledge Is Infectious

The interests of economy and public health collide because the most important way to deal with a pandemic in the interests of public health is to slow the rate of infection (that is, R_0). A person having a disease is a health problem that requires knowing how to treat that person and then doing so. A person having an *infectious* disease is a public health problem because, in addition, that person can pass the disease onto others. Being infectious is what turns an isolated health problem into an interdependent one. Because our typical dealings with other people rely on others being safe to interact with, pandemics destroy interactions and, consequently, the economy.

The BSE infections showed a microcosm of how a lack of safety impacts interactions—in this case, between cattle and humans. But they also showed the importance of knowledge. There is a big difference between knowing someone you interact with is infectious and having to make a guess as to whether that person is infectious. In the former case, you can act and limit the interactions. In the latter case, you have to take a risk. And in evaluating that risk what we care about is not just whether you become infected but also whether you might pass that on to others.

If your goal is to minimize the public health risk, a lack of knowledge dramatically reduces your number of options. If you have no information whatsoever regarding whether any given person is infected, then you have to engage in blanket isolation policies to reduce the rate of infection. You are forced to make judgments regarding what is and what is not essential and draw your isolation boundaries around those lines.

Imagine, for the moment, that instead of no knowledge you had perfect knowledge of whether any particular individual is infected or not. To give you a picture, imagine the virus was such that it inflated people's noses and made them shine bright red like Rudolph the Red-Nosed Reindeer. Imagine also that as those people moved, they left a trail of red that you could see even after a number of hours. Then anyone could easily identify who is safe to interact with and who is not. For those who are unsafe, we could isolate them or approach them only if they or you had suitable protective gear.

The difference between perfect knowledge and no knowledge is what causes an infectious disease to have an impact on social and economic interactions. With perfect knowledge, some people get sick, they are isolated, and life is essentially unchanged. With no knowledge at all and no interventions to prevent infections, then for COVID-19, at its peak, about 21 million people in the United States alone would likely be infectious at one time. With no restrictions on activity, the probability that you interact with one of the infectious people on a given day is 21 million divided by 327 million, or 6.4 percent.[4] However, suppose you interact with only 10 people per week. In that situation, the probability that you are able to avoid any of those infected people is about 50-50. When going to public spaces, you may interact with over a hundred people per week. In that case, your probability of avoiding an infected person becomes close to zero. In other words, perfect knowledge allows you to avoid *all* infected people. No knowledge makes it near certain that you will encounter at least one infected person.

The key to making people safe is knowledge. One way that can occur is to let the virus run its course without interventions. Of course, that is tantamount to saying that public health will not be prioritized over the economy. In the United States, that likely means 15 million hospitalized at the peak and more sick at home. And there are another 3 million likely to die. That is the underpinning of the dark recession scenario. Suffice it to say, if the goal is to

make people safe for interactions, making them completely unsafe for a period of time would appear to defeat the point.

Make People Safe Again

How do we gather that knowledge? The answer with respect to COVID-19 is tests.[5] There are two types of tests that are relevant. First, there are tests that can indicate the presence of the coronavirus in an individual. Second, there are tests that can indicate the presence of COVID-19 antibodies. One type tests whether you have the virus and are likely to be infectious (e.g., equivalent to the Rudolph thought experiment above), while the other tests whether you have had the virus and are likely to be immune. At the onset of the COVID-19 outbreak, tests for the presence of the virus were available, and, depending on the country and the test, there were differences in how quickly they could yield a result. As of the time of writing, antibody tests are being developed but are not verified, let alone widely available.[6] The two types of tests, which I will refer to as HAVE and HAD, respectively, play different roles in making people safe.[7]

The first thing to note is that a HAVE testing regime potentially makes a HAD test redundant. With a perfect HAVE testing regime, you would test everyone at a regular interval and the test would, with high confidence, tell you if you HAVE the virus or not. Given this, on the assumption that having the virus would give you immunity, you would not expect to learn much more from a HAD test.

For COVID-19, no country has a perfect HAVE testing regime. In general, as tests are not widely available, different jurisdictions have different policies regarding the factors that, if present, might require a test. This is somewhat paradoxical because, if you had COVID-19 symptoms (such as a fever, cough, or shortness of breath), you were more likely to test positive for the virus. Thus, if a person with symptoms had a positive test, this is actually *less* information than would be gained if a person without symptoms had a positive test result. Put simply, the more observable are your COVID-19 symptoms, the less valuable a test is.

This is especially the case as many infected people are, in fact, asymptomatic. At the time of writing, the extent to which asymptomatic people are infectious is unclear. However, what is understood is that some symptoms, particularly a cough, can make people more infectious.

Moreover, one value of testing is that it can inform public health officials of the characteristics of the disease, including the base epidemiological properties such as R_0 and how infectious asymptomatic carriers were. Put simply, if you test symptomatic people and find that, say, 80 percent of them have COVID-19, then without knowing how many asymptomatic people have the virus, you only know that a random person in the population likely has COVID-19 with less than 80 percent probability and not how much less.

Fortunately, there were situations where HAVE testing was conducted without reference to underlying symptoms. One case was the Diamond Princess cruise ship that was quarantined in Japan for a period of time and ended up having many victims. However, a cruise ship does not match the properties in the population in terms of like transmission rates (it is a unique situation) nor in terms of other factors such as mortality (as the demographics were different). A better indication came from a proactive study of the town of Vò in Italy whose entire population of 3,300 was tested and retested regardless of symptoms. It was discovered there that half of the positive cases were asymptomatic.[8]

The Vò experience also highlighted the effectiveness of using HAVE tests to identify who should be isolated. The first testing round found 3 percent of the population with the virus. They were isolated, and a second round of test found only 0.3 percent still infected. Importantly, that was not zero and there were still six infected people who also had no symptoms. Identifying them prevented a reemergence of the infection in the population.

There is one final remark to make regarding testing and symptoms. Symptoms are themselves a type of test albeit one with error. For instance, one cost-effective way of regular testing is taking temperatures. These are done at some border crossings and other places where there might be large gatherings of people. The problem with this test is that an elevated temperature may be consistent with other things; for example, the flu. This can be important, as shown in table 5.1.

Table 5.1

Symptom	COVID-19	Flu
Fever	Common	Common
Cough	Common	Common
Fatigue	Common	Common
Runny nose	Sometimes	Sometimes
Headache	Sometimes	Common
Body aches	Sometimes	Common
Shortness of breath	Common	Sometimes
Respiratory issues	Common	Sometimes

Source: Adapted from https://www.medicalnewstoday.com/articles/coronavirus-vs-flu#symptoms.

Notice that, alongside fever, other symptoms are common to both COVID-19 and the flu. The main symptoms that are more clearly common with COVID-19 than the flu are shortness of breath and respiratory issues. Thus, it is these symptoms that give the clearest indication that a person has COVID-19.[9] They may, of course, be hard to measure if they are mild, as the baseline may differ between individuals.[10]

There is one method that would assist in targeting asymptomatic people for testing and then isolation: *contact tracing*.[11] This requires an intensive effort to identify those persons who came in contact with someone who tested positive for COVID-19 (or was otherwise suspected to carry it) over the past week or so. In doing this, those people can be identified and then prioritized for tests (and potentially further contact tracing) even if they do not exhibit symptoms. Again, the goal with testing or gathering information is to be able to isolate people on a more targeted basis than blanket policies that lock down entire regions.[12]

To summarize, a HAVE test is useful because it enables an action. That action is to isolate or quarantine any individual with a positive test until such time as they are held (through additional testing or otherwise) to no longer be infectious. The value of this strategy is that it is potentially more cost-effective (in terms of impact on economic and social life) than using blanket isolation policies to reduce rates of infection.[13] In this way, the availability and use of HAVE testing is a potential way in which countries can reduce the extent of the decrease in

production possibilities during a pandemic.

Certified Safe

While the initial response to the COVID-19 pandemic in many countries (especially in Europe and North America) has been varying degrees of blanket isolation, there will come a time when those isolation policies need to be relaxed. Because HAVE testing has been either nonexistent for most or otherwise imperfect, the only safe individuals to be removed from isolation have been those who were known to have COVID-19 and recovered. Because COVID-19 can be asymptomatic, even if a large share of the population did have the virus at one point, even they may not be sure they are now immune. More broadly, even if they suspect they are immune, there would no easy way to communicate to others that they were safe.

Perhaps no example better illustrates the desire for certification of immunity than what happened during the yellow fever plague that hit New Orleans in the 1800s. In 1853 alone, one in 10 died. The only known defense was "acclimation"—to contract the disease and not die from it. You had a 50-50 chance of that last step. Historian Kathryn Olivarius documented that, despite this, the city (and its region) managed to grow. She recounts the experience of a German immigrant Vincent Nolte:

> Nolte cherished one form of capital above all. In 1806, three months after his arrival in New Orleans, he was bitten by a tiny mosquito and fell sick with yellow fever, the most terrifying disease in the Atlantic World.... Nolte survived his "acclimation." And now what had made him sick made him strong. He possessed "immunocapital": socially acknowledged lifelong immunity to a highly lethal virus, providing access to previously inaccessible realms of economic, political, and social power.[14]

In New Orleans an acclimation certificate was a key asset that determined whether you could engage in economic activity. Indeed, it was so valuable that many immigrants arriving actively tried to get sick, as this would be a ticket to economic prosperity and marriage if they survived.[15] Unfortunately, without a test, it turned out that the best way to become certified was to prove that you lived in a yellow fever–affected area for more than two years.

Contrary to the options available in the nineteenth century, in order to make the labor market safe again at some point, most countries will likely need to deploy HAD tests widely. Those who are found to have the requisite antibodies can then be certified safe. Obviously, this will require careful recording and verification of HAVE test results as well. Then some method of identifying the safe individuals will need to be devised. All this is within the realm of our current institutions and technology, but setting up the apparatus will likely be costly and require some time.[16] Indeed, one could imagine innovative ways of rationing access to such tests when they are scarce—say, by testing in conjunction with blood donations, thereby encouraging that activity as people try to establish their immunocapital.

The question that will arise is what to do with people who do not test positive for HAVE or HAD. One option is for them to remain isolated, but the difficulty here is that there is no obvious end date for that policy. Another policy would be to have guidelines and other preventative measures imposed on those people that limit their interactions with other people who have negative HAVE tests, because if one of those people does end up contracting the disease, they would be able to transmit it to other people who have not yet had it. Overall, the right policy will depend on the proportion of people who test negative. If few people test

negative, those negative-testing people are safer as they return to normal economic life because their chances of interacting with other nonimmune people are reduced. Moreover, the tests can assist in certifying people for interactions with high risk to others such as older people or in high-contact fields such as healthcare.

Nonetheless, the downside and potentially unavoidable consequence of moving to a testing economy in this way is that it will reduce social cohesion. Just as the beef producers who worried that having some producers become certified as BSE safe would cause producers who were not certified to be seen as unsafe, we should be concerned that not being certified safe might become stigmatized with all of the costs that entails.

How Safe Is Safe Enough?

The discussion here thus far has glossed over an important issue with any kind of test: that it is imperfect. In particular, a test conducted on a person who has COVID-19 can return negative—this is a false negative—while a test conducted on a person who doesn't have the virus can be returned positive—a false positive. This impacts on policies that are contingent on test results.

Recall that with a HAVE test, what we want to do is isolate those who test positive and release those who test negative. We are doing this to prevent having to isolate everyone. Thus, if a person has a false positive, relative to the fact that our plan was to isolate that person anyhow, the fact that we choose to isolate them impacts them but not by much relative to the alternative. By contrast, if a person has a false negative, our plan is to release that person from isolation. In that case, however, we are putting someone we wanted to isolate into the population. Suffice it to say, that is costly.

But is it so costly that we should not use a "test, then release" strategy? Typically, there is a trade-off between false positive and false negative rates, with one rising while the other falls. Often this is because a test is a test not just for one factor but for the presence of multiple factors. So, if your test involves looking for the presence of, say, three factors, then you might choose to conclude that the test is positive only if all three factors are present.[17] That means that, given this approach, you are less likely to have a false positive test but more likely to have a false negative test. This along with improperly done nose swabs is why for many COVID-19 tests there was a reported false negative rate of between 10 and 15 percent (in line with other viruses) but a false positive rate of only 1 percent.[18]

One reason many tests appear to err on the side of minimizing false positives is because antiviral treatments might be harmful to some patients or otherwise involve costs, and you do not want to use them on people who do not have a particular virus. By contrast, a false negative test can be followed up with a future test for that patient that may reverse the finding. In other words, you want to be confident that you are treating the right person, and if you have the option to continue observation and test, you may then be comfortable perhaps initially missing a treatable person.

This weight of characteristics changes when you are dealing with a different decision—whether to release a potentially infectious person. In that case, you would want to err on the side of minimizing false negatives. If you want to release someone who has tested negative, you may not have an option to retest them before they do more harm. By contrast, if someone tests positive falsely, you can keep them isolated and then retest them later. This same logic applies to both HAVE and HAD tests but is stronger for HAD tests as the goal is not to retest using that regime. By contrast, a HAVE regime would involve repeated testing of people who returned negative results in the past.

This suggests that our medical practices will need to be informed by the decisions that have to be made—treatment versus release—to an extent that we haven't done to this date. Of course, it goes without saying that tests that can reduce both false positives and false negatives will be more valuable as well. Interestingly, however, our tolerance for tests with errors may be greater than would be apparent at first. For instance, Nobel laureate economist Paul Romer conducted simulations of the movement of infectious diseases like COVID-19 through the population and compared the use of a blanket isolation strategy versus a test and release strategy even when tests had high degrees of false negatives.[19] His analysis suggested that even tests with a false negative rate of 20 percent or more could lead to two or three

times fewer people eventually infected than a no-isolation approach but also involves fewer people required to be in isolation when even imperfect tests are used.

