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Estimating the Costs and Benefits of Supported Quarantine and Isolation in Massachusetts: The Missing Link in Covid-19 Response

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Abstract

The slow rollout of vaccines against SARS-CoV2, the virus that causes Covid-19 disease, and the emergence of viral variants that threaten vaccines' efficacy demonstrate the urgent need to bolster non-vaccine public health strategies to mitigate viral transmission. Quarantine and isolation are critical epidemic mitigation strategies wherein exposed or infected individuals, respectively, stay apart from others until they are no longer contagious. For SARS-CoV-2, the CDC recommends quarantine and isolation periods ranging from 7-14 days. Successfully completing this period of separation may prove too challenging for many individuals. Challenges may include forfeiting wages, forgoing procurement of basic necessities, and failing to fulfill family or community obligations. "Supported" quarantine and isolation refers to public programs that aim to help individuals overcome these challenges by providing financial incentives and wraparound services so that they can successfully complete separation periods and stop transmission of the virus. The purpose of this paper is to estimate the need for a supported quarantine and isolation program in Massachusetts and to describe a budgeting model to help the state calculate the costs of instituting them, compared to the costs of not providing them, for the duration of the SARS-CoV2 epidemic.

To assess the need for supported quarantine and isolation programs we reviewed the literature on successful support programs and interviewed public health practitioners working directly with infected individuals through the Massachusetts contact tracing program. We found three main drivers of failed quarantine and isolation: the need to go to work to maintain salary, the need to purchase essential necessities, and the need for social services counseling. Our model estimates the costs of addressing these challenges, through both home-based and facility based programs. We assessed that providing these supports would result in a weighted-average cost of $430/person. Using current projections of when the epidemic will resolve and the number of new cases per day averaged over the time period from March-December 2020, our model estimates providing these services to infected individuals and their contacts would be in the range of $300-570 million, depending on the trajectory of infections over the next 211 days and assumptions regarding the number of contacts per infected individual. In addition, we modeled the medical care costs of failed quarantines and isolation, in which onward transmission of the virus is not interrupted. Each Covid-19 case is associated with ~$2,500/person in medical care expenses.[1] The model estimates how sensitive direct medical costs are to the Effective Reproduction Number, (R_t), or the average number of people an infected person will in turn infect. A supported quarantine program that reduces infection transmission can offer savings in direct medical costs. For example, if a supported quarantine program could reduce an average R_t of 1.09—the average R_t of the SARS-CoV2 epidemic in Massachusetts through 2020—to 1.06, this intervention could save $610 million in medical costs, exceeding the estimated cost of the program at this level of incidence and transmission. While estimated savings are particularly pronounced when high levels of transmission are brought down, even at low levels of transmission, a reduction in R_t is associated with lower direct medical costs for payors.

[1] Bartsch, Sarah M., Marie C. Ferguson, James A. McKinnell, Kelly J. O'Shea, Patrick T. Wedlock, Sheryl S. Siegmund, and Bruce Y. Lee. "The Potential Health Care Costs And Resource Use Associated With COVID-19 In The United States." *Health Affairs* 39, no. 6 (April 23, 2020): 927–35. https://doi.org/10.1377/hlthaff.2020.00426.

Part I. The case for supported quarantine/isolation

Introduction

The U.S. is now at the most critical moment in the COVID-19 epidemic, breaking records for highest daily mortality every four days, and rapidly approaching 500,000 dead and 25 million infected. The development of vaccines has shown us there is a light at the end of the tunnel but the slow and chaotic roll out of vaccination programs highlights the urgent need to bolster our non-vaccine related public health mitigation strategies in the interim.

At this point in the epidemic, the core elements of the public health strategy required to mitigate this outbreak are well known. One of these core elements is contact tracing. The goal of contact tracing is to rapidly identify people who are infected with the SARS-CoV-2 virus and anyone they may have exposed to it, and then to keep them separate from others to prevent onward transmission of the disease. [2] Contact tracing is a powerful mitigation strategy that has been deployed successfully in a number of countries. However, it has been underutilized across the US and has not met its potential as a disease control strategy for several reasons. Paramount among them has been a lack of investment to support the practical challenges individuals face in adhering to isolation and quarantine guidelines.

This paper describes the primary support services individuals need in order to successfully complete quarantine or isolation according to COVID-19 response guidance and analyzes the costs of providing these support services compared to the costs and ramifications of inaction.

Quarantine and isolation practices have been used for centuries to mitigate the spread of infectious diseases.[3] They involve keeping individuals who may have been exposed to a contagious infection away from others, including household members. Those who are known to have an infection are asked to *isolate* from others. Those who have been in close contact with a confirmed infected person, but who are not themselves confirmed to be infected, are asked to *quarantine*. Quarantine programs were used successfully to combat the spread of Ebola in 2014[4] and SARS in the early 2000s.[5] For the COVID-19 pandemic, countries including Japan, New Zealand, Hong Kong, South Korea, and Singapore have used

[2] CDC. "COVID-19 and Your Health." Centers for Disease Control and Prevention, February 11, 2020. https://www.cdc.gov/coronavirus/2019-ncov/if-you-are-sick/quarantine.html.

