EVALUATING COVID-19 LOCKDOWN AND REOPENING SCENARIOS FOR GEORGIA, FLORIDA, AND MISSISSIPPI

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DISCLAIMER: This work is a preliminary study and will be updated as further information becomes available. We welcome feedback and suggestions for further policy options to test that may be of interest.

ABSTRACT

Background: The United States has been particularly hard-hit by COVID-19, accounting for almost one third of global cases and one quarter of global deaths from the disease that have been reported as of May 10, 2020. We extended our agent-based model for COVID-19 transmission [1] to study the effect of alternative lockdown and reopening policies on disease dynamics in Georgia, Florida, and Mississippi. Specifically, for each state we simulated the spread of the disease had the state enforced its lockdown approximately one week earlier than it did. We also simulated Georgia's reopening plan under various levels of physical distancing if enacted in each state, making projections until June 15, 2020.

Methods: We used an agent-based SEIR model that uses population-specific age distribution, household structure, contact patterns, and comorbidity rates to perform tailored simulations for each region. The model was first calibrated to each state using publicly available COVID-19 death data as of April 23, then implemented to simulate given lockdown or reopening policies.

Results: Our model estimated that imposing lockdowns one week earlier could have resulted in hundreds fewer COVID-19 related deaths in the context of all three states. These estimates underscore that early action may be imperative in the event of a second wave of infection. Further, simulating Georgia's plan to reopen as of April 27, our model found that a reopening policy that includes physical distancing to ensure no more than 25% of pre-lockdown contact rates at reopened businesses could allow limited economic activity to resume in any of the three states, while also eventually flattening the curve of COVID-19-related deaths by June 15, 2020.

Introduction

SARS-CoV-2 – the virus responsible for the novel coronavirus disease 2019 (COVID-19) – has resulted in an estimated 3.1 million reported cases and an estimated 213,000 reported deaths worldwide as of May 10, 2020 [2]. The United States (U.S.) has been particularly hard-hit by the infection, accounting for about one third of all cases and more than one quarter of all deaths worldwide that have been reported as of May 10, 2020 [2]. Recent evidence suggests that this is partly due to states' slow responses in acting to stop the spread of the virus, meaning eventual state lockdowns began weeks after the disease had likely already been spreading rapidly across the country [3]. Here, we use an agent-based simulation to estimate how enacting state-wide lockdowns one week earlier could have curbed transmission of SARS-CoV-2 in Georgia, Florida, and Mississippi.

Further, despite having substantial numbers of infected, as of the week of April 27, many states in the U.S. have already partially reopened businesses and/or let lockdown orders expire, with other states soon to follow [4–6]. In some states, these restrictions are being lifted in direct opposition to federal guidelines that recommend states achieve declines in reported COVID-19 case counts for two weeks before relaxing restrictions [2, 7]. We use our agent-based model to estimate both (1) the effect that proposed reopening plans might have on the transmission of the virus, and (2) the level of physical distancing that must be maintained as businesses reopen in order to prevent further widespread outbreaks of COVID-19. We simulated Georgia's reopening policy to estimate its impact on COVID-19 related deaths under low, medium, and high increase in contact scenarios. The same policy scenarios were simulated for Florida and Mississippi. All projections extend through June 15, 2020.

Model description

Our model, detailed in Fig. 1, is an agent-based Susceptible, Exposed, Infected, Recovered (SEIR) model. It simulates the contact of each individual with others at home, work, school, and in the community; tracks the exposure of each individual to the disease through these contacts; and simulates their progression through the disease course after becoming infected. For work contacts in particular, we associate each agent with a "sector", as defined by the Bureau of Economic Analysis (BEA) [8], depending on their sampled occupation. Agents within the same sector may have "work contacts" only with other agents in their sector. To instantiate the model for a new region, we use census data to create a simulated population matching the demographics of the state as well as the occupations held, combined with data on diabetes and hypertension prevalence for that state. To fit the model to a given state, we calibrate the model's internal parameters such that the number of coronavirus-related deaths produced by the simulation match what has been officially reported over the time period for which data are available. For fitting, daily data on reported deaths were collected from the Johns Hopkins Coronavirus Resource Center [2], as of April 23, 2020. Remaining data sources were collected at either the state-level or country-level, as noted in Table 1. For more details about the model, please see [1].

