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Could the United States benefit from a lockdown? A cost-benefit analysis

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Could the United States benefit from a lockdown? A cost-benefit analysis

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Abstract

Though COVID vaccines are finally available, the rate at which they are administered is slow, and in the meantime the pandemic continues to claim about as many lives every day as the 9/11 tragedy. I estimate that with the promised rate of vaccinations, if no additional non-pharmaceutical interventions are implemented, 406 thousand additional lives will be lost and the future cost of the pandemic will reach \$2.4 trillion, or 11% of GDP. Using a cost-benefit analysis, I assess whether it is optimal for the United States to follow the lead of many European countries and introduce a nation-wide lockdown. I find that a lockdown would be indeed optimal and, depending on the assumptions, it should last between two and four weeks and will generate a net benefit of up to \$1.2 trillion.

JEL classification: I10, I18

Keywords: COVID-19, Pandemic Curve, Cost-Benefit Analysis, Non-Pharmaceutical Interventions, Public Health Policy, Lockdown

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I. Introduction

Operation Warp Speed has successfully delivered two highly effective COVID-19 vaccines, with additional vaccine candidates undergoing clinical trials. However, vaccine production and distribution are slow, with the vaccination target of 70% expected to be reached only by the end of May 2021 according to more optimistic estimates.¹ In the meantime, the number of new infections is at peak levels, and the virus claims about as many lives every day as the 9/11 tragedy.

While some European countries began a new round of national lockdowns, there is resistance to implementing more stringent COVID restrictions in the United States.² The costs of a lockdown are felt in real time in the form of inconveniences and lost wages while the benefits from the reduced number of illnesses and deaths come in the future, and as such they may be perceived as hypothetical and underestimated. Moreover, the public may view the pandemic risks as acceptable because children are largely unaffected and because frontline workers and first responders getting protection from the virus by being among the first to be vaccinated (e.g., Tumpey et al. (2018), Table 12.1).

Despite society as a whole being potentially less concerned about saving the lives of the more vulnerable older adults,³ the older people's lives are valuable to them.⁴ The value of life can be quantified by a person's willingness to pay to stay alive, with metrics such as the value of statistical life (VSL) and discounted quality-adjusted life years (dQALY) being widely used in policy decisions. Moreover, the fatality data shows that COVID-19 also poses substantial risks to the lives of younger people who may be unaware of their health vulnerabilities ex-ante and therefore fail to take adequate precautions.

The COVID experience from around the world has shown that centralized policies are critical to achieving an optimal pandemic management. The failed Swedish experiment has illustrated

¹See, e.g., <https://www.technologyreview.com/2020/12/01/1012817/us-official-says-every-american-who-wants-a-covid-19-vaccine-will-have-one-by-june/>.

²I will use the terms "COVID" and "COVID-19" interchangeably.

³See, e.g., <https://www.texastribune.org/2020/04/21/texas-dan-patrick-economy-coronavirus/>.

⁴For example, a Gallup poll showed that older people were more willing than younger people to choose resuscitation or ventilator support when asked about preferences in the event of terminal illness (Gallup and Newport (1991)).

that it may be impossible to selectively protect the vulnerable population without a government intervention.⁵ Analysing U.S. data, Boehmer et al. (2020) find that increased rates of infection among young people in the June–August 2020 period helped transmit the virus to more vulnerable high-risk groups, such as older adults. This happened in spite of the broad awareness of higher risks faced by the older population.

Even when a COVID infection is not fatal, it is still costly because the sick consume medical services that could have been allocated to other health conditions. They also miss days of productive work, reducing the GDP (or in the case of children and older adults, their caretakers miss productive work days). I perform a cost-benefit analysis of a possible lockdown by comparing its benefits that come from reducing the number of future infections until the vaccination target is reached to the incremental costs it would impose on the economy and finding the optimal stopping time before incremental costs start to exceed incremental benefits. I model the COVID-19 pandemic curve using the SIR (susceptible, infected, recovered) model widely used in epidemiology. I use estimates from the COVID literature to obtain the model parameters, such as the basic reproduction number that prevails with the social distancing measures currently in place, as well as estimates of what it will be with a nation-wide lockdown, similar to lockdowns implemented in Europe in Spring 2020.

The expected future monetary cost of the COVID pandemic is calculated from the following three components: (1) the loss of productivity due to missed work of the symptomatically ill; (2) the cost of medical interventions that could have been used elsewhere; and (3) the value of lives of the projected fatalities. The benefit of a lockdown is calculated based on reducing the number of new infections going forward, and therefore avoiding a portion of these costs. Obviously, the longer the lockdown lasts, the larger the reduction in the number of new cases it will achieve. If a policymaker's only objective were to minimize the attack rate (the fraction of the population that will become symptomatically ill), the optimal solution would be to extend the lockdown until everyone is vaccinated. However, with each additional week of a lockdown the additional reduction in future infections becomes smaller, and since the benefits should be balanced against the costs to

⁵<https://www.wsj.com/articles/long-a-holdout-from-covid-19-restrictions-sweden-ends-its-pandemic-experiment-11607261658>.

the economy, a lockdown should be optimally stopped sooner. Using a range of reasonable assumptions, I find that a lockdown that starts a week from now is optimal because it produces a positive net benefit, and its optimal duration is between two and four weeks, depending on assumptions. I estimate that if no additional restrictions are imposed, even with the vaccination program currently in place, the pandemic will cost an additional \$2.4 trillion going forward if the value of statistical life (VSL) is used to value life and \$619 billion if life is valued with discounted quality-adjusted life years (dQALY).

Evidence shows that the lockdown measures adopted in parts of the United States and Europe in Spring 2020, which included bans on large social gatherings, closures of public places such as gyms, schools, bars and entertainment venues, and shelter-in-place orders, were highly successful at reducing the virus transmission rate (e.g., Courtemanche et al. (2020) and Flaxman et al. (2020)). I estimate that if the United States imposed a nation-wide lockdown similar to the lockdowns in Europe, which, depending on the assumptions, would optimally last between two and four weeks, it will generate a net benefit of up to \$1.2 trillion, or 6% of GDP.

II. The cost-benefit analysis

A. Estimating the future cost of the COVID pandemic

In order to estimate the dollar cost of the COVID-19 pandemic in the U.S., I follow the methodology used in studies of the costs of seasonal and hypothetical pandemic influenza outbreaks (e.g., Molinari et al. (2007) and CEA (2019)).⁶

⁶Throughout the paper, the terms “flu” and “influenza” are used interchangeably.

A.1. Medical outcomes

An individual infected with the COVID-19 virus can have two outcomes: they can be asymptomatic or exhibit symptoms. Asymptomatic individuals do not miss work and do not incur any medical costs, although they can still infect others at the same rate as symptomatic individuals. Conditional on being symptomatic, an individual can have one of four progressively worse outcomes: (1) have mild symptoms and require no medical intervention, (2) have more severe symptoms and require an outpatient visit, (3) be hospitalized and survive, and (4) be hospitalized and die. Figure 1 plots the possible outcomes.