> It is not hard to see why targeting the isolation based on test results reduces the total number of people in isolation. What matters for controlling the infection is how many infectious people it isolates. If people are isolated at random, you have to isolate a lot more to get the same number of people who are infectious.[20]

The good news here is that, while we may want to calibrate test efficacy for the decision made, there is substantial room for error to still have a substantive impact. In other words, a more perfect test is better but not that much better than an imperfect one.[21] Nonetheless, even with very intense testing (say, everyone being tested once every two weeks), this will likely only reduce the intensity of required social distancing and contact tracing. That said, as those activities are the costliest for the economy, it is likely that the social rate of return to widespread testing will be very high. More practically, it is likely the best option would be to be sensible in how tests are allocated and conducted.[22] For instance, in situations where households have been locked down for a month or more, perhaps only one member of a household needs to be tested.

What If It's Worse?

Everything in this book thus far, as well as policy discussions regarding COVID-19, has been based on a very important assumption: once you have contracted the virus and recovered, you are immune. It is for this reason that epidemiologists focus on a sufficient share of the population obtaining immunity from COVID-19 either by past infection or as a result of a future vaccine. If you do this, then even with normal physical interactions, the virus eventually dies out (as R_0 becomes less than 1). In particular, this is why we can talk about HAVE and HAD testing as making people safe again. So, while the crisis is awful, the promise of immunity gives us hope.

What if that hope is unfounded? What if you are not immune even if you have contracted the virus? What if a vaccine is not possible for the same reason? In this case, epidemiologists no longer use the SIR (susceptible–infected–removed) model, as there are no recovered people who are not able to infect others. Instead, we must use the SIS (susceptible–infected–susceptible) model. In that situation, when R_0 exceeds one, the virus never goes away and a share of the population is always infected.[23] The only way to get rid of the virus is by extreme measures—for instance, socially distancing until there are no more infected people or by coming up with treatments such that we don't care if people are infected or not.[24]

Is this outcome possible for COVID-19? Because the virus is relatively new, at the time of writing, it is hard to be sure.[25] Because recovering from COVID-19 required antibodies, scientists were optimistic that such antibodies would give immunity for some period of time. However, in April 2020, South Korea reported 111 coronavirus patients testing positive again after they had recovered (and tested negative twice in a twenty-four-hour period).[26] One possibility is that the negative tests were false negatives. Another is that the virus has reactivated. This is a virus that is latent for a time and but remains inside the cells of the host. This happens with chickenpox, which can decades later reactivate in adults as shingles. Finally, there could be reinfection. This is why the flu is persistent. The antibodies provide immunity only for a time and not against alternative strains of the virus. Coronaviruses are a relatively recent phenomenon, so a lack of immunity remains a possibility.

Let's take that worst-case scenario and presume that infected patients are not permanently immune. One implication is that HAD tests are of little value. Similarly, a vaccine will not be our savior. Nonetheless, HAVE testing could be of value. While the intensity of testing would have to be even higher than what might otherwise be envisaged, the procedure of isolating those who test positive will reduce the ability of infected people to spread the virus around. In this situation, so long as this results in the rate at which those are being infected falling below the rate at which people are recovering from an instance of the infection, the pandemic can be contained, and the virus will eventually be wiped out.

This highlights another reason to invest in the testing economy. When it comes to HAVE tests, these are valuable whether the virus leads to immunity or not, or something in between. As a policy, they are a hedge against this uncertainty.

A Tale of Two Regions

Some countries moved to a testing economy very early in the COVID-19 pandemic. For instance, Taiwan started testing travelers from Wuhan for symptoms on December 31, 2019, and soon after integrated travel histories with national data sets and made them available to hospitals.[27] But Taiwan has special characteristics that make its response somewhat atypical (e.g., Taiwan is an island with a tight relationship with China). More instructive in terms of seeing what a testing economy can achieve is to compare the Lombardy and Veneto regions of Italy.

Both regions applied social distancing and locked down retail areas. But only Veneto put in place a testing regime: testing both symptomatic and asymptomatic cases, testing contacts if someone tested positive, having testing carried out in homes, and implementing general measures to protect healthcare professionals.[28] The result was that, as of March 26, Veneto (with a population of 5 million) had 7,000 cases and 287 deaths, while Lombardy (with a population of 10 million) had five times the number of cases and 5,000 deaths.

The testing economy is what emerges when you have the virus under control, but you do not have widespread immunity either via past infections or a vaccine. This means that tests, like post-9/11 security measures, will likely be a part of our daily lives for many years to come lest we end up more like Lombardy than Veneto.

Key Points

1. Pandemics are fundamentally a problem of a lack of knowledge regarding who is infected and who has been infected. With that knowledge, we can isolate the infected and release the immune. Without that knowledge, physical interactions are unsafe.
2. Being able to conduct tests of whether people have or had COVID-19 will be critical to a faster opening-up of the economy and a restoration of economic and social life.
3. Moving to a testing economy is the way of making workers safe, and tests need not be perfect in order for this to occur.
4. Countries and regions that were able to test, trace, and then isolate the infected were able to contain the virus quickly and reopen their economies sooner.

6

Reemergence

In 2009, an Australian epidemiologist who had moved to Canada (giving me certain affinity with him), Professor Robert Smith?[1] captured some interest by considering the best methods by which the world could ward off a zombie outbreak. Zombies are, to the best of our knowledge, infected humans who are technically dead but—what is relevant here—are still infectious, passing the problem to others by biting them. The resulting mathematical model showed that the way to deal with a zombie outbreak is to stamp it out quickly in one big, determined push. This yielded some support from Neil Ferguson, who would go on to coauthor the influential Imperial report for the COVID-19 crisis.[2]

> My understanding of zombie biology is that if you manage to decapitate a zombie then it's dead forever. So perhaps they are being a little over-pessimistic when they conclude that zombies might take over a city in three or four days.[3]

My understanding from this is that Ferguson thought that lopping a zombie's head off was a pretty straightforward approach, and that was the end of the matter. Nonetheless, the US Centers for Disease Control and Prevention put up a website to inform the public just in case.[4]

Viral pandemics are similar to zombie infestations in two respects. First, they both attack humans, and second, they move from human to human. Where they differ is that viruses can be killed proactively (through antiviral treatments) or passively by eventually either killing or dying out in a host. (Zombies can be killed only via decapitation.) The problem with viruses, as was already discussed in the previous chapter, is the lack of knowledge regarding who is or has been infected. With zombies, it is plain as day.

The upshot of this relatively invisible enemy is that the management strategy for a viral pandemic is likely to be ongoing and its end hard to measure or be sure of. In principle, there are actions that could be taken to suppress COVID-19 in one go. Moreover, suppression requires 100 percent success, and unless knowledge is available very quickly, the type of containment strategy one might use for a zombie situation is not warranted. This means that pandemic management requires an approach that will have to be actively conducted over many months. It will not be comfortably over in the course of a two-hour movie.[5]

In this chapter, I will examine reemergence strategies following initial isolation actions taken with regard to a pandemic. As has already been noted, isolation is economically and socially costly, and, as of the time of writing, it is reasonable to suspect that there will be immense political pressures to plan a path from isolation to reemergence while managing the pandemic and preventing future uncontained outbreaks. It is important to have a clear strategy because, in its absence, there may be pressures to let the virus "burn" through the population, creating herd immunity even with a massive loss of life.

The Cat Is out of the Bag

Before considering a reemergence strategy, it is worth reflecting on why that strategy is needed. The basic epidemiological goal is to move the basic reproduction number of the infection (R_0) to a point where it is less than one. In that situation, even an unmanaged virus will end up being contained and be on a path to dying out. As already emphasized, the issue is knowledge. If we know whether you HAVE or HAD COVID-19, and presuming that gives ongoing immunity, we can use individual-specific interventions to achieve that goal.

The benchmark is to consider what we could have done if we had that requisite knowledge from the outset. In that situation, we could continue to test and isolate those who tested positive. This would not be fun for those so identified, but it is better to isolate justifiably than indiscriminately.

The problem is that such knowledge is not available to even the most alert pandemic response teams. This means that the cat is out of the bag, and, thus, the virus is spreading, making it even harder to acquire the requisite knowledge. Indeed, it is precisely because of this that most countries (starting with China around Wuhan) had to pursue a widespread isolation or lockdown. This will eventually get the rate of infection down, but then what? After all, so long as there are still infected people somewhere, the basic reproduction number itself will not be below one (as too small a share of the population is immune), and the virus, in the absence of interventions, will likely reemerge.

The answer is that when the cat is out of the bag, first you have to put it back in the bag, and then you have to start over again. However, this time, the hope is that you have the capability to acquire knowledge to manage the spread of the virus in round two. In other words, all of the initial actions to contain the spread of the virus (including flattening the curve) are about getting to a point where you can have a “do over.” That means evolving to a testing economy as described in the previous chapter. The question for reemergence is: Can we achieve a “do over” while at the same time allowing a relaxation of the policies surrounding initial containment?

Who's on First?

My starting point is a country that has engaged in a widespread lockdown and has started to see signs that the rate of infection is starting to fall. At this point, it may be possible to predict when the infection rate falls below a level that would cause it to break out again. And before that point, there may be opportunities for a targeted and measured release of people from isolation.

The picture you should have in mind is that there is a set of activities in the economy, and, under containment, we have moved some activities from the unrestricted bucket to the restricted bucket. The question we need to ask ourselves is: When do we remove a given activity from the restricted to the unrestricted bucket? The answer from economics is that you want to move activities out of restrictions earlier if they have a high economic value and a low potential for increasing the spread of the virus. The ones that you want to delay are ones where there are few economic costs to the restriction and/or a large potential for causing the rate of infection to spread quickly.

The question is: What first? The lockdown procedures in most places make a distinction between essential and nonessential work. Essential work is in healthcare, key public services, and food supply. For the most part, "essential" is a designation based on the value of their jobs rather than considerations of whether they were in jobs that may facilitate a faster spread of the virus. Indeed, healthcare work is a case in point, and hospitals, where possible, have put in place measures to stop the spread of the virus within those workplaces and beyond (with those workers being housed away from their homes in some cases).

The harder decisions will be for the nonessential work. There are two criteria that would guide this choice, based on their economic value and their potential to spread the virus. Let's begin with economic value. According to some studies, about 34 percent of the US workforce are in jobs that permit them to work from home.[6] If you work outdoors or work with specialized machinery, however, it is not likely you can work from home. But if you are doing legal, computer, or mathematical work, you do not actually need to be near anyone else to do your job. Thus, on an economic basis, it is reasonable to expect that construction and manufacturing work will rank highly as candidates for movement back from isolation.

The second criterion is on the basis of what types of activities and jobs would potentially pose a lower risk of spreading the virus. In network theory, the issue is how connected people are to a broader network.[7] In modern societies, you can draw links between almost any two people. Those links are sometimes direct but usually indirect. A virus can potentially spread along those links, which is why it is commonplace to see outbreak data given on a country or maybe state basis. There are links between countries, but as fewer people travel between them, the "distance" along the network (in terms of number of people along a path) can potentially be greater.

But for reemergence we are starting from a situation where we have already broken the network. For a "stay in place" lockdown, this is almost to the level of individual households. Those households are components that link with each other. Every household has some members who venture out to obtain food or healthcare, and so, even though they are weaker, there are some links across households by this mechanism. When we take a household and allow members of that household to return to work, we are increasing the number of links between households.

You might think that means that if we allow one member of a household to return to work, we should allow other members to also do so. As that household will be integrated into the

main economy with just one connection, why not have two? However, unless the members are literally going to the same place outside the household, additional household members being released magnifies the problem. Person A goes to their workplace and comes back potentially infected, which infects the household and also person B, who is going somewhere else. Having more links outside embeds the components (in this case, households) more densely in the network, which is what you want to avoid. This suggests that, where possible, at most one member of the household should be, initially, able to return to work.

This logic also explains why it is difficult to, say, remove an entire region from lockdown. In doing this, all of the households in a region become one component, and so if there is any incidence of the virus remaining, it will spread throughout. By contrast, if you take a more targeted release, even within a region, you can keep the basic reproduction factor low.

The related point is that hubs need to be limited. A hub is a single location (which may, of course, also be a transportation conduit) where many people interact. A candidate here is the central business district of a city but it also applies to schools and commuter colleges. The problem here is that if you open up a type of job, say, law firms, then, if they are located in the same place, you create the potential to spread the virus more quickly. This carries over to workplaces in general.[8] To keep the virus from spreading again, you have to limit the number of people in any given location. This means that workplaces need to be open but at a low scale. If they cannot operate in that way, it may be better for those workplaces to move to the back of the queue. This logic almost certainly applies to schools and colleges, which are hubs for interactions and also places where it is hard to use mitigating interventions such as good hygiene practices. It also almost certainly means that public events—sporting events, concerts, conferences, and elections—will not be able to take place as per normal for some time.

This analysis suggests that among the first people to be allowed to return to work following isolation will be a subset of those people who cannot work from home. That subset will be determined by how to ensure that if there are connections between what might be otherwise isolated groups (or components), those connections are sparse (meaning one or very few connections per person). Of course, this can be modified depending on the ability to use methods (preventative gear and cleaning) to ensure a lack of spread in workplaces and on transportation conduits.[9] At the time of writing, it is difficult to say who that subset would be. However, one suspects construction and manufacturing will be high on the list, while schools and colleges may well be low. Schools will perhaps be the greatest challenge given their social importance (not to mention their role in general parental mental health, and their ability to allow even work from home to have higher economic value, and to allow parents to work out of the home).