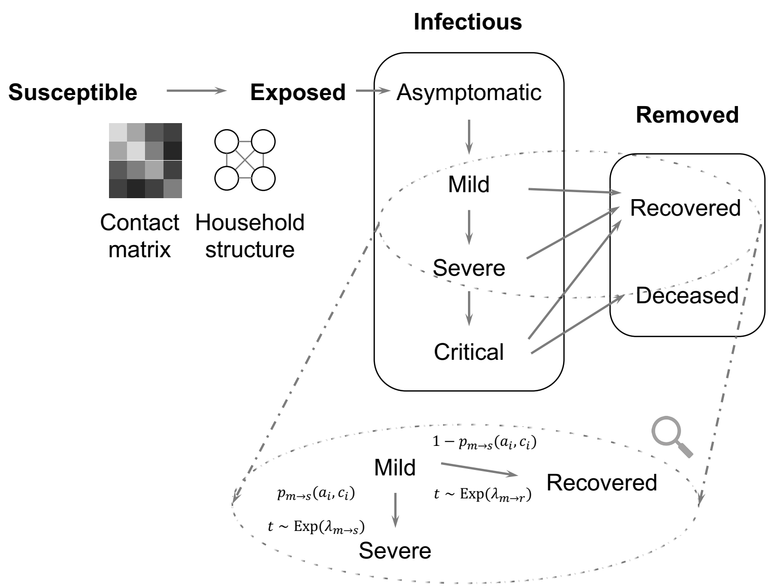

Figure 1: We use a modified SEIR model, where the infectious states are subdivided into levels of disease severity. The transitions are probabilistic, and there is a time lag for transitioning between states. For example, the magnified section shows the details of transitions between mild, recovered, and severe states. Each arrow consists of the probability of transition (e.g., $p_{m \to s}(a_i, c_i)$ to progress from mild to severe), as well as the associated time lag for the transition (e.g., the time t to progress from mild to severe is drawn from an exponential distribution with mean $\lambda_{m \to s}$). In addition, a_i and c_i denote the age and set of comorbidities of the infected individual i, respectively.

Scenarios simulated for Georgia, Florida and Mississippi

We simulated a total of six scenarios for the states of interest, Georgia (GA), Florida (FL) and Mississippi (MS):

- **Round One: Full Lockdowns or Release.**

Table 1: Demographic and comorbidity data sources. *Centers for Disease Control and Prevention

Type	Level	Source	Citation
Contact Matrices	National	Prem et al.	[9]
Age, Household, Occupation Distributions	State	Census Microdata	[10]
Diabetes Rates by Age	State	CDC*	[11]
Hypertension Rates by Age (GA, MS)	State	United Health Foundation	[12]
Hypertension Rates by Age (FL)	State	Smith et al.	[13]

1. **Actual lockdown:** Lockdown was started on the actual date of the shelter-in-place state order and was maintained until the end of the simulation on June 15, 2020 (yellow). The actual lockdown date for Georgia, Florida, and Mississippi was April 3, April 3, and April 1 respectively.
2. **Earlier lockdown:** Lockdown was started on the shelter-in-place order date of New York City (March 23, 2020), and was maintained until the end of the simulation on June 15, 2020 (blue).
3. **Early lift:** Lockdown was started on the actual date of the shelter-in-place state order, but was lifted on April, 23, though schools were kept closed (grey).

- **Round 2: Georgia Reopening Plan.** As of April 27, Georgia has allowed several businesses to reopen subject to employee distancing restrictions, including bars, restaurants, movie theaters, gyms, bowling alleys, salons, and beauty shops [4, 5]. All health centers were also allowed to reopen without distancing restrictions [4]. Further, the official state shelter in place order expired on April 30, 2020 [14]. We simulated this scenario by (1) sending back to work those agents who fall under BEA codes: 111CA, 22, 23, 311FT, 42, 445, 452, 485, 621, 622, 623, 624, 713, 722, and 81, matching the sectors that the governor allowed to reopen, and (2) allowing increased contact by the general population due to their visiting open businesses. However, due to the uncertainty about whether businesses would actually reopen, or whether the population would continue to physically distance themselves as diligently after lifting of the shelter in place order, we simulated three possible reopening scenarios with differing levels of post-lockdown contact increase. In all scenarios, the lockdown was started on the actual shelter-in-place order for the state, listed businesses were reopened on April 27, and lockdown was lifted on April 30, 2020 (though schools remain closed).