An important input into the analysis is the fraction of asymptomatic cases. Mizumoto et al. (2020) analyze the data from the quarantined Diamond Princess cruise ship and find that the asymptomatic fraction was 17.9%. However, given that the Diamond Princess sample consisted predominately of older adults, other studies have since estimated a higher fraction of asymptomatic infections among the general population. For example, Buitrago-Garcia et al. (2020) conduct meta-analysis of published papers using data around the world that they assess to be free of the sample selection bias. They report a higher summary estimate of the proportion of the population that become infected with the virus and remain asymptomatic throughout the course of the infection of 31%. CDC’s latest version of the “COVID-19 Pandemic Planning Scenarios” ⁷ also relies on meta-analysis of published papers to come up with an estimate for the asymptomatic fraction.⁸ I use the assumptions from Scenario 5, “Current Best Estimate,” that the asymptomatic fraction is 40%; it is derived as the mid-point of the estimates from published papers.⁹

Table I describes the probability that an infected person experiences each of the four possible outcomes of the disease as a function of their age and, when available, health risk status. Given that COVID risks increase with age, I divide the population into age groups (when an estimate for

⁷<https://www.cdc.gov/coronavirus/2019-ncov/hcp/planning-scenarios.html#five-scenarios>.

⁸In doing so, CDC acknowledges the limitations of the current studies: “The percent of cases that are asymptomatic, i.e. never experience symptoms, remains uncertain. Longitudinal testing of individuals is required to accurately detect the absence of symptoms for the full period of infectiousness.”

⁹This “best estimate” number aligns with estimates from Oran and Topol (2020), a meta-analysis that estimates the asymptomatic fraction to be 40% to 45%.

a particular age bin is not available from the literature, I calculate it by weighting the estimates for the overlapping age bins by the corresponding population fraction in each.) I obtain COVID hospitalization risks from Reese et al. (2020) and calculate the estimates for the older age bins using CDC’s table on relative hospitalization risks by age.¹⁰ I adjust these estimates for under-reporting by multiplying them by the ratio $2.5/7.7 = 0.32$ (Reese et al. (2020) find that hospitalized COVID cases are under-reported by a factor of 2.5 and overall COVID cases are under-reported by a factor of 7.7). Infection fatality rates (probability of dying conditional on being infected with COVID) are obtained from Levin et al. (2020), which is a meta-analysis of the literature and government reports that is restricted to studies of advanced economies, which includes only countries that currently belong in the Organization for Economic Cooperation and Development. In order to fill the more granular age bins in Table I, I also use the estimates from CDC’s COVID-19 Pandemic Planning Scenarios, “Current Best Estimate.”

Symptomatic individuals may fall into two groups: high- and low-risk. Patients who fall into high-risk health groups have pre-existing conditions that increase the likelihood of complications. The table provides cost estimates associated with each outcome for a symptomatic individual, as a function of age and health risk. Due to the lack of cost estimates specific to COVID infections and because COVID symptoms and the mode of transmission is similar to those of seasonal influenza,¹¹ I use the estimates for the proportion of high-risk individuals as well as medical and productivity costs from the seasonal influenza literature (Molinari et al. (2007) and CEA (2019)). However, early evidence indicates that COVID-19 may be more likely than influenza to leave survivors with long-term negative health effects,¹² which would cause me to underestimate the associated costs of an infection. Finally, for the calculation of the costs of lost productivity due to illness, I follow Barrot et al. (2020) and assume that a missed day of work represents productivity loss of \$520.

For the individuals who die, society loses some productivity due to their inability to work during the period of the illness and, more importantly, the value of life. Policymakers employ several

¹⁰Available from <https://www.cdc.gov/coronavirus/2019-ncov/covid-data/investigations-discover/hospitalization-death-by-age.html>.

¹¹See, e.g., the CDC description at <https://www.cdc.gov/flu/symptoms/flu-vs-covid19.htm>.

¹²See, e.g., <https://www.cdc.gov/coronavirus/2019-ncov/hcp/clinical-care/late-sequelae.html>.

methods to estimate the value of life. Perhaps the most commonly used is the value of statistical life (VSL), which is estimated from studies assessing how much money people are willing to pay to increase the probability of staying alive. Following CEA (2019), I use inflation-adjusted VSL values by age group obtained from Aldy and Viscusi (2008), who estimate them from the wage premia paid by riskier jobs.¹³ Because the value of medical costs are already factored into the value of life estimates, I do not add the medical costs for people who die. To calculate future costs of each pandemic management scenario considered, I calculate the total number of symptomatic individuals in each risk and age group that would fall into each of the four possible disease outcome categories and then multiply them by the associated costs, finally summing them up to obtain the total cost.

A.2. The evolution of the pandemic curve

I use the SIR model to project the number of new COVID-19 infections at a weekly frequency. The starting point is 1/07/2021 (this is week 0), and I use the initial conditions as of this date to project the further evolution of the pandemic in the United States. I calculate the forward-looking costs from this time on and ignore the costs already incurred. Given the requirement for sick people to self-isolate for 14 days, I assume that a newly infected person is contagious for two weeks, during which time they will infect R_0 other people at the beginning of the pandemic, when no one in the population has immunity. (R_0 is called the basic reproduction number.) The number of other people that a contagious person infects is assumed to be spread evenly across the two weeks. Per SIR model, I assume that a recovered individual develops immunity and will not get infected or infect others, and the currently ill cannot be re-infected.

In addition to the immunity acquired by the recovered individuals, I account for the additional contribution to the population immunity from the ongoing vaccination program. Two COVID vaccines are already being administered, with more vaccine candidates going through the FDA ap-

¹³While the authors are unable to estimate VSL for children, other studies obtain estimates from parents' willingness to pay for children's medical costs. The children's VSL estimate does not enter into the total cost calculation since COVID-19 studies assess a near-zero fatality risk for the younger age group.

proval process, and the stated goal to vaccinate 70% of the population¹⁴ is expected to be achieved by June 2021.¹⁵ I add the effect of vaccination to the SIR model by assuming that each person needs two vaccine doses spaced three weeks apart, at which point the vaccinated person is assumed to be fully immune and unable to spread the virus to others. I assume that vaccination starts with the most at-risk older population groups and progresses to younger groups,¹⁶ with an equal number of people being vaccinated each week. I further model vaccinations as having started on December 14, when first doses of the Pfizer vaccine were administered and assume that vaccination will be completed by May 31, with 70% of the U.S. population fully vaccinated.