[3] Conti, A.A. "Quarantine Through History." *International Encyclopedia of Public Health*, 2008, 454–62. https://doi.org/10.1016/B978-012373960-5.00380-4.

[4] "Use of Group Quarantine in Ebola Control — Nigeria, 2014." Accessed December 16, 2020. https://www.cdc.gov/Mmwr/preview/mmwrhtml/mm6405a3.htm.

[5] "SARS | Isolation and Quarantine Factsheet | CDC." Accessed December 16, 2020. https://www.cdc.gov/sars/quarantine/fs-isolation.html#SARS.

contact tracing and isolation to help reduce the spread of infection.[6] In the US, the CDC has recommended the use of isolation and quarantine for a period of 10-14 days, or as short as 7 days if an individual obtains a negative test result.

However, for most individuals and families, maintaining quarantine or isolation is a tall order. It may require an individual to forfeit a paycheck, lose a job, miss school, leave urgent medical issues unattended and be unable to care for others. Moreover, Covid-19 has most affected those individuals for whom adhering to quarantine and isolation is most difficult. Individuals in communities hardest hit by the pandemic suffer from crowded living conditions, food scarcity, and lack of support services such as child or elderly care. Public health authorities may attempt to offer support by providing resources, such as wage replacement, grocery delivery, and childcare to improve compliance with quarantine orders. But if these resources are scarce, a large proportion of the afflicted population cannot maintain quarantine and isolation for the required time period.

Failing to provide supportive resources for marginalized populations to assist with quarantine and isolation augments the risk of Covid-19 becoming a virus that falls even more heavily on communities that already face the greatest disparities related to Covid-19 (and may face delays in access to vaccinations). In this paper, we argue that this is the time to aggressively introduce public support programs to ensure safe and effective quarantine, both to reduce the spread of disease and to prevent the emergence of hotspots which are likely to be a major vector for the ongoing transmission of disease until herd immunity is achieved.

What is quarantine and isolation? How does it fit into a Covid-19 response strategy?

A successful public health strategy to prevent the spread of Covid-19 involves four elements:

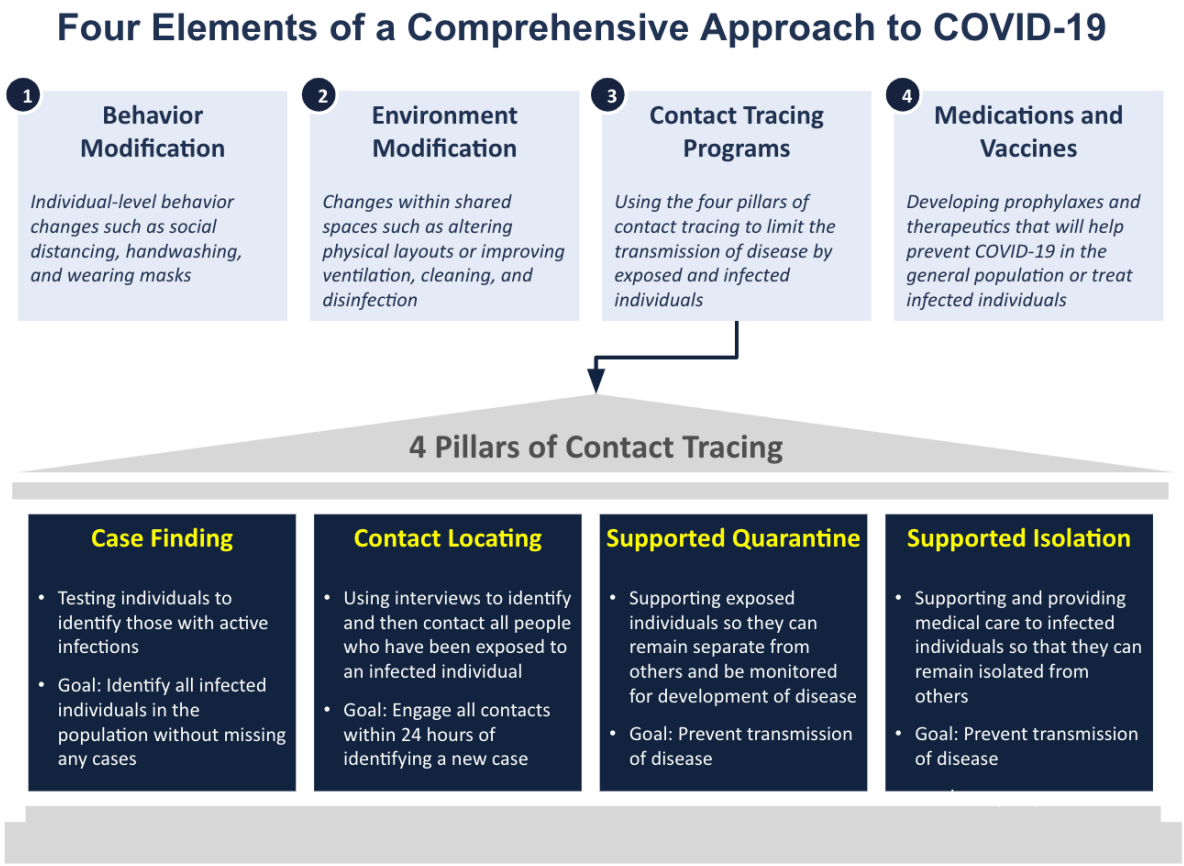
1. **Behavior modifications:** Individual-level behavior changes such as social distancing, handwashing, and mask-wearing.
2. **Environment modifications:** Alterations of shared spaces such as changing layouts of shared workspaces and improving ventilation, air filtration, and disinfection practices.
3. **Contact tracing programs:** Utilizing the four pillars of contact tracing, described and pictured below, to limit the transmission of Covid-19 by exposed and infected individuals.
4. **Medications and vaccines:** Developing prophylaxes and therapeutics that either prevent Covid-19 infections within the general population or can be used to treat infected individuals.