4. **Low increase in contact:** When listed businesses were reopened on April 27, those employees had 25% of their pre-lockdown contact with other employees. When lockdown was lifted on April 30, the general population had 20% of their pre-lockdown contact (blue).
5. **Medium increase in contact:** When listed businesses were reopened on April 27, those employees had 50% of their pre-lockdown contact with other employees. When lockdown was lifted on April 30, the general population has 50% of their pre-lockdown contact (yellow).
6. **High increase in contact:** When listed businesses were reopened on April 27, those employees had 100% of their pre-lockdown contact. When lockdown was lifted on April 30, the general population had 100% of their pre-lockdown contact (grey).

Primary results

Round One

Figs. 2, 3, and 4 show the trajectories for each scenario in Round One. In each graph, we show both the median trajectory (over 500 simulations), and the 25th and 75th percentiles. Thus, the shaded area represents our projected interquartile range for the cumulative number of documented deaths per state. We found that, in our simulation, lifting lockdowns early resulted in a rapid increase in documented deaths, while an early start to the lockdown averted a substantial number of documented deaths compared to the "Actual lockdown" scenario. The projected number of documented deaths in each scenario and for each state are shown in Table 2.

Table 3 provides a comparison between the number of projected documented deaths under the earlier lockdown scenario and the most recently available actual COVID-19 death data [2] in Georgia, Florida, and Mississippi. In all three states, our model found that enacting lockdown just one week earlier could have prevented hundreds of COVID-19 related deaths as of May 10.

Table 2: Projected number of documented deaths by June 15, 2020 (median value over 500 runs), in the earlier lockdown (LD) scenario, as compared to actual reported deaths, and in early lockdown lift scenario, as compared to an extended shelter-in-place. For all three states, earlier lockdown and early lockdown lift were simulated to occur on March 23 and April 23, respectively. The numbers reported in parentheses represent the interquartile range.

Scenario	Georgia	Florida	Mississippi
Actual LD start + extension	1,838 (1,004–2,922)	1,919 (988–3,014)	397 (212–639)
Earlier LD start + extension	378 (206–591)	312 (147–525)	94 (52–160)
Actual LD start + early LD lift	13,149 (7,953–17,935)	20,485 (13,206–28,455)	3,971 (2,723–5,159)

Table 3: Projected number of documented deaths by May 10 (median value over 500 runs) in the earlier lockdown scenario, as compared to actual reported deaths. For all three states, the earlier lockdown start date was set to March 23, 2020. The numbers reported in parentheses represent the interquartile range.

	Georgia	Florida	Mississippi
Actual documented COVID-19 deaths	1,381	1,715	421
Simulated documented deaths under earlier lockdown	348 (190–544)	284 (133–483)	87 (47–145)