Suggestions have been made that the criterion for release should be based on whether a person is at risk from the serious complications from the coronavirus rather than their risk to others. For instance, it was suggested that younger members of the workforce be allowed to return to work.[10] The idea is that even if those groups end up spreading the virus among each other, there will not be serious health consequences relative to the economic value of them being allowed to work. However, risk to self is very different from the criteria of economic value and potential harm to others. Our confidence in doing this would depend on whether those groups would be sufficiently segregated from others as well as what the health effects might actually be. That said, absent a heavy hand in enforcement, as people are released, whether someone stops socially distancing or not is motivated by the assessment of their own risks. The question will then be whether to let what happens happen or to manage the difference between private and social incentives in some other manner.

Finally, it is useful to consider what might happen with regard to travel—not locally but

regionally and internationally. At first blush, it seems that maintaining travel bans is an effective policy. After all, they keep the virus contained within countries. However, as reemergence takes place, trade and travel will grow, consequently increasing the potential for the virus to leak through those boundaries. Given this and the economic importance of some travel, there seems no reason to single out those jobs for continued isolation. Instead, I suspect that, at least through airports, there will be more opportunities for testing (assuming fast tests are available) and also for the use of protective gear. Airports are already places where people have experience in dealing with frictions. The additional frictions that might be required may be relatively cheap from that perspective.

The above discussion focuses entirely on reducing the spread of the virus throughout reemergence. Another possibility is to focus on allowing reemergence subject to the constraint that those who are more vulnerable remain isolated from others. This is akin to the proposed policy of isolating the elderly and others with identifiably compromised immune systems who are most at risk from hospitalization or worse from COVID-19.[11] As a policy to introduce from scratch when people are not practicing social distancing, targeted isolation appeared difficult to achieve in practice. However, for reemergence, we may have more confidence that the virus is free in certain places. Therefore, as we allow movement to reemerge, we can continue to keep people isolated where there are identifiably higher risks, allowing connections only with certain precautions in place. If this were possible, then that would allow a greater number of people outside those groups to be able to operate more freely. Nonetheless, it is unclear at this stage whether we have the requisite knowledge to confidently pursue this approach of using “not at risk” as a criterion for targeted release.

The Big Rationing

The hope is that reemergence can be achieved through some type of testing economy that allows social and economic life to return to "normal." Of course, the best way to end the pandemic and its management is to develop and then distribute a vaccine. COVID-19 is novel, and, to date, vaccines for coronaviruses have not been developed because, prior to this virus, they did not pose a grave health risk. It is for this reason that developing a vaccine that can deal with COVID-19 is a significant challenge. As a result of the protocols governing the development of new vaccines, it will be at least a year before one that is safe to distribute is available.

Even in that somewhat happy instance, there will remain a significant problem: any production process for the vaccine will take time, and so, at any given point, there will be a shortage of vaccines. This means that the available supply will have to be rationed. Absent the use of a market approach to sorting out who gets what when, that requires that a decision on the order of recipients be made.

This is a problem that has been forecast, and government authorities have issued guidelines for rationing. For instance, the US CDC has five tiers of recipients for a typical flu vaccine.[12] There are two dimensions of priority: occupational groups (reflecting the earlier economic criteria) and high-risk populations (reflecting the at-risk criteria for harm from the virus). In tier 1 are the occupational groups who are already priorities for nonisolation during the containment phase today, including healthcare and security services. Tier 2 continues to include essential workers especially with regard to infrastructure services, while the remainder of those are part of tier 3. Using the at-risk criteria, tier 1 includes pregnant women and babies; tier 2 expands that to high-risk children and people who work with young children; tier 3 includes the rest of children; tier 4 is high-risk adults; and the rest is part of tier 5. Notice that there are no occupational groups in tiers 4 and 5.

For COVID-19, the occupational group ordering makes sense and is in line with current practices. However, the at-risk ordering does not reflect what is currently understood about COVID-19, that is, that the older you are the more at-risk you are. The CDC guidelines take age into account when considering children. However, for COVID-19, it appears that the younger you are, the less at-risk you are (although children may be vectors for disease spread). In other words, the guidelines for influenza in general do not reflect the realities of risk with respect to COVID-19. Thus, one would expect those to change. However, this will also generate a decision regarding healthy adults of working age and those who have retired. The latter are far more at-risk, while for the former, there are economic criteria that will favor them. My point is to highlight this potential issue and suggest that there will be no easy decision in this regard.[13]

What the criteria also do not reflect is any sense of network theory. For instance, prison populations are potentially risky areas where infections can break out. If testing was not available, there are arguments that they should receive priority for a vaccine.

Even looking beyond the use of guidelines to assign priority, there will be a large pool of people for whom there is a vaccine shortage but no identifiable way of prioritizing them. In that case, a lottery will likely be used (as it was in the movie *Contagion*). In the end, what we should anticipate is a very fraught process that few will likely forget.

Key Points

1. There will come a point where COVID-19 has been contained and governments will move to relax social distancing policies. However, as most of the population will not be immune, this will likely have to be a staged process.
2. The criteria for release will be a balance of economic importance as well as the likelihood of causing infections to spread. Large gatherings, such as sporting events, will be unlikely to return until the crisis is completely over.
3. Key to release will be the density of the workplace, the location away from central hubs, and the ability to enact workplace-level prevention policies. This will likely mean that people who cannot work from home will be higher on the list. The most challenging decision will come with respect to school openings.
4. If a vaccine should be developed, it will be in short supply. While existing criteria prioritize vaccine candidates based on their personal health risk, it is likely with COVID-19 that these will need to be revised to take into account the same criteria for release from social distancing.

7

Rallying Innovation

This chapter is about how we can innovate our way out of this and future crises. Thus, it seems appropriate to begin with the movie *Mission Impossible 2*. Released in 2000, the antagonist is an Australian-based biotech company (Biocyte Pharmaceuticals, if you must know) with a rather unique commercialization plan. They have developed a virus, Chimera, that could start a very bad pandemic—it lies dormant for 20 hours before destroying the carrier's red blood cells. One plan might have been threatening to release the virus and being paid not to do so. But the folks at Biocyte went one step further. They planned to release the virus itself because they had also developed the cure. And, because of course, they hold the patent on it. I suspect some venture capitalists would call this one "fundable."

The movie plot involved the chase to stop the virus being released but also to secure the cure in case it was. But I wonder, did they have to? The plan was to release the virus and then charge for the cure. Drugs normally, once made available, are easy to copy and so have patents. The plan here was to use the patent to extort world governments to pay up much of global wealth. But herein lies the problem: the patent is granted by those governments. Surely in this situation, they would just invalidate the patent and take the cure?

The point—and you will see that I do have one—is that when it comes to innovations in the face of global pandemics, business as usual for our innovation system is unlikely to apply. The reason is that once an innovation has been created, there are strong pressures to make it freely available and, in the process, push down the return to any R&D that has been conducted. Anticipating this, businesses may not invest in R&D in the first place. And this is not a hypothetical situation.

> Such concerns are likely very salient to firms. For example, after Senator Paula Hawkins (R-FL) asked a major vaccine manufacturer how it could justify charging nearly three times as much to the U.S. government for vaccines as to foreign countries, U.S. manufacturers stopped submitting bids to UNICEF to supply vaccines…. When President Bill Clinton announced his plan to immunize all children against a standard list of diseases in 1993, he said, "I cannot believe that anyone seriously believes that America should manufacture vaccines for the world, sell them cheaper in foreign countries, and immunize fewer kids as a percentage of the population than any nation in this hemisphere but Bolivia and Haiti."… In the face of such statements, potential risks facing firms seem real.[1]

It is very unlikely that governments around the world are going to accept monopoly pricing for a vaccine developed for COVID-19 that potentially will benefit 7 billion people. For life-saving drugs, it is not uncommon for those prices to be in the hundreds of thousands per person. For a vaccine intended to be given to a population such as that of the United States, even $10,000 per dose would set the government back $3 trillion. That is not going to happen.

Will governments likely pay a princely sum for a vaccine for COVID-19? Yes. Will it cover the costs and the risks associated with developing and trialing that vaccine? Hopefully. But given the uncertainty amid the crisis, there is a concern that pharmaceutical companies

and their researchers do not need to add further uncertainty. Moreover, this isn't just about the current crisis. Like SARS and H1N1, coronaviruses are probably with us for the foreseeable future and may require annual vaccine development. There are other innovations (e.g., methods to test and anticipate pandemics) that we might finally demand, having felt the costs of a global pandemic in the modern era. All of those will be of a public nature with the idea of using them widely. That means that the price for these innovations will be set in negotiation with governments that, we can imagine, are unlikely to be less stingy with public funds for pandemic prevention going forward. Given this, how should we think about an innovation system for what are essentially ideas that will enhance the global public good?

Why Traditional Innovation Incentives Won't Cut It

The usual way we try to encourage innovation in a market economy is to reward the innovator with intellectual property protection. If you have a new drug, you can secure a patent that gives you the exclusive right to sell it for about 15 years. In other words, your reward is to make whatever profits you can for a time unimpeded by close competition. That system works pretty well.[2] However, the main problem with regard to innovations that will help avoid or stem the effects of a global pandemic is a contradiction—in order for the innovator to receive profits, we have to allow the innovator to price in such a way that many will be unable to use the innovation. As our goal is widespread use, this contradiction is prohibitive.

The difficulty for a vaccine maker is that a low price on the vaccine reduces their profits but generates much more value for other firms as the economy recovers. There are clever ideas, however, to help the vaccine maker recover some of this value. Consider this, as told by columnist Matt Levine:

> [I]f I ran one of the big index-fund companies, and a pharmaceutical company in my portfolio developed a patented fully effective cure for Covid-19 that it could manufacture cheaply and planned to sell to anyone who could pay $50,000 a dose, I would call that company right up and say "no, you give that pill away for free, because the value to me of Covid-19 going away quickly and the economy recovering—the value to me as an owner of airlines and hotels and chain restaurants and retailers and every other company—is vastly, vastly greater than the value to me of your profits on that pill."[3]

This is pretty ingenious.[4] If you know you have a COVID-19 vaccine, then you know that, when it is released, there will be an economic boom and so you can invest in the stock market on the basis of that information. That should generate a healthy return. Unfortunately, it also requires a very large amount of capital to make the return that would incentivize the innovator. Relying on stock market processes to fund important innovative endeavors is risky at best.

Given the value on the table, the other option is to ignore the market altogether and have the government offer grants and subsidies to defray the costs of conducting research and development. This has certainly been a hallmark of the system of scientific research conducted in most countries following World War II.[5] The challenge is that it is very difficult to evaluate whether grants are being spent in an efficient manner. Consequently, grants tend to be favored where no other sources of funding are available—for instance, for basic research that has no commercial payoff and a high degree of uncertainty—or where there is expertise to evaluate the efficacy of the research program and required expenditures. This latter task, however, is itself not amenable to a quick disbursement of funds. Thus, if there is any urgency, such as lives being lost while research is being conducted, grants are unlikely to be an efficient means of generating innovations.

Advanced Market Commitments

This has caused economists to consider ways of encouraging innovations that combine the elements of grants with market signals. One approach contemplated was the use of prizes. For centuries, benefactors have announced prizes that would be paid in the event certain inventions were generated. The most famous was the prize for a device that measured longitude at sea so as to provide a dramatic improvement in maritime navigation.[6]

Prizes have the advantage that they are clearly solutions to problems someone believes it would be valuable to solve.[7] Thus, they have a market signal embedded in their makeup. The difficulty is that the problems that are usually specified are to achieve some scientific milestone such as proving a mathematical theorem or landing a spacecraft on the moon. These are not necessarily of the class that would require widespread adoption for the global public good. For pandemics and pandemic control, we are talking about inventions whose adoption will impact billions of people. Thus, quality and workability really matter. They cannot simply be scientific advances. The innovations need to be able to work for their intended function. That is a tougher challenge than any one prize for a significant milestone is likely to achieve.[8]

To solve these problems and enhance the market test associated with prize-like mechanisms, Michael Kremer proposed the use of advanced market commitments (or AMCs).[9] Suppose you are trying to encourage the development and then manufacture of a vaccine. An AMC is a contract without a specific counterparty that a donor/sponsor offers to deliver the intended vaccine. The contract specifies that the provider (as yet unknown) will be guaranteed a certain payment per dose of the vaccine up to a specified number of doses. This serves to set a floor on what the provider might earn because the contract specifies a subsidy for every dose actually purchased. So, a country, for instance, may pay a low price (such as $1) per dose but the provider would receive an additional subsidy (say, $15) per dose. Thus, there is a guaranteed payoff for providers, but, in return, providers agree to cap the price they charge for the vaccine. Their overall earnings are greater the more doses are actually sold. Obviously, if there are no candidates that pass certain quality standards, the contract is never paid out.

A key feature of AMCs is that they are not compulsory. Recall that the reason we need AMCs that “stick” for innovations that potentially have high social value is that, in their absence, governments and other donors may claw back on promised returns. Thus, it is important that AMCs are a strong commitment. If AMCs are noncompulsory, then any innovator could choose to sell their product at whatever price they choose if they do not accept the AMC. A compulsory AMC only enhances rather than reduces the returns to any R&D investments. The commitment increases the price above what the market would pay, and, thus, the AMC contains a prize-like element but only if the vaccine is used by lots of people.

How could AMCs be deployed for pandemic-related innovations? It depends on some features of the innovation—specifically, how close current efforts are to a viable product. For innovations that are more technologically distant, the goal is to encourage more R&D effort and resources. This might be the case for a vaccine that could handle most potential coronaviruses as opposed to the specific virus that is currently spreading. The challenge in designing the AMC is setting a price that will induce that R&D effort. This will be an easier task if that price encourages multiple simultaneous attempts to pursue the innovation. At the same time, however, AMC designers will want to ensure that innovators’ payoffs are sensitive to how well their products work, so they push innovation toward products that are

likely to be more effective. Thus, even though the price might be set ex ante, to encourage that effort and align incentives, AMCs for technologically distant innovations will likely remove the floor (in terms of sales guarantees) to give innovators more "skin in the game."