To estimate the fraction of the population already recovered from COVID, it is important to account for under-reporting of COVID cases in the official statistics. I use the latest estimate of under-reporting from CDC, Reese et al. (2020), which analyzes four reasons for under-reporting— asymptomatic cases, symptomatic individuals not seeking medical attention, people seeking medical attention but not getting tested for COVID, and false negative test results—and estimates that due to these reasons, only one in 7.7 COVID cases ends up being detected and reported.¹⁷ Given the overwhelming under-reporting of COVID cases, I assume that the vaccination program will not distinguish between the individuals who have not yet had COVID and those already recovered and immune.

A critical input into the SIR model is the virus R_0 . CDC’s “current best estimate” for the no-intervention COVID R_0 for the U.S. is 2.5.¹⁸ However, increased sanitation, social distancing and the widespread use of face masks widely implemented in the United States were successful in reducing the virus reproduction number below this value. For example, Morley et al. (2020) study the effect of reduced personal mobility resulting from social distancing restrictions on the COVID

¹⁴<https://www.commonwealthfund.org/publications/issue-briefs/2020/dec/how-prepared-are-states-vaccinate-public-covid-19>.

¹⁵<https://www.cnn.com/2020/12/01/trump-covid-vaccine-chief-says-everyone-in-us-could-be-immunized-by-june.html>.

¹⁶This is consistent with the CDC recommendations: <https://www.cdc.gov/mmwr/volumes/69/wr/mm6949e1.htm>.

¹⁷As of January 7, 2021, CDC reports that there were 21.3 million COVID cases in the United States up to now, which implies that there were 163.7 million total infections after adjusting for under-reporting.

¹⁸<https://www.cdc.gov/coronavirus/2019-ncov/hcp/planning-scenarios.html#five-scenarios>.

reproduction number in several New York State counties. They use data from Unacast, a company that tracks and assigns letter grades to the reductions in mobility across various geographic areas; larger reductions in mobility are assigned higher grades. The figure presented on page 610 of the paper reports the effective reproduction rate that corresponds to each Unacast’s mobility-reduction grade (I will use Panel B of the figure that removes outliers from the data). U.S.-wide mobility reduction roughly corresponds to Unacast’s grade “D” assigned for a 40%–74% reduction in mobility. For example, Pishue (2020) finds that between March 14 and April 17 personal vehicle-miles traveled in the United States dropped by 46%, on average. Using a mobility index that aggregates cell phone data to capture changes in human movement over time, Archer et al. (2020) document a fluctuating but slightly larger drop in mobility, which is over 50% on average. Finally, Google’s COVID-19 Community Mobility Report for the United States reports a similar-magnitude decline in the number of visits to public spaces. According to Morley et al. (2020), the “D” grade corresponds to a reproduction number of roughly 1.75. Since the estimates in that paper were made during the early stages of the pandemic, when population-wide immunity was still low, I will use this number as my assumption for the basic reproduction number, R_0 , that prevails with the interventions currently already in place. This R_0 estimate matches the currently observed data very well. Specifically, after inputting the number of recovered and therefore immune individuals into my SIR model with this R_0 parameter, I can match the number of people infected with COVID in the previous week and the current effective reproduction number, R_t (this variable measures the number of other people an infected person infects on average at time t in the pandemic, when a subset of the population has already recovered and gained immunity).¹⁹

Figure 2 depicts a weekly-frequency projection of the number of new symptomatic COVID cases. It shows that with the current immune fraction of the population and the ongoing vaccination program, the number of new cases is projected to decline. Absent a lockdown, the pandemic is going to end roughly by mid-April 2021, and bring about 23.2 million additional symptomatic

¹⁹I estimate the current nation-wide R_t as the state-population-weighted average from the state-level median numbers reported on the website [rt.live](https://www.rtt.live) on January 7, 2021; the current R_t estimate is 1.04.

illnesses and 406 thousand additional deaths.²⁰ When the costs of symptomatic illnesses and the value of life are taken into account, these projections translate into a cost of \$2.42 trillion going forward, with medical costs and lost productivity contributing about 5% to this value and the rest attributed to the value-of-life losses.

B. Modeling the effect of a lockdown at different durations

By drastically reducing mobility, a lockdown holds the promise to significantly lower the virus reproductive number relative to the current value. It has been estimated that the Winter 2020 Wuhan lockdown reduced the COVID effective reproduction rate from above two to 0.3.²¹ Given that lockdowns are likely to be less restrictive and more leniently enforced in Western countries, the drop in R_0 is likely to be more modest. Studies that analyze the effect of the Spring 2020 lockdowns in the United States and in Europe using mobility data, such as Google Community Mobility Index and smartphone GPS location data, find that lockdowns led to significant reductions in spatial movements (e.g., Pepe et al. (2020)). Lockdowns in Western countries were also found to generate large reductions in the virus reproduction rate. Using hospitalization records, Salje et al. (2020) estimate that in France the lockdown reduced the reproduction number by 77%, from 2.90 to 0.67. Flaxman et al. (2020) perform a broader analysis of the effect on the Spring 2020 lockdown across 11 European countries using data on COVID-related deaths and find that lockdowns on average decreased the virus reproduction rate by 81% to an average value of 0.66 across these countries. Using a survey, Jarvis et al. (2020) assess that in the U.K. the Spring 2020 lockdown lead to a 73% reduction in the number of contacts, which they estimate to reduce the R_0 from 2.6 prior to lockdown to a value of 0.62. Given the previously discussed estimate of the no-intervention $R_0 = 2.5$ for the United States, the average of these percent reductions implies that a lockdown will produce $R_0 = 0.58$. However, to err on the conservative side and because the U.K. is most culturally similar to the United States, I will use the U.K. estimate and assume that a national lockdown in the

²⁰The projected fatality rate lower than the assumed average IFR because of the effect of the vaccination program that prioritizes the more vulnerable older population.

²¹<https://qz.com/1834700/rt-the-real-time-r0-guiding-how-to-lift-coronavirus-lockdowns/>.

U.S. will achieve $R_0 = 0.62$. In the sensitivity analyses, I use an even more conservative assumption that the basic reproduction number achievable with a lockdown is 25% higher, or 0.775.

I assume that if a lockdown were to be imposed, it would start a week from now, at the beginning of week 1. After a lockdown is lifted, the virus reproduction rate will revert to the pre-lockdown value. Figure 3 plots the incremental savings achieved from a lockdown as a function of the number of weeks that it is kept in place relative to the baseline of no lockdown depicted in Figure 2. The figure shows the savings increase with each additional week of a lockdown but at a declining rate.