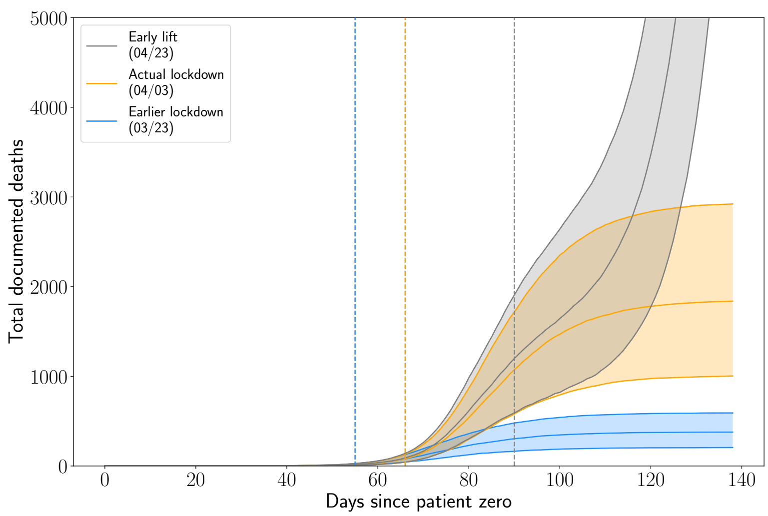

Figure 2: Total cumulative documented deaths in each scenario for Georgia. The blue dashed line indicates the start of the "Earlier lockdown" on March 23, 2020. The yellow dashed line indicates the start of the lockdown (April 3, 2020) for the "Actual lockdown" and "Early lift" scenarios. The grey dashed line indicates the simulated "Early lift" date on April 23, 2020.

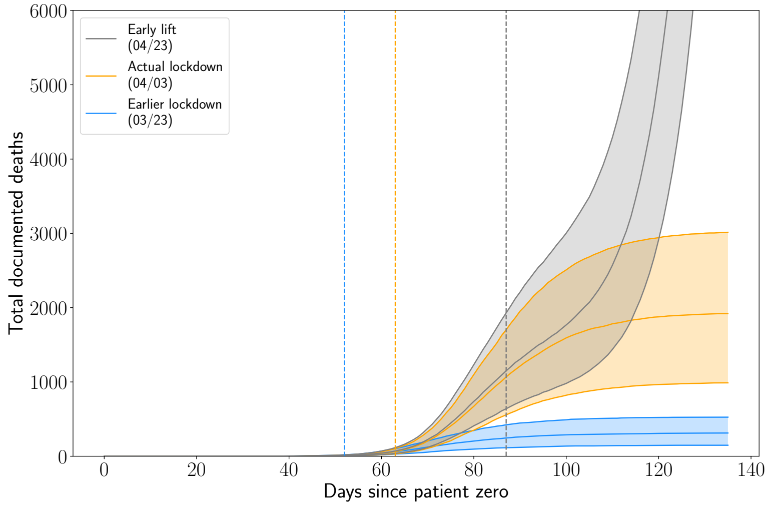

Figure 3: Total cumulative documented deaths in each scenario for Florida. The blue dashed line indicates the start of the "Earlier lockdown" on March 23, 2020. The yellow dashed line indicates the start of the lockdown (April 3, 2020) for the "Actual lockdown" and "Early lift" scenarios. The grey dashed line indicates the simulated "Early lift" date on April 23, 2020.

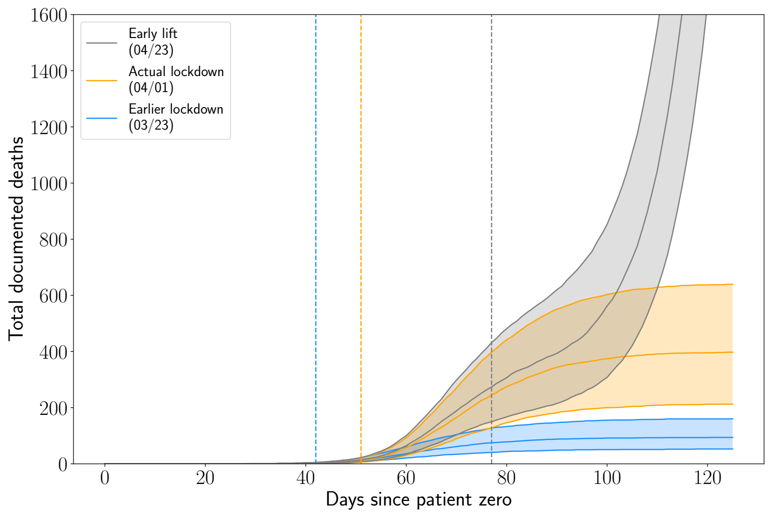

Figure 4: Total cumulative documented deaths in each scenario for Mississippi. The blue dashed line indicates the start of the "Earlier lockdown" on March 23, 2020. The yellow dashed line indicates the start of the lockdown (April 1, 2020) for the "Actual lockdown" and "Early lift" scenarios. The grey dashed line indicates the simulated "Early lift" date on April 23, 2020.