Quarantine and isolation fall under the contact tracing element. Contact tracing in turn rests upon four pillars:

1. **Case finding:** Case finding is defined as identifying individuals infected with Covid-19. The goal of case finding is to identify every new case before the virus is transmitted to others.

[6] Han, Emeline, Melisa Mei Jin Tan, Eva Turk, Devi Sridhar, Gabriel M Leung, Kenji Shibuya, Nima Asgari, et al. "Lessons Learnt from Easing COVID-19 Restrictions: An Analysis of Countries and Regions in Asia Pacific and Europe." *The Lancet* 396, no. 10261 (November 2020): 1525–34. https://doi.org/10.1016/S0140-6736(20)32007-9.

2. **Contact locating:** Contact locating is the process of identifying individuals who may have come into contact with a person infected with Covid-19 such that they were at risk of becoming infected.
3. **Supported quarantine:** Quarantine requests are often "supported," meaning public authorities provide resources that enable at-risk individuals to more easily adhere to a quarantine period. This may include social and material services, including making available residential facilities for individuals to stay in during the quarantine period.
4. **Supported isolation:** As in supported quarantine, the goal of "supported isolation" is to provide information and resources to infected individuals so they can successfully keep away from others until they are no longer infectious. However, supported isolation includes monitoring of individuals' health status so they can quickly receive medical attention if their condition worsens.



Massachusetts has invested in the expansion of testing (including testing sites and the laboratory infrastructure) and has increased its testing capacity over time. The state has also invested heavily in the second pillar, establishing a statewide contact locating program wherein public health authorities notify close contacts of infected persons to ask them to quarantine.[7] However, while contact tracers ask at-risk

[7] "Learn about the Community Tracing Collaborative | Mass.Gov." Accessed December 16, 2020. https://www.mass.gov/info-details/learn-about-the-community-tracing-collaborative.

and infected individuals to quarantine/isolate for 14-days, there has been little movement to provide support to make adherence to such requests easier (pillars 3 and 4).

How to implement supported quarantine and isolation?

There are many historical examples of supported quarantine. For instance, during the 2003 SARS epidemic, Taiwan required compromised individuals to enter quarantine, providing a stipend and wraparound services, including day care for children and other social service supports.[8] Canada initially resisted providing support to those asked to quarantine but eventually changed course, rolling out a minimum stipend to anyone being asked to forego work to quarantine.[9]

Presently, several countries are running supported quarantine programs to manage the COVID-19 pandemic. New Zealand - one of the most successful countries to date in minimizing the death toll from the virus - asks all infected individuals to either enter a quarantine facility, where their basic needs and healthcare are provided, or to quarantine at home. If they choose a facility, most New Zealanders are exempt from paying for these services, which cost $3,100 per person.[10] In South Korea, individuals quarantining at home receive "comfort packages" which contain groceries and hygiene essentials.[11] Taiwan quickly implemented an aggressive quarantine program early into the pandemic, offering a stipend, hygiene products, and entertainment subscriptions to those asked to isolate[12] Recently, some countries including Great Britain have introduced mandatory quarantines in subsidized hotels for international travelers. In comparison, states do not offer similar programs, although there is precedent for local initiatives (e.g. Alameda County in California).[13]

To make quarantines work and mitigate the spread of an infection, public health authorities must seek to improve individual compliance. Unfortunately, research on drivers of quarantine compliance is limited

[8] "Use of Quarantine to Prevent Transmission of Severe Acute Respiratory Syndrome --- Taiwan, 2003." Accessed December 16, 2020. https://www.cdc.gov/mmwr/preview/mmwrhtml/mm5229a2.htm.

[9] DiGiovanni, Clete, Jerome Conley, Daniel Chiu, and Jason Zaborski. "Factors Influencing Compliance with Quarantine in Toronto During the 2003 SARS Outbreak." *Biosecurity and Bioterrorism: Biodefense Strategy, Practice, and Science* 2, no. 4 (December 2004): pg 268. https://doi.org/10.1089/bsp.2004.2.265.

[10] "Welcome Pack | Managed Isolation and Quarantine." Accessed December 16, 2020. https://www.miq.govt.nz/being-in-managed-isolation/entering-isolation/welcome-pack/welcome-pack/.

[11] "Global Learnings from South Korea: Protecting Health Care Workers From COVID-19 – Ariadne Labs COVID-19 Response." Accessed December 16, 2020, pg 21. https://covid19.ariadnelabs.org/global-learnings-south-korea/

[12] Lee, Yimou. "Taiwan's Carrot-and-Stick Approach to Virus Fight Wins Praise, but Strains Showing." *Reuters*, March 27, 2020. https://www.reuters.com/article/us-health-coronavirus-taiwan-quarantine-idUSKBN21E0EE.