B.1. Incremental cost of a lockdown

When assessing the incremental impact of a lockdown on the economy, it is important to note that even in the absence of lockdown orders, a global pandemic depresses economic activity relative to normal times due to voluntary social distancing. Chen et al. (2020) collect a number of high-frequency indicators of economic activity in the United States and Europe, such as electricity usage and mobility indicators, as well as additional economic indicators for the United States, such as unemployment insurance claims and employee-hours worked for small and medium sized businesses that employ hourly workers. The paper documents large reductions in mobility and economic activity even before the adoption of stay-at-home orders and nonessential business closures, and more so in places with more severe COVID outbreaks, indicating that people voluntarily limited their activities in order to protect themselves and others from the virus. Similarly, IMF (2020) uses high-frequency mobility indicators and shows that mobility decreases not only as a result of lockdown orders but also in response to rising COVID cases. The paper estimates that lockdown orders contributed about 40% and voluntary social distancing about 60% to the total decrease in mobility during lockdowns in advanced economies (Figure 2.2 of IMF (2020)).

I combine several estimates for the incremental cost that a lockdown would impose on the U.S. economy. Using a set of assumptions for which economic sectors would be affected and by how much, OECD (2020) estimates that for the G7 economies national lockdowns would cause annual GDP growth to decline by up to 2 percentage points per month of a lockdown. This translates into a

GDP decline of \$107 billion per week for the United States ($0.5\% \times \$21.43$ trillion). However, this estimate is not incremental to the natural decline of economic activity caused by the pandemic. If, as discussed above, voluntary social distancing during the pandemic contributes about 60% to the reduction in economic activity, in line with the results discussed above, the incremental economic cost of an imposed lockdown will be about 40% of that estimate, or about \$43 billion per week.

Scherbina (2020) analyzes which sectors of the economy will be incrementally affected by a lockdown and by how much and also accounts for the additional costs of productivity losses caused by homeschooling demands on working parents. She estimates the incremental cost of a lockdown to be \$35.79 billion per week.

Barrot et al. (2020) obtain a slightly lower estimate for the lockdown cost, \$32 billion per week. Specifically, they estimate the number of workers in each U.S. state employed in the sectors that were closed in that state's Spring 2020 lockdown and who are unable to work from home (the total for the country is estimated to be 12.6 million workers) and multiply this number by the share of U.S. GDP per worker per week (\$2,600) to arrive at the final estimate.

These three estimates are relatively close, and I will use the average of these estimates of \$36.93 billion per week, when assessing the optimal lockdown duration. It must be noted that a number of non-economic costs and benefits of a lockdown have not been considered in the calculation above, as discussion in the Sensitivity Analyses subsection. Therefore, I also consider a more conservative assumption for the incremental cost of a lockdown, assuming that it is 25% higher than the estimate above.

B.2. Optimal lockdown duration

Optimally, the lockdown should end before its incremental benefit falls below its incremental cost to the economy. Figure 4 plots the incremental benefit of each additional week of a lockdown against its incremental cost to the economy. The incremental benefit line is declining, consistent with Figure 3 that shows that the incremental savings level off over time. The incremental savings line

crosses the incremental cost line after four weeks. Therefore, four weeks is the optimal lockdown duration. After subtracting the incremental cost of the lockdown incurred over this time ($4 \times \$36.93$ bil.) from the incremental savings realized from preventing a subset of future infections, I estimate the associated net benefit relative to the baseline scenario of no lockdown to be \$1.18 trillion, which is about 6% of GDP.

C. Sensitivity analyses

Given the uncertainty associated with some of my model inputs, I consider some alternative assumptions. Specifically, I consider changing the methodology for valuing life that would assign an even lower value to the lives of the elderly who are at a higher risk of COVID deaths, a lower assumption for lockdown effectiveness, a higher incremental cost, and a lower IFR.

C.1. Valuing life with discounted quality-adjusted life years

So far, I have used VSL to value life. However, health-adjusted life years (HALY) has been gaining popularity in recent years. Here I consider the quality-adjusted life years (QALY) methodology, which is perhaps the most widely used type of HALY (e.g., Neumann and Greenberg (2009)), Gold et al. (2002), Hubbell (2006) and Prieto and Sacristán (2003)). The morbidity or quality-of-life component is captured by a quality-of-life weight (QOL), which takes values between 0 and 1, with 0 representing death and 1 perfect health. The number of quality-adjusted life years (QALY) lived in one year is equal to the individual's QOL in that year. I follow Sassi (2006) to calculate the discounted value of all future quality-adjusted life years (dQALY):

$$dQALY = \sum_{t=a}^{a+L} \frac{QOL_t}{(1+r)^{t-a}}, \quad (1)$$

where a is the current age, L is the residual life expectancy at age a , QOL_t is the expected health-related quality of life in year t , and r is the discount rate. I use a discount rate of 3% as is common in

the literature (e.g., Sassi (2006) and Hubbell (2006)). The life expectancy for the U.S. population is obtained from Table VI of the 2020 National Vital Statistics Reports. I use cross-sectional average QOL weights by age estimated by Nyman et al. (2007) for the U.S. population using response data for the Medical Expenditure Panel Survey (Table 1 of the paper).

To translate the value of life into monetary terms when evaluating cost-effectiveness of medical interventions, the Institute for Clinical and Economic Review uses a range of \$50,000-\$150,000 per QALY. Song and Lee (2018) conduct a survey of the general Korean population and find that the willingness to pay for a cure treatment is more than twice as high as for a non-cure treatment. Since my objective is to value the lives of potential COVID fatalities, I will use the highest value of this range, that is \$150,000 per QALY. The estimates of QALY-based monetary values of life are provided in Table II, estimated for the lowest bound of each age range.

Despite their increasing popularity, quality-adjusted life-year valuations (and HALY's more generally) have been criticized on technical and ethical grounds. By comparing dQALY values in Table II to VSL values in Table I, it can be seen that the former assign increasingly lower values to older age groups. The reason is that older people have fewer years of life remaining, and these years are of a worse quality due to deteriorating health. Likewise, dQALY would assign a lower value of life to people with disabilities and chronic health conditions relative to healthy people of the same age because the lower embedded QOL values.²² On the technical side, a utility function has to have a very specific and, perhaps, unrealistic functional form, with features such as independence between life years and health status, in order to be consistent with the QALY maximization (e.g., Pliskin et al. (1980) and Prieto and Sacristán (2003)).

When the dQALY methodology is used to value life, absent a lockdown, the pandemic is projected to cost \$619 billion going forward, with lost productivity and medical expenses representing 20% of this total and the value-of-life losses making up the rest. Table III presents the estimates of the optimal lockdown duration and the associated net savings by using dDALY instead of VSL to value life. It shows that a lockdown is still optimal under all assumptions considered, but its

²²See, e.g., Gold et al. (2002) for a discussion of the ethical challenges associated with using health-adjusted life expectancy to estimate the value of life.

length is reduced by two weeks compared to when VSL is used. The net savings, computed as the incremental benefit achieved from reducing the number of future infections and deaths minus the incremental cost of the lockdown, are now substantially lower because of the lower value that this method assigns to the lives of older COVID victims.

C.2. Other incremental impacts of a lockdown

New literature has emerged that studies the non-economic effects of the Spring 2020 lockdowns. However, at this time, it may be too speculative to assign a dollar value to these additional effects that the literature finds since they are still imprecisely estimated.