Writing this, as I am, in the midst of a pandemic, it is reasonable to expect that much of the innovative effort will be focused on products that are much closer to market. An example of this might be vaccines to deal with the current strains of coronavirus or innovations to dramatically improve and reduce the costs associated with testing and treatment. In that situation, there are likely to be a number of candidate prospects in the pipeline,[10] and so the chief constraint is not riskier R&D but instead undertaking trials and then building capacity to bring these products to market. An AMC designer faces a challenge as they would not have accurate information regarding the costs of those activities even if they know they are potentially substantial. The good news is that they have better information regarding precisely what the potential prospects can achieve.

In setting the per unit price for the AMC, for a technologically close product, the designer has to refrain from setting a very low price—even though that may save on overall costs to those using the innovation—and err on the side of a higher price so that the necessary capacity investments actually are made.[11] As there is likely urgency in getting products to market quickly, you would not want to skimp on payments and risk insufficient capacity. Again, this highlights the importance of the AMC's role as a commitment because, having built capacity, there will be pressures to reduce price. The AMC needs to guard against those pressures.

One thing that can take the pressure off prices in this situation is if the AMC can guarantee a certain level of sales for the product. After all, the innovator will be making investments depending on the overall return. Thus, they will be happy to trade off price for quantity so long as the total revenue (that is, price times quantity) does not change. This is a luxury that AMC designers have when setting terms of a technologically close product, as they have a much better sense of the overall level of demand for that product.

A relatively technologically close AMC has recently been undertaken to produce a pneumococcal conjugate vaccine specifically targeting developing countries where 700,000 children are estimated to die from the disease each year. Five countries and the Gates Foundation put up $1.5 billion for an AMC in 2007 and it was launched in 2009. Businesses would compete for a contract to supply the vaccine over a 10-year period with a price capped at $3.50 per dose (much lower than prices paid in developed countries) and a subsidy from the AMC of another $3.50 per dose.[12] In 2010, pharmaceutical companies GSK and Pfizer committed to each supply 30 million doses annually (a substantial fraction of the total need of 200 million). This vaccination campaign appears broadly successful, although we can never be completely sure what would have happened in the AMC's absence. Experience tells us that it would have likely been very little.

More Failure, Please!

Thus far, the discussion here has focused on why business as usual in terms of market and private rewards for innovation are unlikely to be suitable for pandemic-related innovations. However, there is also a sense in which governments, in particular, need to abandon business as usual that often accompanies their own funding on research and development—they are averse to failure.

The innovation challenge is so potentially large that it is very important that we pursue as many different paths as possible. In a sense, there may be very important scientific and innovation directions out there, in which each has unclear and hard to understand potential payoffs. In other words, there is considerable uncertainty. The classic example was the development of the *Spitfire* fighter plane by the British just before World War II. The plane was faster and more maneuverable than anything before and had seemed implausible when it received funding in the 1930s. Winston Churchill opposed it. However, it arguably was instrumental in protecting Britain from invasion, as Churchill would later endorse.[13]

Given that the payoffs can potentially be very high, this suggests that we should be more comfortable pursuing riskier and potentially unconventional scientific approaches. In other words, there is a broad need for a portfolio approach to innovation—spreading our options widely—so as to better understand which paths might prove to be feasible.

The takeaway here is that governments and donors should not be afraid of casting their net very widely and funding not just moonshots but also loon-shots.[14]

A New Manhattan Project

In the midst of World War II, Franklin D. Roosevelt authorized the creation of a highly funded project to build the first nuclear bomb. The Manhattan Project was a stunning success. It brought together a workforce of 129,000 to the New Mexico desert, including a large concentration of scientists (three of whom had won and three of whom would later win Nobel prizes), at a cost of what today would be $23 billion and, in three years, had built a working weapon. That weapon would create a decades-long existential crisis for the whole of humanity, causing fear and sowing mistrust that continues to this very day, but right now we can marvel at the fact that the project met all of its KPIs and ended World War II in relatively short order.

It is not a stretch to suggest that both managing the current COVID-19 pandemic (with tests, antivirals, and a vaccine) and coming up with innovations to more effectively manage future pandemics, a project well in excess of the scale of the Manhattan Project, is warranted.[15] Based on the potential future economic cost alone, there is an easy rate of return justification. What is more, unlike the Manhattan Project, this would not have to be conducted with secrecy; indeed, there would be considerable merit to precisely the opposite in terms of openness.

This is not the place to scope out what that potentially massive endeavor would look like. However, I can list here some key features that should be considered as part of it:

- *International cooperation*: All of these efforts are in terms of contributing to a global public good. The challenge will be to find mechanisms that distribute the costs of achieving these goals in a workable and sustained manner.
- *Regulatory audit*: Each country should pursue a major regulatory audit to ensure that there are no unnecessary impediments to being able to innovate and then to adopt new promising technologies. The COVID-19 crisis has already led to a relaxing of some regulatory rules specifically regarding approvals for public drug release. For instance, the US Food and Drug Administration has fast-tracked various treatments and vaccine trials.
- *Patent pools*: There is merit to pooling together patents associated with COVID-19 and other future pandemic threats. A patent pool is an agreement between patent holders to licensing terms for patents between them. By agreeing to these, it is easier to combine innovations together to build products and services.[16] An example of this emerged during the COVID-19 crisis when a patented HIV therapy, Kaletra, was potentially promising as a treatment for the virus. The patent holder, Abbvie, announced it would not defend its patent rights.[17] A more formalized agreement before the fact regarding licensing would remove frictions even further.
- *Expert review boards*: The research involved will likely be pursued following various promising paths. This happened with the Manhattan Project where two different bomb designs were designed in parallel. To organize these competing streams, expert review boards will likely need to be constituted on an ongoing basis. This could assist in the allocation of funds, the highlighting of impediments, the evaluation of project quality, and the design of AMCs.

There is one thing a crisis of this magnitude should tell us: there is room to do better. The funding for innovation for medical research is a fraction of that devoted to other threats—notably, national security.[18] Our experience in 2020 suggests that our attention has been

misfocused.

What about Pressing Needs?

Before leaving this topic entirely, it is useful to emphasize that the above considerations are focused on the public health innovations that are desperately required—that is, innovations that make it easier to treat or prevent COVID-19 and future pandemics. But there is another dimension of innovative activity that has more urgency but without the commitment concerns that usually govern health-directed innovations: that is, facilitating the recovery from the current crisis. Thus, it is useful to reflect on the nature of innovations for more pressing needs and how businesses should consider the opportunities presented in this regard.

Recall from chapter 6, that, at present, activities are placed in two buckets: restricted and unrestricted. To ensure speedier economic recovery, our goal is to move activities from the restricted to the unrestricted bucket. To minimize the on-going economic costs, however, we would like the activities that are placed in the restricted bucket to have lower cost associated with being in that bucket. Thus, we can see that there are two broad classes of innovations that will be valuable over the next year.

First, there are innovations that reduce the potential for an activity that is currently restricted to generate too high an increase in potential COVID-19 infections. This would be innovations in protection at work, safety on public transport, and, what is likely to happen, a major investment by fashion designers in face-mask couture.

Second, there are innovations that are designed to make it easier to conduct activities that are restricted. This would, of course, include work from home tools such as video conferencing but also investments that may reduce the need for people to be physically present at work in general, such as the use of robots and automation. The latter innovations may simply be the acceleration of recent technological trends.

What is important to note about both of these potential innovative opportunities is that their value depends critically on bad news. This might seem to be a rather grim thought for innovation but that does not make it less true. If you are moving quickly to develop an innovation that either reduces the infection possibilities from releasing an activity or making it easier to cope with restrictions, if it turns out that we have good news regarding COVID-19 —say, it is less infectious, can be controlled with weaker economic restrictions, or is less dangerous to long-term health —then the economy may return to normal quickly. That will reduce the demand for any of the solutions that one of these innovations might present.

Nonetheless, while it is the case that our current innovative efforts have a return that is based on bad news—the virus turns out to have effects on the worse side of our expectations —the way to look at it is this: if it turns out that outcomes are good, then we can cheer from not having to hope for these innovations while if they are bad, by making the attempt we have taken out some insurance cover. Overall, innovations will improve our prospective well-being.

Key Points

1. In pandemics, the usual way of rewarding innovative activity breaks down because governments and donors will put pressure on innovators to reduce price. Anticipating this, they may not invest in treatment, vaccines, or other innovations.
2. The need to commit to returns while ensuring wide dissemination of innovations means that advanced market commitments—contracts that provide pricing and volume guarantees prior to innovations being created—are worth being considered as a primary vehicle for globally relevant advances in knowledge.
3. The urgent nature of the crisis means that governments need to be failure-tolerant in pursuing a wide variety of approaches to solve a given problem.
4. The analogy for the innovative effort required is the Manhattan Project, which led quickly to the development of the atomic bomb and ended World War II. This implies devoting a substantial amount of resources to innovation in medicine and elsewhere to deal with COVID-19 as well as future pandemics.

8

The Future

As in the present crisis, economists did not have a frontline role in World War II and their expertise was primarily applied to management and planning. That allowed some of them room to think about the future. At the time, it was easy to draw a line from the Great Depression to the rise of fascism and, hence, the war. And John Maynard Keynes had seen the problem even earlier in the retribution imposed on Germany following World War I.[1] So it was no surprise that he and his US counterpart, Henry Dexter White, were planning how to do better when the war was over. On April 21, 1944, the Allies came to an agreement to establish new postnational economic institutions to assist in managing the world economy and preventing crises such as the Depression. A preliminary meeting was held in Bretton Woods, New Hampshire, later that year with 730 delegates from 44 countries. It led to establishment of the International Monetary Fund (IMF), an institution that exists to this very day, to allow free conversion of currencies and management of what was then a complex series of fixed exchange rates tied to a fixed price for gold. The goal of the IMF was to provide a means of ensuring that member countries complied and did not adjust their exchange rates wildly for their own short-term motivations. The motives were not retribution but continued cooperation. It was a superior approach.

What will happen once the COVID-19 pandemic has been tamed? It is too early to state definitively what lessons we will have learned or the specifics of how we should respond and react going forward. But there are some general principles likely to be of relevance. For instance, if we look around the world today, the countries that were the closest to previous outbreaks (SARS in 2003 or H1N1 in 2009) enacted clearer plans at an earlier point than others (e.g., Taiwan, Singapore, South Korea, Japan, and China). But while that may have contained COVID-19 outbreaks within their borders, it is plainly apparent that the costs imposed on them because other countries did not have those plans were significant. The global economy is interconnected. If just a few countries manage pandemics appropriately, that does not prevent a large fallout and difficult recovery. In other words, management of the outbreak needs to be global even if its immediate impacts on health are most clearly local.

The issues of international cooperation become more serious when you realize that outbreaks emerge from specific places. In the case of COVID-19, it was in a neighborhood in Wuhan, China. There is insufficient information right now to know whether that outbreak could have been prevented from spreading. But the relevant information was closely held within governments in that area, and, thus, the response and expertise to deal with it had to be similarly confined. The alternative is that there is a *global pandemic response* unit with the expertise and monitoring of health across countries that can come in and dictate appropriate actions to prevent the spread earlier. This creates issues of national sovereignty, cooperation, the bearing of costs, compensation, and myriad other complications. But the social value, globally, from being able to contain an outbreak quickly and close to its source is very high, indeed. If the meeting at Bretton Woods could cause countries to cede some control of their international finances to a supranational body, that should at least give us hope that a future global pandemic response institution might be possible.

The question we will want to answer is the following: Knowing what we know now, what institutions would we have liked to see in place with regard to this and future pandemics? My presumption here is that this will likely be a pan-national institution like the IMF with a set of resources to contain future pandemics and ensure an international, harmonized response. The

hope is that it would have both public health and economic expertise to do the job properly. Indeed, it may even assume the role of promoting and managing a new Manhattan Project–type innovation offensive against future viruses and disease.

The goal of this final chapter is to highlight the high-level economic challenges that a move in this direction will have to confront. There are political and moral challenges as well, but I will leave those for others to contemplate. My focus here is on how we will determine how much we should spend on managing pandemics proactively going forward.

The Inevitability of Pandemics

Pandemics have some of the mathematical properties of the rice on a chessboard that was discussed in chapter 2 but also some important differences. The main similarity is that it has to start somewhere. The SAR-CoV-2 or novel coronavirus that causes the disease COVID-19 infected one person initially. That person then housed the virus as it spread throughout their body and then, most probably by leaving it on surfaces, transmitted the virus to others. This can seem like a fluke. However, when you realize there are millions or billions of viruses out there, it was just a matter of time. One of them is going to spread.

The mathematical key here is to realize that we care about how likely one or more of those viruses will become a problem. For any given virus that might be out there, there is a low—perhaps one in a million chance—of it becoming a problem. That sounds comforting until you realize there are a billion such viruses. So, yes, you are rolling a million-sided dice but you are rolling it a billion times and you are hoping never to "win." The probability that one of those rolls will come up the wrong way is so hard to calculate that it is easier to calculate the probability that there won't be a problem (i.e., you'll lose a billion times) and subtracting it from 1:

$$1 - (1 - 1/1{,}000{,}000)^{1{,}000{,}000{,}000} = 0.999999999999999999999999\ldots$$

This is the probability a virus will become a problem. It isn't 1 but it is very close to 1. If there are only a million viruses, we still get a 63 percent chance that one of them is going to be a problem. The point is that it is inevitable; so inevitable that you would be forgiven if you never wanted to go near another person again.