[13] Stieg, Cory. "Could You Get Paid to Quarantine during the COVID-19 Pandemic? Some Local Governments Are Already Doing It." CNBC, September 2, 2020. https://www.cnbc.com/2020/09/02/getting-paid-to-quarantine-during-the-covid-19-pandemic.html.

and mostly qualitative or survey-based, largely because we have experience with very few international epidemics to begin with.[14] However, even out of the limited literature, a few themes have emerged:

1. Wage replacement programs

Loss of income is one of the most frequently cited reasons individuals use to explain their inability or unwillingness to adhere to quarantine measures. Thus, many quarantine programs have historically included wage replacement provisions, with a key example being the range of policies enacted by countries in response to severe acute respiratory syndrome (SARS) in 2003.[15] Although some workers may have access to some paid leave through their work, there is no specific program in Massachusetts to cover all workers for quarantine leave. Low-wage workers are least likely to have the kind of jobs that offer quarantine-eligible paid leave.

2. Logistical and social service supports

Across the literature, individuals report concerns about meeting their daily needs for groceries, health care, and prescription drugs during quarantine. Ordering and delivery assistance and provision of health care within the program would address these fears. Further, those suffering from mental health and/or substance use disorders require additional support to successfully complete quarantine.[16] The Massachusetts contact tracing program, the "Community Tracing Collaborative," employs case resource managers who can work with the existing social service programs and local community organizations to cobble together supports for quarantining and isolating individuals. [17] This may include having the case resource manager connect with available services to assist a quarantining household set up grocery delivery or negotiate with a landlord to keep a quarantining family at risk of eviction housed. However, there is no state organized and resourced program of support.

3. Availability of quarantine or isolation facilities

COVID-19 is likely to spread rapidly in households with many members, or multi-generational members, especially when household members live in close quarters. Home-based quarantine and isolation are not practical or feasible where an individual cannot stay in a separate room, when there is risk of domestic

[14] Research on the drivers of adherence to quarantine relies on a small subset of case studies (e.g. from the 2002-03 SARS and the 2009 swine flu epidemic responses in various parts of the world). Much of this research is qualitative and deals with select populations who are subject to behavioral biases (e.g. respondents who opt-into surveys, surveys distributed only in English, recall bias). Still, this research consistently points to the drivers discussed above. Other drivers not discussed include: effective public communications about the importance of quarantine compliance and penalties for noncompliance.

[15] Mark A. Rothstein and Meghan K. Talbott, "Encouraging Compliance With Quarantine: A Proposal to Provide Job Security and Income Replacement," *American Journal of Public Health* 97, no. Suppl 1 (April 2007): S49–56, https://doi.org/10.2105/AJPH.2006.097303.

[16] "The Missing Piece In America's COVID-19 Isolation And Quarantine Strategy: Wraparound Services | Health Affairs Blog." Accessed December 16, 2020. https://www.healthaffairs.org/do/10.1377/hblog20201207.458415/full/.

[17] "Learn about the Community Tracing Collaborative | Mass.Gov." Accessed December 16, 2020. https://www.mass.gov/info-details/learn-about-the-community-tracing-collaborative.

violence, or where family members are also the designated caregivers for children or parents. A common practice to enable successful quarantine or isolation for those who cannot remain in their homes, and for the population experiencing homelessness, has been to provide publicly managed facilities (typically converted hotels) to accommodate individuals who cannot or choose not to quarantine at home.

In the next section we turn to estimating the costs of providing those services to individuals, as well as the costs of unsuccessful quarantines or periods of isolation.

Part II. Estimating the cost of a supported quarantine/isolation program

Below we present estimations of the costs associated with a supported quarantine program for Massachusetts using publicly available information, academic research, interviews with local officials, and Excel modeling. We also present cost sensitivities to critical assumptions.

Our model relies on a range of estimates under a variety of assumptions to add to the public knowledge base on COVID-19 response strategies. We also include an Excel model tool to compare the impacts of various assumptions. Because of the widely recognized value of test-trace-isolate strategies, these estimates are a starting point to consider a state-level supported quarantine program appropriation.

We also provide an order-of-magnitude[18] model to estimate the cost of inaction. Here, we use publicly available information on COVID-related costs to conduct a mathematical exercise. First, we estimate the infections that might result over the course of the remainder of the pandemic. This estimate is based on the rate and magnitude of spread that occurred in 2020 with current mitigation measures in place. Then, using publicly available research, we estimate associated direct medical costs and deaths resulting from these infections. We then compare these costs against the cost of a supported quarantine program to assess the likelihood of the program being able to offset the investment.

[18] An order-of-magnitude estimate is a rough assessment of a complex cost. The estimates presented in this paper are not intended to substitute for the detailed work of a state budgeting office or epidemiological analysis of disease incidence.