Mental health. There is evidence that symptoms of depression and anxiety have increased during the lockdown. Pieh et al. (2020) evaluate several mental health and well-being indicators through an online survey with 1,006 respondents in the United Kingdom during the COVID-19 lockdown and find that the prevalence of depressive and anxiety symptoms increased relative to the pre-pandemic period. However, it is unclear from the study how much of this effect can be attributed to the pandemic itself and whether an incremental impact of a lockdown is positive or negative. Furthermore, in what could be interpreted as another negative indicator for mental health, the American Medical Association reports that the number of opioid and other drug-related deaths has increased during the Covid pandemic.²³ However, more research needs to be done to identify how much of the overdose increase can be attributed to the Spring lockdown.

Despite the evidence that lockdowns may have adverse effects on mental health, data does not show a positive association between lockdowns in suicides. Faust et al. (2020) study records from the Massachusetts Department of Health Registry of Vital Records and Statistics from January 2015 through May 2020 and find that suicide rates have actually decreased to 0.67 per 100,000 person-months from 0.81 per 100,000 person-months during the same period of 2019. Similarly, German data shows that suicides declined during the Spring 2020 lockdown relative to the same

²³<https://www.ama-assn.org/system/files/2020-11/issue-brief-increases-in-opioid-related-overdose.pdf>.

period of 2019, which may be partly explained by the lockdown's positive incremental effect on mental health, for example by reducing anxiety about being infected, eliminating commute to work, and allowing more time with family.²⁴ More research is needed to more precisely isolate the incremental effect of lockdowns on mental health.

Traffic injuries and fatalities. A clear benefit of a lockdown is a reduction in traffic and the ensuing decline in the number of traffic injuries and fatalities, which were estimated to fall by half in California during the Spring 2020 lockdown (Shilling and Waetjen (2020)). For the country as a whole, the National Highway Traffic Safety Administration estimates that for the April–June 2020 period, 302 fewer traffic deaths were recorded relative to the same period in 2019.²⁵ This reduction in traffic deaths translates into a VSL benefit of \$202 million for each week of the lockdown (using the population-average VSL of \$8.68 million), and the benefit is even higher if the medical costs of caring for the injured are taken into account.

Environmental impact. Another benefit of reduced traffic is less pollution, which has health benefits. Venter et al. (2020) utilize a network of air quality stations distributed across 34 countries to measure the air quality during the lockdown period up until May 15, 2020. They estimate that the air quality has substantially improved, which resulted in large public health benefits. The study estimates that a total of 49,900 pollutant-related deaths and 89,000 pediatric asthma emergency room visits were avoided in the 34 countries in the study sample. Similarly, Archer et al. (2020) document that the reduction in personal mobility caused by the COVID pandemic lead to a significant decrease in NO₂ concentrations in the United States.

Crime. Spring lockdowns are documented to have reduced the overall crime rate but increased the incidence of domestic violence. Citing the “opportunity theory” of crime, which posits that restrictions on mobility and social interactions will present fewer opportunities for criminal activity, the United Nations Office on Drugs and Crime (UNODC (2020)) investigates crime rates around the world and documents that reported incidents of robbery, theft and burglary declined by more than 50

²⁴<https://www.dw.com/en/is-social-distancing-during-coronavirus-causing-more-suicides/a-53584282>.

²⁵<https://www.reuters.com/article/us-health-coronavirus-usa-traffic-exclus/u-s-traffic-deaths-fell-after-coronavirus-lockdown-but-drivers-got-riskier-idUSKBN26M6KR>.

per cent in most countries, and the declines were larger in countries with stricter lockdown regimes (however, the report notes that some of the decline may be attributed to under-reporting). The number of homicides has also greatly declined, but only in some countries, and started rebounding once lockdown measures were relaxed.

These findings are largely corroborated in Bullinger et al. (2020), who analyze crime data and 911 calls made in Chicago during the Spring 2020 stay-at-home orders. They find that overall crime-related arrests decreased by 57%²⁶ and 911 calls decreased by 6% during this period. However, 911 calls reporting domestic violence have increased by 7%, though domestic-violence-related arrests decreased by 27%. The authors speculate that the decrease in domestic violence arrests may be partly explained by under-reporting. The increase in the number of 911 calls reporting domestic violence during the pandemic is consistent with evidence presented in other papers (e.g., Leslie and Wilson (2020)).

Reduction in overall mortality. Kung et al. (2020) show that the New Zealand lockdown lead to an 11% decrease in the weekly death rate relative to historical trends. The authors provide evidence that this reduction was largely explained by the reduction in seasonal influenza and pneumonia, though other factors, such as fewer traffic deaths, reduced air pollution and lower occupational hazards, likely played a role as well.

Additional incremental effects. A lockdown would likely have additional shorter- and longer-term costs and benefits. One clear benefit is that an increased reliance on technology will help boost future GDP growth. An increased ability to work remotely will allow more individuals to enter the workforce, and companies will be able achieve a higher return on investment by saving on real estate leases and travel costs. Moreover, with less commuting and reduced traffic, employees may gain productive hours.

Lockdowns also have a number of negative incremental effects, in addition to the ones already mentioned. Reduced access to medical services may lead to negative health consequences in the

²⁶This decrease may be partly explained by a new policy to limit or halt prosecutions of low-level, non-violent offenses, adopted by the Chicago Police Department on March 20 in an effort to protect first responders.

longer term. A lower education quality may result in a marginally less productive future workforce. Lockdowns may cause an incremental increase in the number of bankruptcies, resulting in dead-weight losses associated with a less efficient re-deployment of business assets. In the sensitivity analyses presented in Table III, I make a more conservative assumption for the incremental cost of a lockdown by increasing it by 25%, to \$46.16 billion a week. The table shows that for the main results, the higher incremental cost does not shorten the optimal lockdown duration but reduces the estimated net savings.

C.3. Reducing the IFR

The IFR estimates in the paper are based on meta-analyses of academic papers and government data for developed economies. The implied population-weighted average IFR of 1.33% is consistent with a number of other estimates for the COVID mortality rate. However, I also try a more conservative estimate, by assuming that the IFR for each age bin is reduced by 25%, thus resulting in a population-weighted average IFR of 1.00%. Under this assumption, absent a lockdown, the future death toll is projected to be almost 305 thousand, and the future cost of the pandemic to be \$1.84 trillion, with medical costs and lost productivity representing 6% of this number and the rest attributed to value-of-life losses. When dQALY are used to value life, the pandemic is projected to cost \$490.39 billion going forward, with medical and productivity costs representing 24% of this number.

Table AII in the Appendix reports the estimates of the optimal lockdown duration and the corresponding net savings for this IFR assumption. Compared to the main results, the optimal lockdown duration is shortened by one to two weeks when VSL is used to value life and by one week for two sets of assumptions when dQALY is used. And since projected fatalities are lower, the estimated net benefits of a lockdown are reduced.