But we do. And if we do nothing, then, at some point, a pandemic catastrophe will happen. Now it has happened, and the probability that another problematic virus emerges in the future remains close to inevitable.

Prior to COVID-19, our approach to viruses continued to be to accept the inevitable and hope to mitigate and adapt when the time comes. But that strategy relied critically on our ability to accept the mathematics and act quickly. That means we need to know what is going on as early as possible.

In this, I am reminded of a scene from the Cold War movie *Dr. Strangelove*. In it, the Soviets have described a doomsday machine that will be triggered should they be subject to a nuclear attack by the United States. Strangelove himself, modeled loosely on the game theorist and mathematician Jon von Neumann, remarks on how "essential" it is to deterrence, as no one would attack the Soviet Union if they *knew* it would end up destroying the world and them with it. However, he then exclaims: "but the … whole point of the doomsday machine … is lost … if you keep it a secret! Why didn't you tell the world, eh?" Ultimately, that lack of common knowledge ended up (spoiler alert) destroying the world.

If we are going to act as if viruses are not a concern most of the time, we have to be able to recognize when they do become a concern. Secrets or a lack of knowledge can push us away from sensible behavior. In other words, we need to know and then realize the implications when the first grain of rice is placed on the chessboard. Not having a global monitoring and response institution will continue to leave us all susceptible.

How Much Should Be Paid?

In 2015, Microsoft founder-turned-philanthropist Bill Gates gave a TED talk warning of the costs of a future pandemic and our lack of preparation.[2] The costs of a global flu pandemic were estimated to be in the millions of deaths and a reduction in global wealth of $3 trillion. This was the prediction of a catastrophe. But it was also an indication of what we might be willing to pay to prevent it. The budgets for pandemic preparedness were in the low billions and we know that wasn't enough.

When the benefits are monetary, it is easy to calculate a rate of return on expenditures for preparedness. A reduction in global wealth in the trillions alone suggests that to prevent COVID-19 or another specific pandemic, budgets in the hundreds of billions would still be worthwhile. But my guess is that it will be tough to convince governments to allocate those funds on that basis. Why? Because there are already a number of potential catastrophes that fall into that category of magnitude. Each of those has a different likelihood of happening, but each could happen, impacting on our willingness to pay to prevent any single one. Indeed, when you add up potential global catastrophic risks, one thought you might have is whether it really is worth spending hundreds of billions to avoid one of these things when the others could get us anyway.

That was my thought up until 2015 when a paper appeared that changed my mind. It was written by Ian Martin and Bob Pindyck and was entitled "Averting Catastrophes: The Strange Economics of Scylla and Charybdis."[3] Scylla and Charybdis are a reference to Homer's *The Odyssey*. In that tale, the sailor Odysseus sought to avoid both the sea monster Scylla (a shoal) and the sea monster Charybdis (a whirlpool) but could not avoid both. The choice was made using a cost–benefit analysis: passing by shoal might cause the loss of a few of the crew, but the whirlpool could take the entire ship. The choice for Odysseus was to avoid Charybdis and to pass close to Scylla.

What should we do with regard to the myriad modern catastrophes, especially when we are often faced with decisions that, like Charybdis, could take the entire ship? Not only pandemics but climate change, asteroid strikes, or nuclear war. Martin and Pindyck write:

> Naturally, we would like to avoid all such catastrophes. But even if it were feasible, is that goal advisable? Should we instead avoid some catastrophes and accept the inevitability of others? If so, which ones should we avoid? Unlike Odysseus, we cannot turn to the gods for advice. We must turn instead to economics, the truly dismal science.[4]

Their answer is not to rely on a separate cost–benefit analysis for each one. Nor is their answer to just give up as if there were two whirlpools and no hope. Instead, there is value to picking and choosing which to confront.

To understand this, let's put it in terms of issues that will likely arise: Should we spend money dealing with a future pandemic? Should we spend money dealing with mitigating the climate change disasters that no doubt will come? Both? Or neither? Let's suppose that someone was to argue, What's the point of dealing with pandemics if you believe that we are going to face climate change disasters? The Martin–Pindyck answer is that the case for dealing with pandemics is actually *higher* (not lower) if you are worried about climate change. You should want to deal with it even more intensively than you might have thought.

The intuition is this: if you spend ongoing resources to mitigate pandemics, the fact that

you may have to deal with the consequences of a climate emergency (e.g., hurricanes, sea-level rises, extreme heat) means that, in the future, you expect some suffering. That means that you will actually value what you do have *more* and want to spend more to protect it. In other words, if there is harm in your future, you want to spend resources to mitigate another threat because you value what you have more than what you might have had in a disaster-risk free world. Consider this: if you live in a big house and a fire threatens to potentially raze half of it, you will be willing to spend more to protect the remaining half than you would have spent to protect one of the halves alone.

Once you are expending resources to insure against one catastrophe, the losses you might face if the other one happens are relatively lower. But this raises another question: Which catastrophes should you prioritize? Could it be that concentrating your resources to mitigate a few of them might be better than spreading your resources to deal with them all? You may overstate the returns to tackling one catastrophe if you do, in fact, also deal with another catastrophe. However, an analysis of the costs and benefits of so doing are still informative. For instance, if you assess the mitigation of one catastrophe to have both the highest benefit and lowest cost, you should definitely try to avert that one. Interestingly, Martin and Pindyck's simple calculations suggest that dealing with a global pandemic may fit precisely that bill.

In other words, the message from Martin and Pindyck is not to be fatalistic and give up because you are worried about numerous catastrophes. This analysis gives us strong comfort that, just because we face multiple catastrophes, we should not give up on dealing with some of them. Instead, a cost–benefit analysis should be conducted with an eye to those other risks and what is being done about them. After all, climate change, for instance, is a risk with a different time horizon and profile than pandemics, which are something that could recur quite often. Given that, it is highly unlikely that the case for dealing with one will be undermined if the world chose to deal with the other.

Moreover, in evaluating any catastrophe, assessing things in purely monetary terms is somewhat limited. Pandemics, like some other catastrophes, also have implications with respect to the loss of life. Preventing death is well and truly on the "benefits" side of any set of measures to prevent pandemics.

One way economists have sought to be persuasive on these questions is by trying to come up with a method of expressing the costs associated with a loss of life in monetary terms. Macabre though this is, the intent was to force policymakers to at least take into account loss of life in their calculations, which could otherwise too easily be ignored. But what value? One possibility is to just add up someone's potential lost earnings, as is sometimes done when calculating damages in litigation. But would this really be the value someone placed on their own life? Economists Thomas Schelling and Kip Viscusi are among those who suggest that if we look at people's risky behavior (activities that people know might lead to death), we could estimate the value they were placing on their own lives (for instance, by looking at wage differentials for working in certain construction jobs or in security). This is the value of a statistical life. Numerous government agencies have put that value at $10 million.[5] If that is the case, then for pandemics of even modest size, the loss-of-life component dwarfs the economic cost.[6]

What this all suggests is that spending hundreds of billions of dollars per year to mitigate substantially the risk of global pandemics is as close to a no-brainer as we are likely to get. That said, prior to COVID-19, we did not engage in that spending. Our experience confirms this error.

Future Resolve

Returning to the present, there will come a point in the COVID-19 panic that we will declare victory. At the time of writing, we do not know when that point will be. We do not know the number of deaths the outbreak will cause. We do not know how and whether the economy will bounce back soon after. We do not know whether life will be again regarded as normal. But, right now, for reasons I cannot fully explain, I am confident that there will be a point where we will collectively believe COVID-19 has been conquered.

Then, sadly, the trouble begins. Victory is a dangerous thing. It comes with relief. It comes with exhaustion. It comes with hope that we are done. Therein lies the danger.

World War I was called "the war to end all wars." The victors went back home and were done. For France, this was especially so. They were finished but had also decided to make huge investments to give them a sense of security. They envisaged and then built an incredible series of fortifications along the entire border with Germany. Basically, it was a low-level mountain range with tracks to move troops, 100 miles of tunnels, barracks, and even air conditioning. The Maginot Line would protect France from a direct assault. Half a million troops could be embedded there. No army would try to breach it.

That, of course, was understood by all. If the Germans attacked, they would have to go through the Netherlands and Belgium (or maybe Switzerland). The French plan was to meet the invading force in those countries, which seemed secure. But as with all such things, there were weak links. Belgium decided to stay neutral in the Second World War. More critically, when the Germans were still preoccupied in the east against Poland, the French army chose not to cross the Maginot Line and preemptively attack. Their strategy had been one of defense. But even Napoleon had said that those who decided to stay within the fortress have already lost. And when the Germans did attack, they managed to slide into France through the Ardennes Forest. It had been believed that the forest was a natural barrier against attack, as it would be slow to traverse. That plan did not account for tanks, which covered the distance in days rather than more than a week.[7] France was cut in two and fell in just over a month. As soon as the invasion had moved to their soil, resolve seemed to evaporate.

The idea that success can breed the seeds of its own destruction is not a new one. In management, the term "disruption" describes the situation where successful businesses cannot adopt new technologies because they continue to do the things that made them successful in the first place.[8] Precisely why it happens and whether it is stupid, complacent,[9] or can be "rationalized" is not material at this point. If and when we are victorious against COVID-19, whatever is driving that phenomenon will likely be present again.

It is also worth noting that, in many respects, COVID-19 was a somewhat "lucky" pandemic. The virus, unlike measles, did not stay alive in the air. It did not lead to contaminated food. It appeared to be relatively genetically stable. And it left children (and many others) mostly unaffected. There was no reason for all of those things to have happen. And so, there is no reason to predict that they will be absent in a future pandemic. But there is reason to be worried that we may forget that once we are done with the current crisis.

To build the global institutions we need to mitigate the costs of future pandemics, we will need that resolve. There are signs of hope. As this book was going to press, Bill Gates moved to build manufacturing facilities for seven vaccine candidates, knowing only one or two would be viable. Why? Because doing that would save months of time. That is what resolve looks like.

Any victory we have over the next two years needs to come with a warning. The eye

cannot be taken off the ball. And if you need any guide from history, remember that we did not get the IMF or the United Nations until we had not one but two world wars.

Notes

Preface

1. *The Onion*, September 26, 2001 (https://local.theonion.com/not-knowing-what-else-to-do-woman-bakes-american-flag-1819566173).

Chapter 1

1. Mike Hume, "Plague, Inc. Removed from China's App Store," *Washington Post*, February 28, 2020.
2. At the beginning of 2020, it terms of popular discussion, the main candidate for human extinction was, and it seems laughable now, artificial intelligence (AI). The robots were coming from our jobs and worse. Indeed, philosopher Nick Bostrom had speculated in his best-selling book, *Superintelligence* (Oxford University Press, 2014) that the way this might occur was through plain old stupidity. One day, a talented engineer would design an AI that would be tasked with making paper clips. That sounds mundane enough, but that design is so good, the AI improves itself and becomes superintelligent. It then applies that intelligence to sucking up all of the world's resources in the mindless pursuit of making more paper clips, killing us all in the process. That both sounded bad and was hard to rule out because we all knew people who made stuff and failed to forecast the consequences. It seemed like a matter of time. Who knew a virus might get us first?
3. Eduardo Porter and Jim Tankersley, "Shutdown Spotlights Economic Cost of Saving Lives," *New York Times*, March 24, 2020 (https://www.nytimes.com/2020/03/24/business/economy/coronavirus-economy.html).
4. Paul Romer, "The Dismal Kingdom," *Foreign Affairs*, March/April 2020 (https://www.foreignaffairs.com/reviews/review-essay/2020-02-11/dismal-kingdom).
5. The SIR Model (https://mathworld.wolfram.com/SIRModel.html), which was first introduced in 1927 and models the spread of an infectious disease by calculating who are suspectible (S), infectious (I), and removed (R) over time. For a primer for economics, see Andrew G. Atkeson, "What Will Be the Economic Impact of COVID-19 in the US?," mimeo., UCLA, March 2020 (https://drive.google.com/file/d/1ZWLpUxFZekCTMxCzxZIZ6rWxcXAh8pUc/view).
6. Sergio Correia, Stephan Luck, and Emil Verner, "Pandemics Depress the Economy, Public Health Interventions Do Not: Evidence from the 1918 Flu" (March 26, 2020) (https://ssrn.com/abstract=3561560 or http://dx.doi.org/10.2139/ssrn.3561560).
7. The definition of public health here is somewhat narrow for expositionary purposes. In reality, actions like social distancing can cause impacts on mental health, in particular, and actions that prioritize treatment of COVID-19 patients may impact on treatments and other health activities that are non-pandemic in nature.
8. Economist Tyler Cowen, at the beginning of all this, explained the difficulty of forecasting how bad COVID-19 would be. He saw two, quite distinct, camps: "growthers" and "base-raters." Growthers understand exponential growth and the idea that small things can grow into big things quickly. If you see and extrapolate from observations that the number of infected people is doubling in less than a week, you realize that you are a month or so away from a health crisis. Growthers, therefore, tend to be in favor of overreaction at the outset.

   The other group, base-raters, which Cowen speculated was initially most people and politicians, understand the mathematics but doubt whether the worst-case scenarios will play out. They tend to look at how things are and wonder if it could really get that bad. It takes a real cognitive effort to become anxious when there are only a few people sick—and, by "few," I mean less than a dozen. Maybe something will interrupt the mathematics. Not every past potential crisis has become a crisis.