Cost model methodology

We estimate the cost of a supported quarantine program according to the following formula.[19]

Total program cost = number of individuals to quarantine * weighted-average cost to quarantine per individual

Where:

Number of individuals to quarantine/isolate = [**A** + (**A***B**)] * **C**

A = new Covid-19 cases per day (1200 cases), also known as "infected persons per day"
B = contacts per case (4.25 close contacts), where A*B is "the close contacts of infected persons"
C = days remaining of the pandemic (211 days)

Weighted-average cost to quarantine per individual = (**D***E) + [(**1-D**)*F]

Where:

D = proportion of individuals quarantining at-home (95% of quarantining individuals)
E = total quarantine cost ($385), which is the cost of at-home quarantine per day ($55/individual) * the number of days spent in quarantine (7).
(1-D) = proportion of individuals quarantining in a facility (5% of quarantining individuals)
F = cost of facility-based quarantine (~$1,300 per person over 7 days).

Discussion of cost model inputs

(A) New Covid-19 cases per day

The number of people who will require quarantine is the sum of people with confirmed infections *and their close contacts*. To estimate the number that will require quarantine over the course of the pandemic, we take the average daily positive case count and multiply it by the expected "days remaining" of the pandemic. This approach was developed by healthcare experts Farzad Mostashari, Andy Slavitt, and Scott Gottlieb in an April letter to Congress estimating the cost of a federal supported quarantine program.[20] We adopt it here.

[19] This model estimates variable costs of a supported quarantine program. As a practical matter, there will be fixed costs associated with the set up and administration of this program, as there are with the administration of any statewide program. These fixed costs are not estimated here.

[20] "Bipartisan Public Health Leaders Letter on Covid19 Tracking and Tracing - Document Viewer: NPR." Accessed December 16, 2020. https://apps.npr.org/documents/document.html?id=6877567-Bipartisan-Public-Health-Leaders-Letter-on.

We assume a stabilized case count for the remaining duration of the pandemic at 1,200 cases per day. The average case count from March through December 2020 was ~1200 cases per day. It is admittedly counterintuitive to take a "stabilized" case count approach because cases ebb and flow. In fact, we have seen case counts higher than 5,000+ positive new cases per day in December and as low as a few dozen per day in late August. In reality, case counts will depend upon many other factors, including: the availability of testing to diagnose cases, the level of adherence to mask wearing and social distancing practices, and the occurrence of super spreader-potential public events like social gatherings and sporting events, as well as the roll-out of vaccines. However, there is not enough available research on Covid-19 spread to consider the exact relative contributions of these factors. In the absence of this research, and because a cost model is largely indifferent to the timing of costs, we believe using the average daily new case count is the best approximation for future case counts available.

Sensitivities for various case count scenarios ranging from 700-1400 cases per day are shown in the Appendix.

(B) Contacts per case

We assume approximately 4.25 contacts per infection. We arrive at this number by breaking the infected population down into two groups: those practicing social distancing (50%) and those not (50%). We assume a 50-50 split between these groups. We expect those practicing social distancing are in close contact with members of their households only. Since the average family size in Massachusetts is 2.5, we assume those practicing social distancing have on average 1.5 close contacts. For those not practicing social distancing, we assume they have on average 7 close contacts.

It is possible this latter assumption is too low. Recent analysis reveals that when Covid-19 spreads, it is often through large gatherings and "superspreader" events.[21] An ECDC survey of EU countries found that average contacts per case depending upon whether the infected individual was in lockdown or not at the time of the test result. Those receiving a positive test result prior to lockdown had 7-20 close contacts. (Those in lockdown at the time of receiving their positive test result, on the other hand, had 2-3 close contacts, in line with our assumption that individuals practicing social distancing are only in close contact with members of their family.)[22] Further, early studies of the efficacy of contact tracing for Covid-19 in Singapore and Taiwan yielded averages of 31 and 27 contacts per case, respectively.[23] However, both of these surveys use data from the early months of the pandemic -- since then, the public has undergone months of socialization about the importance of minimizing close contacts. For this reason, we use a more conservative estimate of contacts per case.

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[21] MIT News | Massachusetts Institute of Technology. "Covid-19 'Super-Spreading' Events Play Outsized Role in Overall Disease Transmission." Accessed January 17, 2021. https://news.mit.edu/2020/super-spreading-covid-transmission-1102.

[22] European Centre for Disease Prevention and Control. "Contact Tracing for Covid-19: Current Evidence, Options for Scale-up and an Assessment of Resources Needed," May 5, 2020. https://www.ecdc.europa.eu/en/publications-data/contact-tracing-covid-19-evidence-scale-up-assessment-resources.

[23] Keeling, Matt J., T. Deirdre Hollingsworth, and Jonathan M. Read. "Efficacy of Contact Tracing for the Containment of the 2019 Novel Coronavirus (Covid-19)." *J Epidemiol Community Health* 74, no. 10 (October 1, 2020): 861–66. https://doi.org/10.1136/jech-2020-214051.

(C) Days remaining of the pandemic

The model assumes the pandemic will come under control by August 31, 2021. We start the estimation period on February 1, 2021. Thus, we estimate 211 "days remaining" of the pandemic.

As vaccine distribution ramps up, we do not yet know how long the pandemic will last in the United States. The true end of the pandemic will occur when herd immunity is achieved. While a significant share of the population has already been infected, we do not have conclusive evidence that antibodies provide long-term resistance.[24] So we understand herd immunity to be achieved after a vaccine is sufficiently administered across the US, [current estimates include a 75% to 85% vaccination rate]. In that world, a supportive quarantine program would no longer be required to control the spread of Covid-19.