Round Two

Figs. 5, 6, and 7 show the trajectories for simulating Georgia's reopening plan for each of the three states. In each graph, we show both the median trajectory (over 500 simulations), as well as the 25th and 75th percentiles. Thus, the shaded area represents our projected interquartile range for the cumulative number of documented deaths per state. We found that under all scenarios, there was risk of causing hundreds more deaths than if lockdowns were maintained. However, also notable is that under the "low increase in contact" scenario in which physical distancing ensured no more than 25% pre-lockdown contact, the number of new daily deaths approached 0 by June 15. This is in contrast to both the medium increase scenario (in which the number of new daily deaths were either near constant, or still slowly climbing) and the high increase scenario (in which deaths were increasing exponentially). The projected number of documented deaths in each scenario and for each state are shown in Table 4.

Table 4: Projected number of documented deaths by June 15 (median value over 500 runs), under various reopening scenarios, in comparison of an extended shelter-in-place policy. For all three states, business were reopened on April 27 and lockdown was lifted was on April 30 in the simulation. The numbers reported in parentheses represent the interquartile range.

Scenario	Georgia	Florida	Mississippi
Lockdown maintained	1,838 (1,004–2,922)	1,919 (998–3,014)	213 (398–640)
Low increase in contact	2,350 (1,310–3,563)	2,537 (1,273–4,106)	592 (340–904)
Medium increase in contact	2,712 (1,604–4,236)	3,296 (1,799–5,382)	747 (453–1,180)
High increase in contact	7,154 (4,279–9,748)	11,418 (7,106–15,523)	2,738 (1,865–3,463)

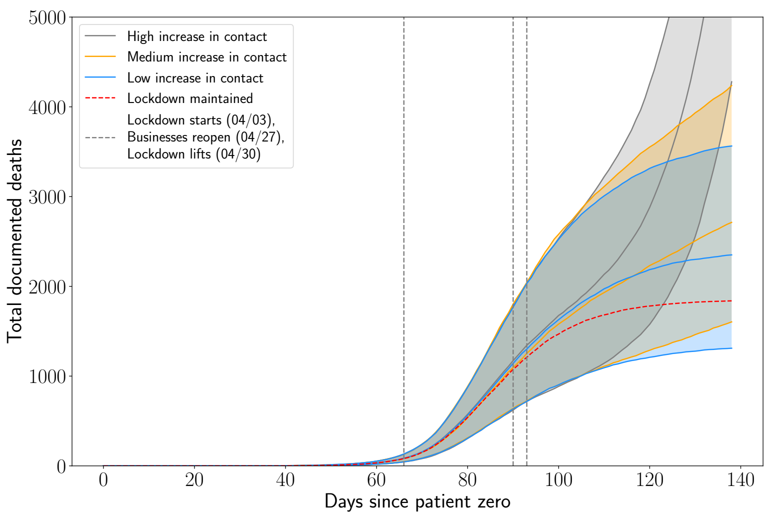

Figure 5: Total cumulative documented deaths for Georgia's reopening plan scenarios simulated for Georgia. The first vertical dashed line indicates the start of the lockdown (April 3, 2020). The second and third vertical dashed lines indicate the date of business reopening (April 27, 2020) and lockdown lift (April 30, 2020). The red dashed line shows the median projected documented deaths under the scenario in which businesses stayed closed and the lockdown was maintained (Fig. 2, yellow).