   See Tyler Cowen, "Bill Gates Is Really Worried about the Coronavirus. Here's Why," *Bloomberg*, March 3, 2020 (https://www.bloomberg.com/opinion/articles/2020-03-03/how-fast-will-the-new-coronavirus-spread-two-sides-of-the-debate).
9. For a clear discussion of endgames, see John Daley, "The Case for Endgame C: Stop Almost Everything, Restart When Coronavirus Is Gone," *The Conversation*, March 20, 2020 (https://theconversation.com/the-case-for-endgame-c-stop-almost-everything-restart-when-coronavirus-is-gone-134232). In this book, I exposit the case for Endgame C leading to a restart where we can implement Endgame B (test and trace).
10. Economists were thinking about this very quickly. See Richard Baldwin and Beatrice Weder di Mauro (eds.), *Economics in the Time of COVID-19*, March 6, 2020 (https://voxeu.org/content/economics-time-covid-19), and Richard Baldwin and Beatrice Weder di Mauro (eds.), *Mitigating the COVID Economic Crisis: Act Fast and Do Whatever it Takes*, March 18, 2020 (https://voxeu.org/content/mitigating-covid-economic-crisis-act-fast-and-do-whatever-it-takes).
11. Tomas Pueyo calls the containment phrase "the hammer" and the reset phase "the dance." Tomas Pueyo, "Coronavirus: The Hammer and the Dance," *Medium*, March 19, 2020 (https://medium.com/@tomaspueyo/coronavirus-the-hammer-and-the-dance-be9337092b56).
12. The hollowed-out portion of the PPF is a nonconvexity. This is a direct implication of the SIR model of pandemics. Specifically, if we consider public health as an increasing function of s, the share of susceptible people (as opposed to infected) we have once the pandemic is over, and the economy as an increasing function of R_0 (the basic reproduction number), then it has been calculated that $\text{Log}(s) = R_0(s - 1)$. If you plot this in ($R_0$, s) space, you will obtain the nonconvex portion in figure 1.3a. See Tiberiu Harko, Francisco Lobo, and M. K. Mak, "Exact Analytical Solutions of the Susceptible–Infected–Recovered (SIR) Epidemic Model and of the SIR Model with Equal Death and Birth Rates," *Applied Mathematics and Computation* 236, no. 1 (2014): 184–194.
13. Before economists jump up and down, it is possible to imagine social utility functions that might cause us to want to be in the "bite." For instance, if economy and health are strict complements, that could easily happen. However, the tendencies that we obtain from a PPF approach alone tell us that we likely want to prioritize either the economy or

public health.

14. Eric Budish, "$R < 1$ as an Economic Constraint: Can We 'Expand the Frontier' in the Fight against Covid-19?," mimeo., University of Chicago Booth School of Business, April 1, 2020 (https://faculty.chicagobooth.edu/eric.budish/research/Budish_expand_the_frontier_covid19.pdf).
15. As explained in chapter 2, this involves targeting a basic reproduction number (R_0) not as low as possible but below 1.

Chapter 2

1. This is a paraphrase of a famous Indian fable; see https://en.wikipedia.org/wiki/Wheat_and_chessboard_problem.
2. If you think that calculation is still somewhat onerous, mathematicians have good news for you. A simple form is this: $T = 2^{64} - 1$.
3. At any point in time, t, Rt is the expected number of people an infectious person is likely to infect at that time. This will vary of the life of the pandemic—rising and then falling. The goal is to get to a point where $Rt < 1$.
4. https://en.wikipedia.org/wiki/Basic_reproduction_number.
5. For an interesting paper on the complexity of R_0, see P. L. Delamater, E. J. Street, T. F. Leslie, Y. T. Yang, and K. H. Jacobsen, "Complexity of the Basic Reproduction Number (R_0)," *Emerging Infectious Diseases* 25, no. 1 (2019): 1–4 (https://doi.org/10.3201/eid2501.171901).
6. See Frederick Chen, Jiang Miaohua, Scott Rabidoux, and Stephen Robinson, "Public Avoidance and Epidemics: Insights from an Economic Model," *Journal of Theoretical Biology* 278, no. 1 (2011): 107–119; Eli P. Fenichel, "Economic Considerations for Social Distancing and Behavioral Based Policies during an Epidemic," *Journal of Health Economics* 32, no. 2 (2013): 440–451; Benjamin R. Morin, Eli P. Fenichel, and Carlos Castillo-Chavez, "SIR Dynamics with Economically Driven Contact Rates," *Natural Resource Modeling* 26, no. 4 (2013): 505–525; Frederick Chen, "A Mathematical Analysis of Public Avoidance Behavior during Epidemics Using Game Theory," *Journal of Theoretical Biology* 302 (2012): 18–28; and Flavio Toxvaerd, "Rational Disinhibition and Externalities in Prevention," *International Economic Review* 60, no. 4 (2019): 1737–1755.
7. Jude Bayham, Nicolai V. Kuminoff, Quentin Gunn, and Eli P. Fenichel, "Measured Voluntary Avoidance Behaviour during the 2009 A/H1N1 Epidemic," *Proceedings of the Royal Society B: Biological Sciences* 282, no. 1818 (2015): 20150814.
8. Michael Springborn, Gerardo Chowell, Matthew MacLachlan, and Eli P. Fenichel, "Accounting for Behavioral Responses during a Flu Epidemic Using Home Television Viewing," *BMC Infectious Diseases* 15, no. 1 (2015): 21.
9. Flavio Toxvaerd, "Equilibrium Social Distancing," mimeo., Cambridge University, 2020.
10. Impacting on people's incentives to stay at home would be their comfort levels there. It is arguably the case that in many countries, staying at home is more pleasant than ever due mainly to the internet. However, in this crisis, there is evidence that even within countries such as the United States, there is a wide disparity in home comfort; see Lesley Chiou and Catherine E. Tucker, "Social Distancing, Internet Access and Inequality" (April 3, 2020) (https://ssrn.com/abstract=3568255 or http://dx.doi.org/10.2139/ssrn.3568255).
11. It is possible that if governments do not take action that, say, increases hospital capacity, individuals may decide to try to become infected earlier so that they are not sick when there is a capacity crunch. This fatalism is explored by Callum Jones, Thomas Philippon, and Venky Venkateswaran, "Optimal Mitigation Policies in a Pandemic: Social Distancing and Working from Home," mimeo., New York (https://callumjones.github.io/files/covid.pdf). In a calibrated model for COVID-19, they find that this incentive could well have existed.
12. Richard J. Hatchett, Carter E. Mecher, and Marc Lipsitch, "Public Health Interventions and Epidemic Intensity during the 1918 Influenza Pandemic," *PNAS* 104, no. 18 (May 1, 2007): 7582–7587; first published April 6, 2007 (https://doi.org/10.1073/pnas.0610941104).
13. Matthew Jackson, *The Human Network* (New York: Pantheon Books, 2019), chapter 3. Another factor that slowed the flu in 1918 was having less pollution in one's city. See Karen Clay, Joshua Lewis, and Edson Severnini, "What Explains Cross-City Variation in Mortality during the 1918 Influenza Pandemic? Evidence from 438 U.S. Cities," *Economics and Human Biology* 35 (2019): 42–50.
14. The Novel Coronavirus Pneumonia Emergency Response Epidemiology Team, "The Epidemiological Characteristics of an Outbreak of 2019 Novel Coronavirus Diseases (COVID-19)—China, 2020[J]," *China CDC Weekly* 2, no. 8 (2020): 113–122 (http://weekly.chinacdc.cn/en/article/id/e53946e2-c6c4-41e9-9a9b-fea8db1a8f51).
15. Tomas Pueyo, "Coronavirus: The Hammer and the Dance," *Medium*, March 19, 2020 (https://medium.com/@tomaspueyo/coronavirus-the-hammer-and-the-dance-be9337092b56).
16. Jin Wu, Weiyi Cai, Derek Watkins, and James Glanz, "How the Virus Got Out," *New York Times*, March 22, 2020 (https://www.nytimes.com/interactive/2020/03/22/world/coronavirus-spread.html?referringSource=articleShare).
17. Jim Stock uses the SIR model to show that a critical piece of knowledge is precisely how many in the population are already infected/recovered when you are considering putting social distancing rules in place. If there are few in this category, you want to adopt more extreme social distancing. If there are many, then you can relax, as a good proportion of the population may be immune. The only way to discover the true R_0 at that time is through large sample testing. See J. H. Stock, "Data Gaps and the Policy Response to the Novel Coronavirus" (2020), NBER Working Paper 26902.
18. The reader should note that I am using a day for illustration. It may be that information will be expected to arrive in the next week or month.
19. Ben S. Bernanke, "Irreversibility, Uncertainty and Cyclical Investment," *Quarterly Journal of Economics* 98, no. 1 (1983): 85–106.

Chapter 3

1. John Maynard Keynes, “How to Pay for the War,” in *Essays in Persuasion* (London: Palgrave Macmillan, 2010), 367–439.
2. *Micromotives and Macrobehavior* (New York: Norton, 1978), 20.
3. Patrick Bolton and Joseph Farrell, “Decentralization, Duplication, and Delay,” *Journal of Political Economy* 98, no. 4 (1990): 803–826.
4. Some will note that perhaps market or mechanism design could give us the best of both worlds. Bolton and Farrell deal with that, but some of the baseline trade-offs remain. Also, design takes time and must be matched to every crisis, so it does not seem feasible.
5. Daniel M. Horn, “How American Can Avoid Italy’s Ventilator Crisis,” *New York Times*, March 22, 2020 (https://www.nytimes.com/2020/03/22/opinion/health/ventilator-shortage-coronavirus-solution.html?smtyp=cur&smid=tw-nytopinion).
6. Ibid.
7. Susan Adams, “The Economics of Panic Buying,” *Forbes*, March 5, 2020 (https://www.forbes.com/sites/susanadams/2020/03/05/the-economics-of-panic-buying/#647d46e85e27). Indeed, some of us thought that people could certainly economize on the toilet paper they had or switch to alternatives like bidets.
8. That said, they are at home more so there may be a shift in the allocation of “activity.” Nonetheless, this is analogous to the types of shortages that arose during the Soviet Union based on consumer hoarding of products they expected to be off the shelves quickly, like soap. See Martin L. Weitzman, “Price Distortion and Shortage Deformation, or What Happened to the Soap?,” *American Economic Review* (June 1, 1991): 401–414.
9. Jack Nicas, “He Has 17,700 Bottles of Hand Sanitizer and Nowhere to Sell Them,” *New York Times*, March 14, 2020 (https://www.nytimes.com/2020/03/14/technology/coronavirus-purell-wipes-amazon-sellers.html).
10. John K. Galbraith, “The Disequilibrium System,” *American Economic Review* 37, no. 3 (1947): 298, note 16.
11. Piotr Dworczak, Scott Duke Kominers, and Mohammad Akbarpour, “Redistribution through Markets” (December 24, 2019), Becker Friedman Institute for Research in Economics Working Paper No. 2018-16 (https://ssrn.com/abstract=3143887).
12. Scott Duke Kominers, “Keep Sanitizer Out of the Invisible Hand,” *Bloomberg*, March 16, 2020 (https://www.bloomberg.com/opinion/articles/2020-03-16/coronavirus-emergency-why-price-gouging-for-sanitizer-is-wrong).
13. This is what Noah Smith suggested when he advocated the use of apps that inform people of where there are stocks of essential goods. Such apps had been deployed to inform consumers of where face masks were for sale in Taiwan. See Noah Smith, “How to Limit Hoarding and Keep America’s Hands Clean,” *Bloomberg Opinion*, March 19, 2020 (https://www.bloomberg.com/opinion/articles/2020-03-19/rationing-and-tech-can-limit-covid-19-soap-toilet-paper-hoarding).
14. “Love in the Time of HIV: Testing as a Signal of Risk,” mimeo., University of Toronto, 2019.
15. David Katz, “Is Our Fight against Coronavirus Worse than the Disease?,” *New York Times*, March 20, 2020 (https://www.nytimes.com/2020/03/20/opinion/coronavirus-pandemic-social-distancing.html).
16. Alex Tabarrok, “The Internal Contradictions of Segregating the Elderly,” *Marginal Revolution*, March 22, 2020 (https://marginalrevolution.com/marginalrevolution/2020/03/the-internal-contradictions-of-segregating-the-elderly.html). See also Megan McArdle, “Here’s Why It Won’t Work to Just Isolate the Vulnerable,” *Washington Post*, April 3, 2020 (https://www.washingtonpost.com/opinions/2020/04/03/heres-why-it-wont-work-just-isolate-elderly-vulnerable/).
17. There are challenges in enforcing them. In Spain, dog walking was permitted and so markets sprang up to match dog owners with others who needed to get about. See “Walking the Dog: A Get-Out-of-Jail Card in Lockdown Spain,” *France24*, March 19, 2020 (https://www.france24.com/en/20200319-walking-the-dog-a-get-out-of-jail-card-in-lockdown-spain?fbclid=IwAR2kdovFMNRMwz37e_A-UF_C6E_O6sDthfqxem1lE4Wiebneh0zj5rfy8MU). It goes without saying that dogs received great benefits from widespread social distancing.
18. Similarly, there is discussion of the use of face masks as many cases are asymptomatic. There are proposals to make wearing of this compulsory. At the time of writing, the shortages of masks may have prevented that from happening, but it will be interesting to see whether mandatory dress requirements might emerge and be experimented with.