The CDC has not yet issued guidance about when in 2021 to expect herd immunity through vaccination. The US's leading infectious disease expert Dr. Anthony Fauci has suggested that the vaccine will become available to the general public as early as April 2021 with widespread vaccination continuing through the summer into Q3 2021.[25] However, delays in administration and logistics suggest the true herd immunity may be achieved later than original estimates.

For this model, we assume that the pandemic will continue through the end of August 2021. This implies there are "211" days of the pandemic from February 1, 2021 through August 31, 2021.

We show sensitivities depending upon the end date of the pandemic in the Appendix.

(D) Proportion of individuals quarantining at home

We assume 95% of individuals will quarantine at home, while those unable to do so will seek public facilities where they can complete their quarantines (5%).

While we expect the vast majority of individuals asked to quarantine choose to do so at home, we do not have a firm estimate of the share that would prefer this option to a facility. Because this variable is a critical determinant of cost (since facility-based quarantine is significantly more expensive than at-home quarantine) we show sensitivities for this assumption below for a range of 90%-100% of quarantines being at-home.

(E) Cost of at-home quarantine

We assume an at-home quarantine will have an average daily cost of ~$55/individual. Over a 7 day quarantine period, this sums to $385 per person.

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[24] Healthline. "How Long Does Immunity Last After Covid-19? What We Know," October 14, 2020. https://www.healthline.com/health-news/how-long-does-immunity-last-after-covid-19-what-we-know.

[25] Stieg, Cory. "When Dr. Fauci and Other Experts Say You Can Expect to Get Vaccinated for Covid-19." CNBC, December 14, 2020. https://www.cnbc.com/2020/12/14/who-gets-the-covid-vaccine-first-timeline-and-priority-explained.html.

The average cost per patient per day will depend on the duration and design of the supportive quarantine program. As for duration, in December 2020 the CDC issued guidance that quarantine may end for individuals after 7 days with a negative test result. Else, it may end after 10 days without a test, so long as an individual has no symptoms.[26] We assume a quarantine period of 7 days in the cost model.

As for design, we estimate the cost of a program aligned to best practices that will provide:

- A universal stipend of $50/day

  This amount is equivalent to federal compensation for jury duty pay. However, there is some variance in this payment according to benchmarks. For example, Taiwan is compensating individuals for quarantining at home for roughly ~$33 USD per day.[27] Alameda County, California has piloted a payment program of $1,250 for the quarantine period, or approximately ~$90 per day over a 14-day quarantine period.[28] Notably, the State of Massachusetts has a law requiring payment for quarantine that "shall not exceed $2/day."[29] This law was last updated in 1938[30], so $2/day would imply a payment of ~$36/day in 2020 dollars. The Appendix shows sensitivities for different payment amounts, ranging from $30 to $70.

  We assume a universal stipend to make the cost model more conservative. A means-tested program could significantly reduce overall program costs.

- Logistical support as needed. We estimate that 30% of the quarantined population will require additional supports, like grocery and necessity delivery. We estimate the cost of grocery delivery to be ~$60 per person per week and the cost of other delivery supports to be ~$50 per person per week.[31]

- Substance abuse and mental health counseling as needed. We assume that 5% of quarantined individuals will require mental health or substance abuse wraparound services (e.g. counseling).

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[26] CDC. "Covid-19 and Your Health." Centers for Disease Control and Prevention, February 11, 2020. https://www.cdc.gov/coronavirus/2019-ncov/if-you-are-sick/quarantine.html.

[27] "Taiwan Is Battling Coronavirus with Technology and Trust," August 23, 2020. https://theweek.com/articles/932199/taiwan-battling-coronavirus-technology-trust.

[28] East Bay Times. "Alameda County to Give Stipends to Some Coronavirus Victims," August 5, 2020. https://www.eastbaytimes.com/2020/08/05/alameda-county-to-give-stipends-to-some-coronavirus-victims.

[29] "General Law - Part I, Title XVI, Chapter 111, Section 95." Accessed December 16, 2020. https://malegislature.gov/laws/generallaws/parti/titlexvi/chapter111/section95.

[30] Lawfare. "Quarantine and Isolation Authorities in States Affected by Covid-19," March 6, 2020. https://www.lawfareblog.com/quarantine-and-isolation-authorities-states-affected-covid-19.

[31] The $60 per person grocery cost is taken from the USDA's estimates for a "moderate-cost" weekly food plan. The $50 in delivery support is an assumption.

We estimate the cost of these services by taking the reported average hourly pay rate for counselors in Massachusetts.

Summary of assumptions:

At-home quarantine costs		% Requiring It	Cost/usage	# times needed in quarantine period (7 days)	Cost per quarantine (7 days)
Wage loss mitigation					
	Stipend	100%	$50	7	$350
Logistical supports					
	Groceries	30%	$60	1	$18
	Deliveries	30%	$50	1	$15
Wraparound services					
	Counseling	5%	$30	1	$2
Total per person					$385
Total per person per day					$55

(F) Cost of facility-based quarantine

We estimate that each quarantine facility will cost ~$640,000 per month to rent and operate. We also estimate that if 5% of the population requiring quarantine uses facilities, this implies a per patient cost of $1,300 per 7-day quarantine period.