D. Limitations

I use a number of parameters reported in the COVID literature as inputs into my analysis, such as the magnitude of under-reporting of cases, the fraction of asymptomatic cases, the hospitalization rate, and the infection fatality ratio (IFR). Therefore, I would like to caveat the findings by pointing out that these inputs may be imprecisely estimated. For example, robustness analyses show that the optimal lockdown duration may be shorter if the IFR is lower. If the speed of vaccinations is slower than what I assume, or if vaccinations do not prioritize the older population, the optimal lockdown duration may be longer. Additionally, early evidence is emerging on the late sequelae of COVID-19.²⁷ If the long-term consequences of COVID are severe enough to result in large medical expenses, productivity losses, and shortened life spans, the optimal lockdown duration should be longer than estimated in order to help further minimize the number of new infections.

Another critical parameter is the reduction in the virus transmission that can be achieved with a national lockdown. I rely on estimates obtained from studies of the Spring 2020 European lockdowns, which may not be perfectly applicable to the United States. In the sensitivity analyses, I consider a more conservative assumption.

The incremental costs that a lockdown would impose on the economy may be imprecisely estimated. In the sensitivity analyses, I use a more conservative cost estimate and still find that a lockdown would be beneficial, albeit with a shorter optimal length in some specifications. It is also possible that the incremental costs to the economy may be increasing with each subsequent week of a lockdown, perhaps through the higher likelihood of bankruptcies and the associated dead-weight losses. In that case, the optimal lockdown duration may be shorter than estimated.

New literature has emerged on the non-economic costs and benefits of a lockdown, such as its impact on crime, air pollution, mental health, etc. Overall, this literature finds a number of positive or ambiguous incremental effects. Presently, due to the lack of precise estimates, it is unclear how to assign a monetary value to these incremental effects. However, if those were taken into

²⁷See, e.g., <https://www.cdc.gov/coronavirus/2019-ncov/hcp/clinical-care/late-sequelae.html>.

consideration, they may help reduce the estimated cost of a lockdown, which is calculated purely as the cost to economic activity.

Finally, I do not model the worsening of medical outcomes as a function of the number of new infections. A high number of new infections may overwhelm the medical system and result in a higher likelihood for severe medical outcomes. Taking this effect into account would make a lockdown more beneficial and potentially extend its optimal duration.

III. Conclusion

To my knowledge, this paper presents the first attempt to examine whether it is beneficial for the United States to follow the lead of a number of European countries and order a national lockdown and to estimate its optimal duration while using current conditions and explicitly modeling the ongoing vaccination program. I find that even with ongoing vaccinations a lockdown will generate significant net benefits and that it should optimally last up to four weeks. When I use a more conservative approach to valuing lives, using discounted quality-adjusted life-years that assigns a significantly lower values to the lives of older individuals, I find that a lockdown is still beneficial but that its optimal duration decreases to two weeks. Additionally, when I consider more conservative assumptions for the lockdown effectiveness, its incremental cost to the economy, and IFR, I still find that a lockdown would be optimal, albeit at a shorter duration.

A number of additional arguments can be made in favor a lockdown. First, the vaccination program is currently progressing at a substantially slower speed than initially promised. With the vaccination end-goal shifted further into the future, additional non-pharmaceutical interventions would be even more helpful. Second, adding to the costs of the pandemic is the emerging evidence of serious long-term complications resulting from COVID infections. If those lead to large productivity losses and medical expenses and shortened life spans, the associated costs should be added to the estimated cost of the pandemic. Third, reports are currently emerging that hospitals

are preparing to ration care due to an influx of COVID cases.²⁸ While currently outside of the model, a lockdown will help reduce the pressure on the medical system and result in better medical outcomes for COVID patients. Fourth, the literature on the Spring 2020 lockdowns documents a number of positive effects for public health and well-being, such as reduced traffic accidents, lower pollution, and lower mortality due to influenza and pneumonia. While some effects, such as domestic violence and mental health are negative, the overall effect is likely positive. Taken together, these arguments imply higher lockdown benefits and lower incremental costs than those used in the paper and point to a longer optimal lockdown duration.

Despite the obvious benefits, there is widespread reluctance to impose additional mobility restrictions in the United States. COVID presents a low threat to the young and healthy but a high threat to the elderly and those with underlying health conditions. And while a lockdown may not benefit each individual it will benefit society as a whole, as the analysis in this paper shows.

²⁸<https://www.healthline.com/health-news/hospitals-may-have-to-ration-care-as-covid-19-hits-record-highs>.

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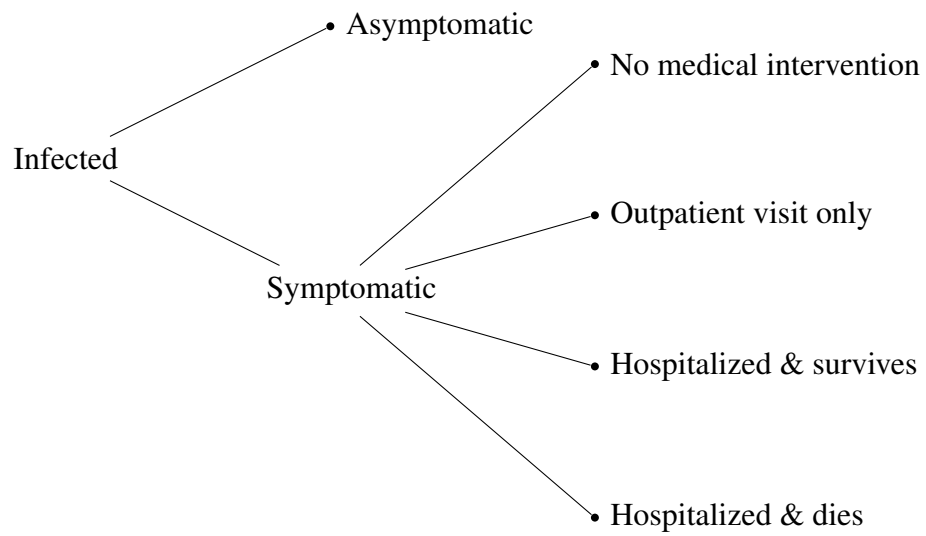


Figure 1. Outcomes for an infected person.

NOTES The figure presents possible outcomes for a person infected with the COVID-19 virus.