Chapter 4

1. One of the earliest descriptions and prescriptions for the economy came from Steven Hamilton and Stan Veuger, "A Recession Is a Public Health Necessity. Here's How to Make It Short and Sharp," *The Bulwark*, March 14, 2020 (https://thebulwark.com/a-recession-is-a-public-health-necessity-heres-how-to-make-it-short-and-sharp/). They wrote: "The key thing to grasp is that this will be no normal recession. Economics textbooks don't cover how to deal with the fallout from a global pandemic."
2. The HIV/AIDS crisis was of a similar magnitude in terms of deaths but was spread out for many more years.
3. Robert J. Barro, Jose F. Ursua, and Joanna Weng, "The Coronavirus and the Great Influenza Epidemic: Lessons from the 'Spanish Flu' for the Coronavirus' Potential Effects on Mortality and Economic Activity," AEI Economics Working Paper 2020-02, March 2020.
4. https://twitter.com/Austan_Goolsbee/status/1239649835969646592?s=20.
5. Perhaps the most complete articulation to date regarding how this recession will differ from normal ones and what this means for policy has been provided by Veronica Guerrieri, Guido Lorenzoni, Ludwig Straub, and Ivan Werning, "Macroeconomic Implications of COVID-19: Can Negative Supply Shocks Cause Demand Shortages?," mimeo., MIT, April 2020 (https://economics.mit.edu/files/19351).
6. Scott Ellison quoted by Tyler Cowen, "Stopping Time: An Approach to Pandemics?," *Marginal Revolution*, March 19, 2020 (https://marginalrevolution.com/marginalrevolution/2020/03/stopping-time-an-approach-to-pandemics.html).
7. Different metaphors have been used to describe this type of policy direction. While I have chosen to use "pause" here, others have used hibernation, medically induced coma (and thereby requiring life support), and a freeze. If I had could have my way, I would have gone with "frozen in carbonite."
8. https://www.cloverfoodlab.com/2020/03/17/psa-call-for-help-please-if-you-run-a-tech-services-company-offer-your-restaurant-clients-3-months-credit-asap/.

9 What this pause notion does not quite capture is what to do about potential disruption and restarting of complicated supply chains. See Matthew Elliott, Benjamin Golub, and Matthew V. Leduc, "Supply Network Formation and Fragility," mimeo., Harvard University, April 3, 2020 (http://bengolub.net/papers/SNFF.pdf).

10. https://www.antievictionmap.com/covid.
11. Steven Erlanger, "Macron Declares France 'at War' with Virus, as EU Proposes 30 Day Travel Ban," *New York Times*, March 16, 2020 (https://www.nytimes.com/2020/03/16/world/europe/coronavirus-france-macron-travel-ban.html).
12. Derek Thompson, "Denmark's Idea Could Help the World Avoid a Great Depression," *The Atlantic*, March 21, 2020 (https://www.theatlantic.com/ideas/archive/2020/03/denmark-freezing-its-economy-should-us/608533/?utm_source=nextdraft&utm_medium=email).
13. Emmanuel Saez and Gabrielle Zucman, "The Crisis Calls for Massive Government Intervention: Here's How to Do It," *The Guardian*, March 17, 2020 (https://www.theguardian.com/commentisfree/2020/mar/17/governments-crisis-coronavirus-business).
14. The idea of making adjustments after the fact rather than before gained some traction during the crisis. This was earlier articulated by Claudia Sahm, "Direct Stimulus Payments to Individuals," in Heather Boushey, Ryan Nunn, and Jay Shambaugh (eds.), Recession Ready: Fiscal Policies to Stabilize the U.S. Economy (2019), and then by Greg Mankiw at http://gregmankiw.blogspot.com/2020/03/a-proposal-for-social-insurance-during.html.
15. Sendhil Mullainathan, "We All Need Small Businesses. Don't Let Them Die," *New York Times*, March 19, 2020 (https://www.nytimes.com/2020/03/19/business/small-businesses-coronavirus-help.html).
16. Peter Ganong and Pascal Noel, "Liquidity vs. Wealth in Household Debt Obligations: Evidence from Housing Policy in the Great Recession," mimeo., University of Chicago, 2020.
17. Joshua Gans and Stephen King, "The Housing Lifeline: A Policy for Short-Run Housing Affordability," *Agenda* 11, no. 2 (2004). See also comments by Bruce Chapman at https://www.anu.edu.au/news/all-news/hecs-style-loans-can-help-beat-the-coronavirus-cash-crisis.

Chapter 5

1. Joseph E. Aldy and W. Kip Viscusi, "Risk Regulation Lessons from Mad Cows," *Foundations and Trends in Microeconomics* 8, no. 4 (2013): 231–313.
2. Details of this case are drawn from ibid.
3. Bryan Caplan, *The Case against Education: Why the Education System Is a Waste of Time and Money* (Princeton University Press, 2018).
4. These calculations are based on http://gabgoh.github.io/COVID/index.html with an $R_0 = 2$ and no interventions.
5. See Paul Romer and Alan M. Garber, "Will Our Economy Die from Coronavirus?," *New York Times*, March 23, 2020 (https://www.nytimes.com/2020/03/23/opinion/coronavirus-depression.html?searchResultPosition=1); and Alex Tabarrok, "A Solution if We Act," *Marginal Revolution*, March 30, 2020 (https://marginalrevolution.com/marginalrevolution/2020/03/a-solution-if-we-act.html). However, the genesis of this idea was a post by Tomas Pueyo, "Coronavirus: The Hammer and the Dance," *Medium*, March 14, 2020 (https://medium.com/@tomaspueyo/coronavirus-the-hammer-and-the-dance-be9337092b56). His hammer reflected the containment phase I have discussed, while the dance was testing and tracing as part of the reset phase. Some formal modeling of the economic value of testing is contained in Facundo Piguillem and Liyan Shi, "The Optimal COVID-19 Quarantine and Testing Policies," Working Paper, 20/04, EIEF, March 2020 (http://www.eief.it/eief/images/WP_20.04.pdf).
6. Gretchen Vogel, "New Blood Tests for Antibodies Could Show True Scale of Coronavirus Pandemic," *Science*, March 19, 2020 (https://www.sciencemag.org/news/2020/03/new-blood-tests-antibodies-could-show-true-scale-coronavirus-pandemic).
7. For more details of the two types of test, see M. Dewatripont, M. Goldman, E. Muraille, and J.-P. Platteau, "Rapidly Identifying Workers Who Are Immune to COVID-19 and Virus-Free Is a Priority for Restarting the Economy," VoxEU.org, March 23, 2020 (https://voxeu.org/article/rapidly-identifying-workers-who-are-immune-covid-19-and-virus-free-priority-restarting-economy).
8. Donato Paolo Mancini and Clive Cookson, "Aggressive Testing Helps Italian Town Cut New Coronavirus Cases to Zero," *Financial Times*, March 17, 2020 (https://www.ft.com/content/0dba7ea8-6713-11ea-800d-da70cff6e4d3).
9. Toward the end of March 2020, medical practitioners began observing that many COVID-19 cases were accompanied by a loss of sense of taste and/or smell. If this were the case, then it would provide a solid symptomatic way of identifying those who have the virus by putting them in close proximity to a dog or teenager. For more, see Michael Lewis, "A Coronavirus Fix That Passes the Smell Test," *Bloomberg*, April 1, 2020 (https://www.bloomberg.com/opinion/articles/2020-04-01/tracking-coronavirus-by-smell-test-is-risk-manager-s-project-now), and Joshua Gans, "Smell Test Now," *Medium*, April 1, 2020 (https://medium.com/@joshgans/smell-test-now-2bf533d8b955). Using Google trends information, Seth Stephens-Davidowitz also conjectured eye pain may be a symptom; see "Google Searches Can Help Us Find Emerging Covid-19 Outbreaks," *New York Times*, April 5, 2020 (https://www.nytimes.com/2020/04/05/opinion/coronavirus-google-searches.html). There may also be other ways symptoms can be measured at an individual level and then aggregated up to see where outbreaks may be emerging; see Lauren Goode, "Can a Wearable Detect Covid-19 before Symptoms Appear?" *Wired*, April 14, 2020 (https://www.wired.com/story/wearable-covid-19-symptoms-research).
10. If there is a flu test, then the information from the test can be used to potentially raise the relevance of co-symptoms if the flu test turns out to be negative for an individual.
11. There were estimates that for COVID-19, if 70 percent of contacts from someone who tested positive could be traced this would be sufficient to reduce R_0 below one and end the pandemic. See John Hellewell, Sam Abbott, Amy Gimma, et al., "Feasibility of Controlling COVID-19 Outbreaks by Isolation of Cases and Contacts," *The Lancet*, February 28, 2020 (https://doi.org/10.1016/S2214-109X(20)30074-7).
12. Digital technologies are being deployed to assist with contact tracing through community reporting of symptoms and cases and also the use of mobile phone tracking (https://www.foreignaffairs.com/articles/asia/2020-03-20/how-civic-technology-can-help-stop-pandemic). In April 2020, Apple and Google announced plans to develop contact tracing capabilities on both the iOS and Android mobile operating systems. Of course, these raise issues of surveillance and privacy that will not be easily resolved. That said, some innovators have been able to develop methods of contact tracing that appear to be able to protect privacy of those being traced. (An example of this is the Safepaths app developed by a team at MIT: http://safepaths.mit.edu/.) For a broader discussion of these methods, see Vi Hart et al., "Outpacing the Virus: Digital Response to Containing the Spread of COVID-19 while Mitigating Privacy Risks," COVID-19 Rapid Response Impact Initiative, White Paper No. 5, Edmond J. Safra Center for Ethics, Harvard University, April 3, 2020 (https://ethics.harvard.edu/files/center-for-ethics/files/white_paper_5_outpacing_the_virus_final.pdf), and, from Nicky Case, see https://ncase.me/contact-tracing/?v=2 for a graphic description of how we may be able to have our cake and eat it too.
13. See David Berger, Kyle Herkenhoff, and Simon Mongey, "An SEIR Infectious Disease Model with Testing and Conditional Quarantine," mimeo., Duke University, March 24, 2020 (http://www.simonmongey.com/uploads/6/5/6/6/65665741/bhm_corona_v4.pdf).
14. Kathryn Olivarius, "Immunity, Capital and Power in Antebellum New Orleans," *American Historical Review* 124,

no. 2 (April 2019): 425.

15. At least if you were white. Olivarius found that for blacks, by being acclimated, they only became more valuable slaves.

16. Germany reportedly will introduce certification for those who have recovered from COVID-19 (https://www.telegraph.co.uk/news/2020/03/29/germany-will-issue-coronavirus-antibody-certificates-allow-quarantined/). Dare I say it that this might be time for the blockchain! See Christian Catallini and Joshua Gans, "Some Simple Economics of the Blockchain," *Communications of the ACM*, forthcoming. Others have suggested that some form of group testing could result in higher speed and lower testing costs. See Olivier Gossner, "Group Testing against COVID-19," mimeo., CREST, March 29, 2020 (http://gossner.me/wp-content/uploads/2020/03/group-testing20202328.pdf), and Christian Gollier, "Optimal Group Testing to Exit the Cover Confinement," mimeo., Toulouse School of Economics, March 2020 (https://www.tse-fr.eu/sites/default/files/TSE/documents/doc/by/gollier/group_testing.pdf).

17. In the case of COVID-19, the main factors are whether there is RNA material on the swab (or enough to be detected), whether it contains the RNA sequence matching COVID-19, and whether there no other PCR failures.

18. David Louie, "COVID-19 Testing Is Important but Has 10 to 15% Rate of Producing False, Negative Results, Pathologist Says," *ABC7 News*, March 26, 2020 (https://abc7news.com/6053940).

19. https://paulromer.net/covid-sim-part3.

20. https://paulromer.net/covid-sim-part2.

21. Biochemists Jussi Taipale and Sten Linnarsson (https://medium.com/@sten.linnarsson/to-stop-covid-19-test-everyone-373fd80eb03b) point out that we can potentially get away with testing fewer people in the population if we want to get the basic reproduction number below 1. If we identify someone as positive and quarantine them, suppose that instead of R_0 the basic reproduction number for quarantined people is R_q ($< R_0$). If we test a proportion of the population, c, and if our test has a true positive rate of p, then the average basic reproduction number is $cpR_q + (1 - cp)R_0$. We want this to be less than 1, so $cp > (R_0 - 1)/(R_0 - R_q)$. If $R_0 = 2.4$ and $R_q = 0.3$, then we need $cp > 2/3$. Interestingly, for an accurate test, the higher the prevalence of the virus in the population, the *lower* is the amount of testing you need. See also Berger et al., "An SEIR Infectious Disease Model."

22. See Matthew Cleevely, Daniel Susskind, David Vines, Louis Vines, and Sam Wills, "A Workable Strategy for Covid-19 Testing: Stratified Period Testing Rather Than Universal Random Testing," mimeo., Oxford University, April 15, 2020 (https://static1.squarespace.com/static/57d002e01b631bc215df193b/t/5e96e6ad445bca269b0671c0/1586947760671/st

23. That share is $(R_0 - 1)/R_0$. So, if the R_0 for COVID-19 is greater than 2, at least half of the population will be infected at any given time.

24. For a discussion, see Robert Rowthorn and Flavio Toxvaerd, "The Optimal Control of Infectious Diseases via Prevention and Treatment," mimeo., Cambridge University, 2017.

25. Gregory Barber, "What If Covid-19 Returns Every Year, like the Common Cold?," *Wired*, April 15, 2020 (https://www.wired.com/story/what-if-covid-19-returns-every-year-like-the-common-cold).

26. Park Si-soo, "South Korea Confirms 111 Cases of Coronavirus Reinfection," *The Korea Times*, April 12, 2020 (https://www.koreatimes.co.kr/www/nation/2020/04/119_287752.html). There were also similar cases reported in Shenzhen and Wuhan China.

27. C. J. Wang, C. Y. Ng, and R. H. Brook, "Response to COVID-19 in Taiwan: Big Data Analytics, New Technology, and Proactive Testing," *JAMA*, published online March 3, 2020 (doi:10.1001/jama.2020.3151).

28. See Gary Pisano, Raffaella Sadun, and Michele Zanini, "Lessons from Italy's Response to the Coronavirus," *Harvard Business Review* online, March 27, 2020 (https://hbr.org/2020/03/lessons-from-italys-response-to-coronavirus).