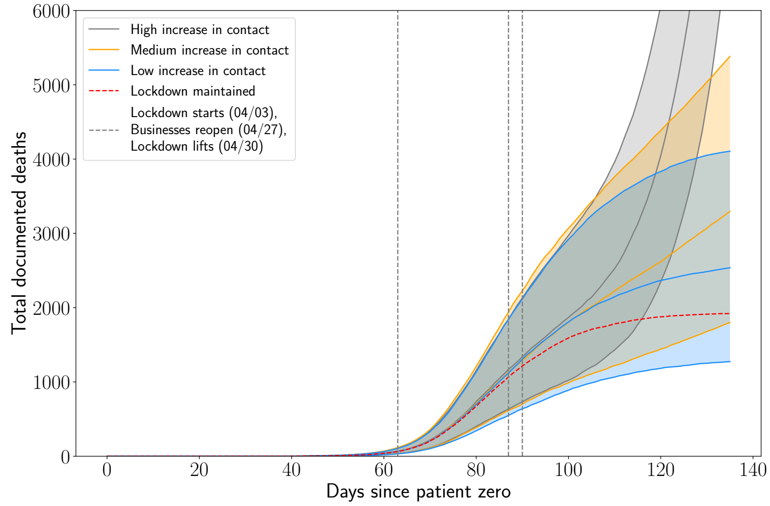

Figure 6: Total cumulative documented deaths for Georgia's reopening plan scenarios simulated for Florida. The first vertical dashed line indicates the start of the lockdown (April 3, 2020). The second and third vertical dashed lines indicate the date of business reopening (April 27, 2020) and lockdown lift (April 30, 2020). The red dashed line shows the median projected documented deaths under the scenario in which businesses stayed closed and the lockdown was maintained (Fig. 3, yellow).

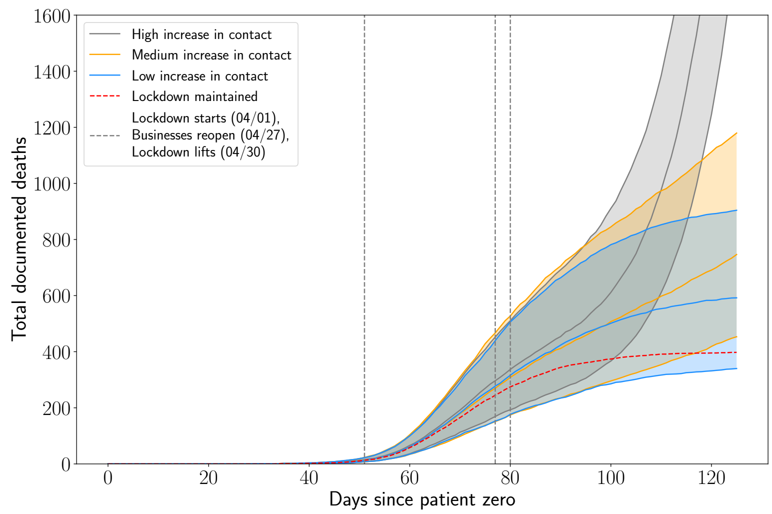

Figure 7: Total cumulative documented deaths for Georgia's reopening plan scenarios simulated for Mississippi. The first vertical dashed line indicates the start of the lockdown (April 1, 2020). The second and third vertical dashed lines indicate the date of business reopening (April 27, 2020) and lockdown lift (April 30, 2020). The red dashed line shows the median projected documented deaths under the scenario in which businesses stayed closed and the lockdown was maintained (Fig. 4, yellow).

Discussion

Our simulations provide estimates about the relative impact of different policy decisions on the projected number of COVID-19 related deaths. First, our results suggest that locking down even one week earlier in any of the three states could have saved on the order of hundreds of lives. Such early action will be critical in the event of a "second wave" of infections, something that epidemiologists warn could happen, even without full relaxations of physical distancing, given the expected low prevalence of immunity in the population [15, 16].

Second, our simulations of reopening scenarios under various levels of contact increase provide multiple insights. Importantly, our model found that if businesses strictly enforced physical distancing rules *and* the general public practiced their own strict physical distancing, such that the population's effective contact was reduced to 20–25% of their pre-lockdown rate, then the number of daily new documented deaths could substantially decrease by June 15, 2020. In contrast, if this effective contact was 50% of its pre-lockdown rate, our simulations showed constant or increasing daily new deaths by June 15, and at 100% contact, deaths increased exponentially. This suggests that in order to safely reopen even limited sectors of the economy, as outlined in [4, 5], it will be critical to adopt a temporary new normal in which the population's contact is greatly reduced (20–25% of pre-lockdown rate) by means such as wearing personal protective equipment and practicing strict physical distancing.