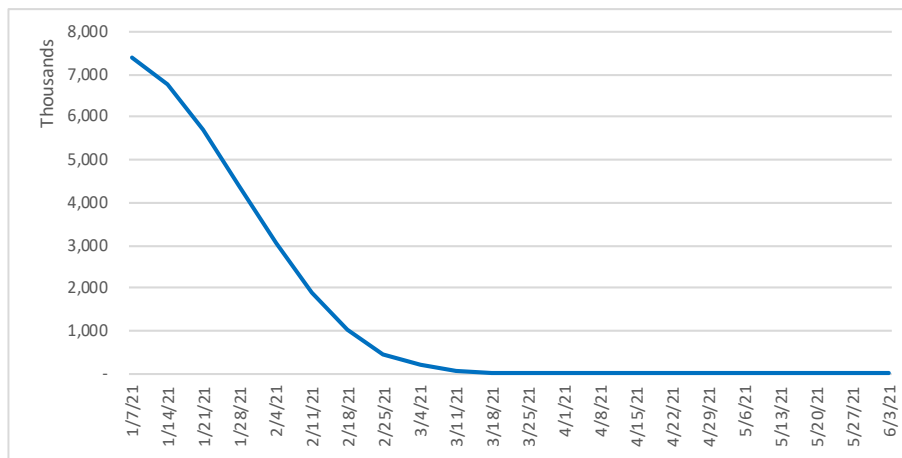


Figure 2. New symptomatic cases with no lockdown.

SOURCES CDC COVID Data Tracker, Census Bureau, author's calculations. SIR model inputs described in Table AI of the Appendix. **NOTES** The figure plots the predicted number of new symptomatic cases produced by SIR model. The model includes the effect of additional immunity acquired through vaccinations.

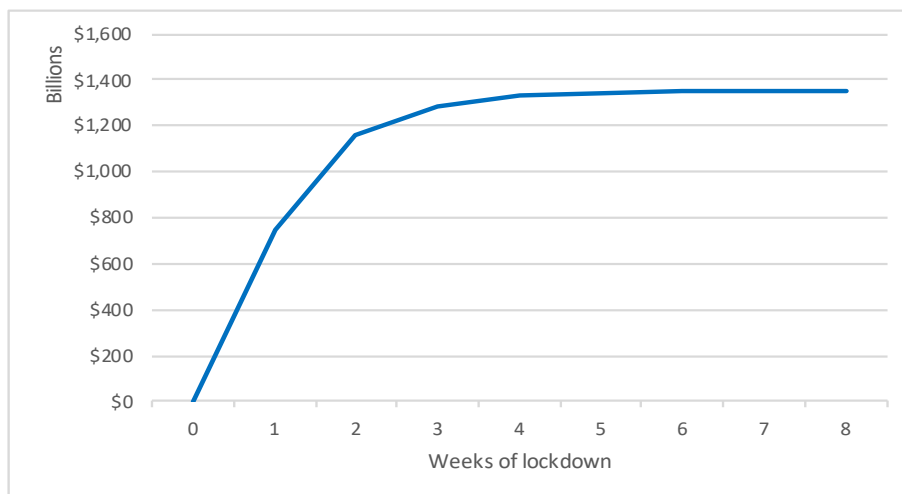


Figure 3. Savings from a lockdown as a function of its duration.

SOURCES CDC COVID Data Tracker, Census Bureau, author's calculations. SIR model inputs and other inputs used in the calculations are described in Table AI of the Appendix. **NOTES** The figure plots projected savings from a lockdown as a function of the number of weeks it is kept in place, assuming that it is imposed a week from now.

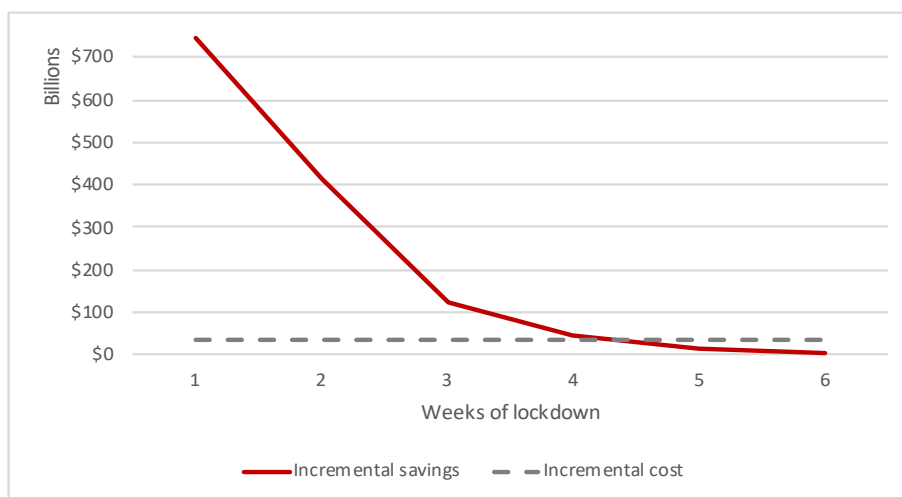


Figure 4. Incremental costs and savings of each additional week of a lockdown.

SOURCES CDC COVID Data Tracker, Census Bureau, author's calculations. Specific sources for SIR model inputs and incremental savings and cost estimates of a lockdown are provided in Table AI of the Appendix. **NOTES** Assuming that a lockdown is imposed a week from now, this figure plots projected incremental costs and savings of extending lockdown by another week, to the number of weeks specified on the horizontal axis.

Table I
Risks Associated with COVID-19 Infection by Age Group

	Age Group						
	0-19	20-44	45-54	55-64	65-74	75-84	≥85
% of US population	25%	33%	13%	13%	9%	5%	2%
OUTCOME PROBABILITIES							
Clinical outcomes							
Prob. of hospitalization	1.29%	2.27%	4.23%	6.17%	13.96%	22.34%	60.00%
Probability of dying (IFR)	0.003%	0.020%	0.423%	0.500%	2.500%	8.500%	28.300%
Outcomes for symptomatic patients							
Proportion high-risk	8%	15%	24%	33%	51%	51%	51%
Outpatient visit							
- low-risk patients	32%	32%	32%	31%	62%	62%	62%
- high-risk patients	77%	63%	63%	63%	82%	82%	82%
COST ESTIMATES							
Case not medically attended							
Medical cost (all risk)	\$5	\$5	\$5	\$5	\$5	\$5	\$5
Lost productivity (all risk)	\$260	\$260	\$260	\$260	\$520	\$520	\$520
Outpatient visit							
Low-risk medical cost	\$161	\$212	\$233	\$254	\$410	\$410	\$410
Low-risk lost productivity	\$520	\$520	\$780	\$1,040	\$1,560	\$1,560	\$1,560
High-risk medical cost	\$1,098	\$1,227	\$1,234	\$1,240	\$806	\$806	\$806
High-risk lost productivity	\$2,080	\$1,040	\$1,560	\$2,080	\$3,640	\$3,640	\$3,640
Hospitalization							
Low-risk medical cost	\$25,408	\$32,174	\$34,960	\$37,745	\$19,379	\$19,379	\$19,379
Low-risk lost productivity	\$4,680	\$6,240	\$6,500	\$6,760	\$6,760	\$6,760	\$6,760
High-risk medical cost	\$70,938	\$80,760	\$75,334	\$69,908	\$28,346	\$28,346	\$28,346
High-risk lost productivity	\$11,960	\$10,920	\$11,700	\$12,480	\$9,360	\$9,360	\$9,360
Fatalities							
Low-risk lost productivity	\$4,680	\$6,240	\$6,500	\$6,760	\$6,760	\$6,760	\$6,760
High-risk lost productivity	\$11,960	\$10,920	\$11,700	\$12,480	\$9,360	\$9,360	\$9,360
Value of statistical life (\$, mil.)	5.76	12.34	10.05	7.75	5.29	5.29	5.29