Quarantine facilities both require a site (e.g. a hotel) and operating costs to manage care for isolating/quarantining patients. Facility costs were estimated from an interview with a local official who managed the Chelsea-Revere Covid-19 isolation site that was organized in late spring to deal with a local surge.[32] The most important drivers of cost were the facility itself (usually a hotel), PPE, on-site healthcare, and sanitation services.

Because isolation facilities in late spring were set up in a state of emergency, they likely incurred excess costs that could have been avoided had there been significant centralized coordination and price negotiation. The facility we interviewed incurred monthly costs in excess of $1.4m over a 2 month period. We use most of their costs as our baseline but build in a 20% economies of scale discount to estimate that each facility in the model will cost ~$640,000 per month to operate. It is likely even more savings could be discovered through planning and economies of scale.

This cost also depends on how many facilities are needed. We do not know how many would choose to isolate in a facility so show a range for this value from 0-10%. (That is, "10%" means that if 10% of the

[32] City staffer managing Chelsea/Revere quarantine facility, interview by Anne Hoyt, May 15, 2020.

population requiring quarantine/isolation chooses to do so in a facility, the state would require four facilities per day.)

Program cost results

Given these assumptions, we would expect a supported quarantine program that offers a universal stipend to cost within a range of $300m to $570 million over the remaining duration of the pandemic, covering approximately 800,000 to 1.3m Massachusetts residents through August 2021. On a per person basis, this breaks down to an expenditure of ~$430 per quarantined individual.

The bulk of this program cost supports at-home quarantines, but a significant share covers facility-based quarantine for a minority of individuals. For example, if 95% of individuals choose to quarantine at home, the high-end estimate of program cost ($570m) breaks down ~$485m to support at-home quarantines and ~$85m to support facility-based quarantines. If 100% of individuals quarantine at home (that is, if no facility-based quarantine is offered), then the estimated cost of supported quarantine is ~$510m.

The estimate of $570m is likely an extreme upper bound on the program cost because we would expect supported quarantine to reduce the average case count and contacts per case over time. In other words, as the program makes it easier for individuals to quarantine and isolate, we would expect fewer future infections, meaning fewer people have to be covered by the program over time. We do not know by exactly how much we might expect the program to reduce the average case count or contacts per case. However, we can offer some benchmarks. For example, if supported quarantine can reduce the average contacts by case by just 1 to 3.25 contacts per case, we would expect this program to cost in the order of ~$475m. If the program could reduce the average case count by 2 to 2.25 contacts per case, we would expect the program to cost ~$350m, and so on. *Thus, depending upon the efficacy, we would expect this program to roughly cost between $300-600m.*

Overall, this cost projection is highly sensitive to the daily case count and contacts per case (which can be mitigated through other public health interventions like mask-wearing and better ventilation and air filtration of indoor spaces). We also note that we believe this model is conservative because it does not account for vaccinations or antibody immunity; these factors would drive down the population susceptible to infection and thus the population requiring quarantine.

The estimated cost of such a program, especially if universally applied, is no doubt substantial. However, to put this number in perspective, the Commonwealth has already spent over $1.1 billion on Covid-19, including $350 million on personal protective equipment, $85 million on field hospitals and shelters and $111 million on supplemental payments to hospitals and providers.[33] In particular, the state has paid at

[33] "Baker Signs $1.1 Billion COVID-19 Spending Bill." Accessed February 17, 2021. https://www.wbur.org/news/2020/07/24/baker-signs-covid-spending-bill-juneteenth.

least $66m on contact tracing efforts through September 2020[34] and over $150 million on providing COVID-19 testing, including surveillance testing programs in congregate settings and investments in laboratory capacity to process samples.[35] Despite these investments, the pandemic has persisted, reaching its most staggering numbers in December 2020. To deliver the benefits of testing and contact tracing to prevent transmission effectively, a full investment in actually keeping people at home is required. The next section adds context to this estimate by exploring the counterfactual: what is the cost of failed periods of quarantine and isolation?

[34] News. "Massachusetts Scales Up Contact Tracing, But Some Experts Question Its Value," December 3, 2020. https://www.wgbh.org/news/local-news/2020/12/03/massachusetts-scales-up-contact-tracing-but-some-experts-question-its-value.

[35] "Baker-Polito Administration Launches New Testing Infrastructure to Increase Testing Capacity & Efficiency Statewide | Mass.Gov." Accessed February 17, 2021. https://www.mass.gov/news/baker-polito-administration-launches-new-testing-infrastructure-to-increase-testing-capacity.

Part III. Estimating the cost of inaction

Counterfactual model and discussion of inputs

Failure to provide assistance to individuals who need help to quarantine and isolate creates significant costs – it increases the incidence and burden of the disease and its associated socio-economic consequences. We contextualize the estimated program costs against the counterfactual: the possibility of incremental infection spread by individuals who cannot stay at home without this program and the associated financial costs of that spread.