Additionally, our results suggests that greater testing capacity could assist in determining an appropriate date for releasing the lockdown. More specifically, our model still estimated that even the low increase in contact scenario (20–25% pre-lockdown rate) could result in hundreds more documented deaths than if the lockdown was maintained. This is because whenever the reopening occurred in our model, some asymptomatic carriers inevitably returned to the public, spread the infection, and ultimately caused more documented deaths. The number of asymptomatic carriers that return to the public is directly related to the number of new daily infections occurring when the lockdown is released. In our simulations, that number of new daily infections was still large (i.e., on a steep part of the curve) when the lockdown was released, leading eventually to a larger number of documented deaths than in extended lockdown scenarios. This suggests that having sufficient testing capacity at the time of reopening would be highly beneficial for two reasons: (1) it would allow policymakers to more accurately estimate how many asymptomatic carriers they expect to return to the population *before* making a reopening decision, and (2) *after* reopening, it would allow those asymptomatic carriers to be detected and isolated quickly.

These results provide useful insights about how decisions to enact lockdowns or reopen businesses could affect the health of the populations of Georgia, Florida, and Mississippi. However, like all simulations, our results should be considered as one input of many when making complex policy decisions.

Regarding the choice of timing for our simulated lockdown lifts, we used the latest information available in the press at the time the simulations were run. As more announcements are made by public officials across all states, our simulations can be updated to reflect, in each locality, the current evolution of the outbreak/local infection profile, the timing of reopening decisions, and the types of policies that are recommended in the post-lockdown phase.

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Appendix

Model fitting

The three parameters which must be tuned are: (1) p_{inf}, the probability of transmission given contact between an infected and susceptible individual; (2) t_0, "day zero" of the infection, which is not exactly known in most regions but must be tuned since it exerts a large impact on the trajectory of cases and deaths, due to rapid doubling times; (3) d_{mult}, which addresses remaining differences in the rate of mortality between locations of interest that are *not* captured by demographic factors in the model (e.g., the impact of greater pollution rates, or availability of hospital beds). $d_{\text{mult}} = 1$ corresponds to the COVID-19 mortality rate in New York since the model's age- and comorbidity-specific COVID-19 mortality rates were calibrated using data from that region [17, 18]. The parameters used for each state are shown in Table 5.

Table 5: Well-fitting parameters used to simulate the infection in each state.

State	p_{inf}	t_0	d_{mult}
Georgia	0.0229	Jan. 29	2.0
Florida	0.0210	Feb. 1	1.5
Mississippi	0.0240	Feb. 11	1.5

Validation

Our model closely matched the actual number of documented deaths, up to the most recent data available at the time of calibration (April 23, 2020). Moreover, we cross-referenced in Table 6 our projections for the "actual lockdown" scenario, by comparing against the cumulative number of documented deaths projected by three other models (as of April 23, 2020).

Thus, in the baseline scenario, all of the interquartile ranges projected by our model are aligned with the confidence intervals and point estimates of other publicly available and widely referenced models.

Table 6: Projected number of documented deaths in Georgia, Florida, and Mississippi, in the scenario where lockdown is maintained, in comparison with three other models. The projection is by May 12, 2020 for UT Austin, and by June 15, 2020 for IHME and MIT ORC. For UT Austin, the provided range of values is determined over 10 distinct runs. For IHME, the numbers reported in parentheses represent the 95% confidence interval. In our model, the numbers reported in parentheses represent the interquartile range. Finally, the publicly available MIT ORC output does not include any measure of uncertainty in death estimates.

Model	Georgia	Florida	Mississippi
UT Austin	(930-1723)	(993-1,644)	(203-434)
Us (May 12)	1,575 (852-2,513)	1,619 (834-2,553)	348 (185-556)
IHME	2,253 (990-6,252)	1,620 (999-3,381)	400 (208-1,014)
MIT ORC	1280	2144	777
Us (June 15)	1,838 (1,004-2,922)	1,919 (988-3,014)	397 (212-639)