SOURCES For hospitalization risks: Reese et al. (2020) and CDC; for IFR: Levin et al. (2020) and CDC's "COVID-19 Pandemic Planning Scenarios," Scenario 5; for high- and low-risk probabilities and cost estimates: Molinari et al. (2007) and CEA (2019); for productivity losses: Barrot et al. (2020); for VSL: Aldy and Viscusi (2008) and CEA (2019); author's calculations. **NOTES** This table presents the risks and per-person medical risks and productivity costs associated with various outcomes of the COVID-19 infection.

Table II
Value of Discounted Quality-Adjusted Life Years, by Age

	Age Group						
	0-19	20-44	45-54	55-64	65-74	75-84	≥85
Value of dQALY (\$, mil.)	4.05	3.44	2.73	2.22	1.71	1.14	0.82

SOURCES Nyman et al. (2007) for QOL weights; National Vital Statistics Reports for life expectancy by age; author's calculations. **NOTES** This table presents the dollar value of discounted quality-adjusted life years, calculated at the lower boundary of each age group. The discount rate is 3% per year, and the dollar value of QALY is \$150,000.

Table III
Sensitivity of the optimal lockdown duration to alternative assumptions

Lockdown R_0	Assumptions		Optimal lockdown duration	Net savings relative to no-lockdown baseline (\$, billion)
	Life is valued with	Incremental cost of lockdown		
0.620	VSL	\$36.93 bil.	4 weeks	\$1,184.89
		\$46.16 bil.	4 weeks	\$1,147.96
	dQALY	\$36.93 bil.	2 weeks	\$220.56
		\$46.16 bil.	2 weeks	\$202.09
0.775	VSL	\$36.93 bil.	4 weeks	\$1,051.19
		\$46.16 bil.	4 weeks	\$1,014.26
	dQALY	\$36.93 bil.	2 weeks	\$182.31
		\$46.16 bil.	2 weeks	\$163.85

SOURCES Author's calculations. **NOTES** This table presents the optimal lockdown duration as a function of the assumptions listed in the table. The right-hand column presents the incremental net savings of a lockdown of optimal length calculated as its benefits minus the associated costs incurred over the lockdown duration.

Appendix for

“Could the United States benefit from a lockdown? A cost-benefit analysis”

Table AI
Summary of variables, sources, and assumptions used in the paper

COVID basic reproduction number with social distancing measures currently in place, R_0 (1.75). Sources: Morley et al. (2020) for the COVID reproduction number as a function of reduced mobility and Archer et al. (2020), Pishue (2020), and Google’s COVID-19 Community Mobility Report for mobility reduction estimates for the United States.

COVID effective reproduction number, R_t (1.04). Source: website rt.live and author’s calculations.

COVID basic reproduction number with a national lockdown (0.62). Source: Jarvis et al. (2020). A 25% higher estimate, 0.775, is used in sensitivity analyses.

COVID case under-reporting (true number of COVID cases is 7.7 times higher than official statistics). Source: Reese et al. (2020).

Number of COVID cases. Source: CDC COVID Data Tracker, adjusted for under-reporting.

Vaccination. Assume that vaccinations started on 12/14/2020 and will be completed by 05/31/2020, with the objective to get 70% of the population fully vaccinated by that date. Vaccination involves two vaccine doses, administered three weeks apart. The vaccinated cannot get infected with or spread the virus to others. Vaccination is assumed to progress at a constant speed, with the same number of people immunized each week, from oldest to youngest population groups. Due to the inability to determine who has already recovered from COVID, vaccinations include recovered individuals as well.

Fraction of asymptomatic cases (40%). Source: CDC “COVID-19 Pandemic Planning Scenarios,” Scenario 5: “Current Best Estimate.”

Medical costs and outcomes (as reported in Table I). Sources: For hospitalization risks: Reese et al. (2020), Table 1, with missing age bins augmented by CDC’s estimates on relative hospitalization risks by age (<https://www.cdc.gov/coronavirus/2019-ncov/covid-data/investigations-discovery/hospitalization-death-by-age.html>), with all estimates multiplied by 0.32 to adjust for hospital and overall case under-reporting per Reese et al. (2020); for IFR: Levin et al. (2020) and the CDC “COVID-19 Pandemic Planning Scenarios,” Scenario 5: “Current Best Estimate.” A 25% lower IFR estimate for each age bin is used in sensitivity analyses. For high- and low-risk probabilities and cost estimates: Molinari et al. (2007) and CEA (2019), Table 2.

VSL (as reported in Table I). Sources: Aldy and Viscusi (2008) and CEA (2019).

dQALY (as reported in Table II). Sources: Nyman et al. (2007) for QOL weights, National Vital Statistics Reports for life expectancy by age, 3% discount rate, \$150,000 value per QALY, author's calculations.

Incremental cost of a lockdown (\$36.93 billion per week). Source: average estimate from OECD (2020), Scherbina (2020), and Barrot et al. (2020). A 25% higher estimate, \$46.16 billion per week, is used in sensitivity analyses.

Table AII
Sensitivity of the optimal lockdown duration to alternative assumptions, with IFR reduced by 50%

Lockdown R_0	Assumptions		Optimal lockdown duration	Net savings relative to no-lockdown baseline (\$, billion)
	Life is valued with	Incremental cost of lockdown		
0.620	VSL	\$36.93 bil.	3 weeks	\$866.76
		\$46.16 bil.	2 weeks	\$791.13
	dQALY	\$36.93 bil.	2 weeks	\$159.31
		\$46.16 bil.	1 week	\$104.04
0.775	VSL	\$36.93 bil.	3 weeks	\$759.12
		\$46.16 bil.	2 weeks	\$676.47
	dQALY	\$36.93 bil.	2 weeks	\$129.02
		\$46.16 bil.	1 week	\$82.51

SOURCES Author's calculations. **NOTES** This table is an update of Table III in the main text based on the assumption that IFR for each age bin is reduced by 25%. It presents the optimal lockdown duration as a function of assumptions listed in the table. The right-hand column presents the incremental net savings of a lockdown of optimal length calculated as its benefits minus the associated costs incurred over the lockdown duration.