Chapter 6

1. The question mark is part of the name.
2. Neil Ferguson et al., *Report 9—Impact of Non-Pharmaceutical Interventions (NPIs) to Reduce COVID-19 Mortality and Healthcare Demand*, March 16, 2020 (https://www.imperial.ac.uk/mrc-global-infectious-disease-analysis/news--wuhan-coronavirus/).
3. Pallab Ghosh, "Science Ponders 'Zombie Attack,'" *BBC News*, August 19, 2009 (http://news.bbc.co.uk/2/hi/science/nature/8206280.stm).
4. https://www.cdc.gov/cpr/zombie/index.htm.
5. If you do want to know more about potential government response to zombies, I can recommend Daniel Drezner, *Theories of International Relations and Zombies* (Princeton University Press, 2011). He also presented an updated discussion in light of COVID-19: Daniel Drezner, "What I Learned about the Coronavirus World from Watching Zombie Flicks," *Foreign Affairs*, April 11, 2020 (https://foreignpolicy.com/2020/04/11/what-i-learned-about-coronavirus-world-from-zombie-movies/). That piece ended with the hopeful thought, "Never count out a species responsible for duct tape."
6. Jonathan Dingel and Brent Neiman, "How Many Jobs Can Be Done at Home?," mimeo., Becker Friedman Institute for Economics, University of Chicago, April 6, 2020 (https://bfi.uchicago.edu/working-paper/how-many-jobs-can-be-done-at-home/).
7. For a good and accessible introduction to network theory, see Matthew O. Jackson, *The Human Network* (New York: Pantheon, 2019).
8. Some jobs are more high-intensity contact than others. See Fernando Leibovici, Ana Maria Santacreu, and Matthew Famiglietti, "Social Distancing and Contact-Intensive Occupations," *On the Economy Blog*, St. Louis Fed, March 24, 2020 (https://www.stlouisfed.org/on-the-economy/2020/march/social-distancing-contact-intensive-occupations).
9. Workplaces did not necessarily have to be told to take these measures. Walmart started to require temperature checks for employees with guaranteed pay if they were sent home (https://corporate.walmart.com/newsroom/2020/03/31/additional-steps-were-taking-for-the-health-and-safety-of-our-associates), while Amazon started to construct testing facilities at their workplaces (https://blog.aboutamazon.com/company-news/scalable-testing-for-coronavirus). These actions provide support that workplaces might (1) be able to pass a certification for safe practices or (2) choose protocols with backed up by liability claims should they be found to be responsible for spreading the virus.
10. This was suggested in a report by Andrew Oswald and Nattavudh Powdthavee, "The Case for Releasing the Young from Lockdown," CAGE Policy Briefing, April 2020, University of Warwick.
11. Debraj Ray and S. Subramanian, "Covid-19: Is There a Reasonable Alternative to a Comprehensive Lockdown?," *Ideas for India*, March 28, 2020 (https://www.ideasforindia.in/topics/macroeconomics/is-there-a-reasonable-alternative-to-a-comprehensive-lockdown.html).
12. https://www.cdc.gov/flu/pandemic-resources/pdf/2018-Influenza-Guidance.pdf.
13. Some work has already been done on thinking how to use different criteria to ration other items in short supply like ventilators. The idea is to allow people to self-select what criteria might be appropriate and then use methods developed in market design—specifically, matching markets—to determine the ration order. See Parag Pathak, Tayfun Sonmez, M. Utku Unver, and M. Bumin Yenmez, "Triage Protocol Design for Ventilator Rationing in a Pandemic: A Proposal to Integrate Multiple Ethical Values through Reserves," mimeo., MIT, April 2020 (http://economics.mit.edu/files/19358). Another option is to broaden the ability of ventilators to be shared across regions; see Simon Loertscher and Leslie M. Marx, "A National Ventilator Exchange Could Address Critical Shortages," *The Hill*, March 27, 2020 (https://thehill.com/opinion/healthcare/489858-a-national-ventilator-exchange-could-address-critical-shortages).

Chapter 7

1. Michael Kremer and Heidi Williams, "Incentivizing Innovation: Adding to the Tool Kit," *Innovation Policy and the Economy* 10, no. 1 (2010): 13.
2. It is not without its problems. For a recent discussion, see Joshua Gans and Andrew Leigh, *Innovation + Equality: Creating a Future That Is More Star Trek than Terminator* (MIT Press, 2019).
3. https://www.bloomberg.com/opinion/articles/2020-03-19/curing-a-pandemic-could-make-you-rich.
4. For more of the type of thing, see Jack Hirshleifer, "The Private and Social Value of Information and the Reward to Inventive Activity," in *Uncertainty in Economics* (Academic Press, 1978), 541–556.
5. See the recent survey by Pierre Azoulay and Danielle Li, "Scientific Grant Funding," Working Paper No. 26889, NBER, March 2020.
6. https://en.wikipedia.org/wiki/Longitude_rewards.
7. Alex Tabarrok ("Grand Innovation Prizes to Address Pandemics: A Primer," *COVID-19 Policy Brief*, Mercatus Center, George Mason University, March 19, 2020) has been a forceful proponent for them to deal with COVID-19 innovation (https://www.mercatus.org/publications/covid-19-policy-brief-series/grand-innovation-prizes-address-pandemics-primer).
8. For more on these methods, see Nicholas Bloom, John Van Reenen, and Heidi Williams, "A Toolkit of Policies to Promote Innovation," *Journal of Economic Perspectives* 33, no. 3 (2019): 163–184.
9. For additional discussions of AMCs, see Michael Kremer, "Creating Markets for New Vaccines: Pt. 1, Rationale," and "Creating Markets for New Vaccines: Pt. 2, Design Issues," both in *Innovation Policy and the Economy*, vol. 1, ed. Adam Jaffe, Josh Lerner, and Scott Stern (Cambridge, MA: MIT Press, 2001); Michael Kremer and Rachel Glennerster, *Strong Medicine: Creating Incentives for Pharmaceutical Research on Neglected Diseases* (Princeton, NJ: Princeton University Press, 2004); Owen Barder, Michael Kremer, and Ruth Levine, *Making Markets for Vaccines: Ideas to Action* (Washington, DC: Center for Global Development, 2005).
10. For a discussion of the potential vaccine alternatives and their diversity see Derek Lowe, "Coronavirus Vaccine Prospects," *Science Translational Medicine*, April 15, 2020 (https://blogs.sciencemag.org/pipeline/archives/2020/04/15/coronavirus-vaccine-prospects).
11. Note that it is important for a technologically close innovation that the price actually be set rather than a per dose subsidy. Michael Kremer, Jonathan Levin, and Christopher Snyder ("Designing Advanced Market Commitments for New Vaccines" (2019), mimeo., Harvard University) show that this latter case may actually cause too little capacity to be built as that will be sufficient for an innovator to appropriate what might be available to fund the product.
12. Michael Kremer, Jon Levin, and Chris Snyder, "Advance Market Commitments: Insights from Theory and Experience," *American Economic Association Papers and Proceedings*, 2020.
13. For an account, see Tim Harford, *Adapt: Why Success Always Starts with Failure* (Picador, 2012).
14. Safi Bahcall, *Loonshots: How to Nurture the Crazy Ideas That Win Wars, Cure Diseases and Transform Industries* (St. Martin's Press, 2019).
15. This is perhaps most critically directed at the idea of vaccine platforms—that is, methods that can quickly generate vaccines for almost any virus. This is being pursued by organizations such as CEPI (https://cepi.net/research_dev/technology).
16. Josh Lerner and Jean Tirole, "Efficient Patent Pools," *American Economic Review* 94, no. 3 (2004): 691–711; Josh Lerner and Jean Tirole, "Public Policy toward Patent Pools," *Innovation Policy and the Economy* 8 (January 1, 2007): 157–186.
17. Phil Taylor, "AbbVie Won't Enforce Patents for COVID-19 Drug Candidate Kaletra," *PharmaPhorum*, March 25, 2020 (https://pharmaphorum.com/news/abbvie-wont-enforce-patents-for-covid-19-drug-candidate-kaletra/).
18. Iain M. Cockburn, Scott Stern, and Jack Zausner, "Finding the Endless Frontier: Lessons from the Life Sciences Innovation System for Energy R&D," in *Accelerating Energy Innovation: Insights from Multiple Sectors* (University of Chicago Press, 2011), 113–157.

Chapter 8

1. John Maynard Keynes, *The Economic Consequences of the Peace* (Macmillan, 1921).
2. https://www.ted.com/talks/bill_gates_the_next_outbreak_we_re_not_ready?language=en#t-442139.
3. Ian W. R. Martin and Robert S. Pindyck, "Averting Catastrophes: The Strange Economics of Scylla and Charybdis," *American Economic Review* 105, no. 10 (2015): 2947–2985.
4. Ibid., 2948.
5. Thomas C. Schelling, "The Life You Save May Be Your Own," in *Problems in Public Expenditure Analysis*, ed. Samuel B. Chase, Jr. (Washington, DC: Brookings Institution, 1968), 127–161, and W. Kip Viscusi and Joseph E. Aldy, "The Value of a Statistical Life: A Critical Review of Market Estimates throughout the World," *Journal of Risk and Uncertainty* 27, no. 1 (2003): 5–76.
6. See, for instance, Robert E. Hall, Charles I. Jones, and Peter J. Klenow, "Trading Off Consumption and COVID-19 Deaths," mimeo., Stanford University, April 2020 (http://klenow.com/Consumption_vs_COVID19.pdf). There are a myriad of complications with even using the value of a statistical life to decide on things. First, the values are averages, so would you really use it to tip the scales in a tough choice regarding whether to avert a catastrophe? Second, reducing the value of a life to a monetary figure is dehumanizing. One suspects that it is better for the weights to be decided more broadly and even subjectively (see Romer, "The Dismal Kingdom"). Third, for catastrophes, it is surely no better to add up the value of lives than thinking about the value of those lives together, which is likely to be a much different calculation. Nonetheless, in a recent paper, Ian Martin and Bob Pindyck do take that approach in better accounting for death in their calculations; see Ian Martin and Robert Pindyck, "Welfare Costs of Catastrophes: Lost Consumption and Lost Lives," *Economic Journal*, forthcoming. Fourth, with respect to COVID-19, there is an awkward fact: the loss of life was disproportionately concentrated amongst the elderly. Calculations by David Spiegelhalter (https://medium.com/wintoncentre/how-much-normal-risk-does-covid-represent-4539118e1196) showed that the increase in risk from COVID-19 as a function of age was modest. This is because when you are older, you are more likely to die in general. Thus, if such risk were explicitly taken into account, this would reduce the estimated monetary losses from death from COVID-19. Suffice it to say, I take this as another argument as to why using these valuation techniques is unlikely to be helpful relative to more subjective measures. Finally, it is worth noting that, with respect to the costs of dealing with COVID-19 (as opposed to the benefits in terms of saved lives), it appears that essential workers are more likely to be women than men (Titan Alon, Mattias Doepke, Jane Olmstead-Rumsey, and Michele Tertilt, "The Impact of COVID-19 on General Inequality," mimeo., Northwestern University, March 2020, http://faculty.wcas.northwestern.edu/~mdo738/research/COVID19_Gender_March_2020.pdf, and Simon Mongey and Alex Weinberg, "Characteristics of Workers in Low Work-from-Home and High Personal-Proximity Occupations," mimeo., University of Chicago, March 2020, http://www.simonmongey.com/uploads/6/5/6/6/65665741/mw_covid_occupations_v1.pdf) and younger workers rather than older workers (Andrew Glover, Jonathan Heathcote, Dirk Krueger, and Jose-Victor Rios-Rull, "Health versus Wealth: On the Distributional Effects of Controlling a Pandemic," mimeo., University of Pennsylvania, April 2020, http://www.jonathanheathcote.com/healthwealth.pdf).
7. Another flaw for both the British and the French was, despite having invented the tank in World War I, they still invested in warfare based on the horse. Tim Harford, "Why Big Companies Squander Good Ideas," *Financial Times*, September 6, 2018 (https://www.ft.com/content/3c1ab748-b09b-11e8-8d14-6f049d06439c).
8. See my book on the subject, *The Disruption Dilemma* (MIT Press, 2016).
9. For a discussion of this see Robert Meyer and Howard Kunreuther, *The Ostrich Paradox: Why We Underprepare for Disasters* (Philadelphia: Wharton School Press, 2017).

About the Author

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At Rotman, he teaches MBA and Commerce students Entrepreneurial Strategy. He has also coauthored (with Stephen King and Robin Stonecash) the Australasian edition of Greg Mankiw's *Principles of Economics* (published by Cengage), *Core Economics for Managers* (Cengage), *Finishing the Job* (Melbourne University Publishing), *Parentonomics* (MIT Press), *Information Wants to Be Shared* (Harvard Business Review Press), *The Disruption Dilemma* (MIT Press), *Prediction Machines: The Simple Economics of Artificial Intelligence* (Harvard Business Review Press), and *Innovation + Equality* (MIT Press).

While Joshua's research interests are varied, he has developed specialties in the nature of technological competition and innovation, economic growth, publishing economics, industrial organization, and regulatory economics. This has culminated in publications in the *American Economic Review*, *Journal of Political Economy*, *RAND Journal of Economics*, *Journal of Economic Perspectives*, *Journal of Public Economics*, and the *Journal of Regulatory Economics*. Joshua serves as department editor of *Management Science* and the *Journal of Industrial Economics* and is on the editorial boards of the *Economic Analysis and Policy* and *Games*. In 2007, Joshua was awarded the Economic Society of Australia's Young Economist Award. In 2008, Joshua was elected as a Fellow of the Academy of Social Sciences, Australia. He has also written for the *Financial Times*, *Sloan Management Review*, and other outlets with over 200 opinion pieces.