The spread of COVID-19 is associated with several social, economic, and health costs that in turn lead to financial costs, including:

- **Direct medical costs of health care during or within a year of infection**
- **Death and disability, causing immeasurable emotional loss to families and economic losses for families (e.g. lost income and family instability)**
- Longer-term symptoms that may require long-term care (e.g. lung damage, migraines)
- Reduced consumer willingness to engage in physical public consumption (e.g. shopping and dining), which results in foregone tax revenue and threatens to close businesses
- Increased likelihood of economic shutdowns. As infection rates tick up and approach exponential growth rates, the likelihood of an economic shutdown dramatically increases. Shutdowns can result in diminished economic activity, job loss and business bankruptcies that are sustained over a long period of time or never recover. These harms also take a direct toll on state budgets by reducing sales and business tax revenue and increasing unemployment payments and need for other social services.

Below we consider increases in death and disability as the two critical factors determining the costs of not investing in supported quarantine and isolation.

There is an incremental spread of COVID-19 that occurs in the absence of a supported quarantine program. In other words, supported quarantine reduces R_t, or the average infections caused by one infected person. Here we conduct an arithmetic exercise to estimate how much supported quarantine would have to uniquely impact R_t based only on the two costs highlighted above - short-term direct medical costs (financial) and deaths (in numbers).

First, we project one-days-worth of infections, which we take as the average number of infections per day from 2020 (~1200). We estimate how many subsequent infections we would expect this one-days-worth group to collectively cause between February 1 and the end of the pandemic holding R_t constant at its average through the end of 2020. Then we estimate the direct costs associated with the total new infections, including deaths and direct medical costs to the state and other payors. Finally, we assess what impact the program would have to have on R_t, and therefore on the total infections and associated costs, compared to the estimated program cost of ~$300-570 million.

Future infections expected based on known infections on February 1 = $\sum_{t=1}^{H} A * G^H$
Where

A = estimated average Covid-19 cases on February 1 (taken as the 2020 average of 1200 cases per day)[36]

G = average R_t (1.09 average from March 3, 2020 through December 31,2020)[37]

H = expected number of transmission chains

A "transmission chain" occurs when an infected person passes Covid-19 onto another person. The measure for how long it takes for the virus to transfer from one person to another is called a "serial interval." This is the period of time from when patient A (infector) shows symptoms to the time patient B (infectee) shows symptoms. Research suggests that the serial interval for Covid-19 is a little over 5 days,[38] but public health interventions can lengthen or shorten this window. This 5 day estimate, however, is consistent with the understanding that Covid-19 has a 5 day incubation period.[39]

Expected number of transmission chains = days remaining pandemic/serial intervals

The days remaining in the pandemic are given above as 211 days. Given a serial interval of 5.3 days, we might estimate that a group of 1200 infected individuals on February 1 could go on to create 40 new transmission chains before the end of the pandemic.

In other words, to calculate how many future infections this February 1 infected group would cause through the end of the pandemic, we sum up all the new infections in each of 40 serial intervals. This calculation yields ~440,000 expected infections if this one-day infected group spreads the virus at the average R_t through August 2021.

Then, there are two "costs" of these expected total infections:

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[36] This 1200 starting point is not to be confused with the true reported number of infections on February 1, 2021, which was in fact 2,270. Here we take the stabilized average from 2020 of 1200 as representative of a "days worth" of known cases. Further, using the stabilized 2020 average of 1200 is likely an underestimate because reported cases are a subset of true cases. Medical costs are incurred based on the true number of cases, regardless of if they were reported. Thus, using 1200 makes the counterfactual cost model conservative.

[37] "Massachusetts Rt." Accessed January 23, 2021. https://rt.live/us/MA. Rts change based on the effectiveness of the control measures put in place. This estimated Rt is the average Rt in Massachusetts with current disease control strategies in place. We use the R_t from 3/3/20-12/31/20 to represent the "average."

[38] Rai, Balram, Anandi Shukla, and Laxmi Kant Dwivedi. "Estimates of Serial Interval for Covid-19: A Systematic Review and Meta-Analysis." *Clinical Epidemiology and Global Health* 9 (2021): 157–61. https://doi.org/10.1016/j.cegh.2020.08.007.

[39] Lauer, Stephen A., Kyra H. Grantz, Qifang Bi, Forrest K. Jones, Qulu Zheng, Hannah R. Meredith, Andrew S. Azman, Nicholas G. Reich, and Justin Lessler. "The Incubation Period of Coronavirus Disease 2019 (Covid-19) From Publicly Reported Confirmed Cases: Estimation and Application." *Annals of Internal Medicine* 172, no. 9 (March 10, 2020): 577–82. https://doi.org/10.7326/M20-0504.

(1) Expected deaths =case fatality * expected total infections

Where, with a case fatality of 1.7%[40], we would expect ~7,500 more deaths.

(2) A subset of expected costs: Direct medical costs

Bartsch et al estimate that each COVID-19 patient is associated with an average of ~$2,500 in direct medical costs[41] that occur within a year of the virus (e.g. hospitalizations and critical care).[42] This implies that through this estimation exercise, we would expect the February 1 infected group to not only cause ~440,000 new infections, but also, to create ~$1.1 billion in direct medical costs.[43] So on a per person basis, the medical costs of an unabated pandemic (~$2,500 per infected individual) exceeds the program cost (~$430 per quarantined individual).

Based on this estimation exercise, if a supported quarantine program could reduce the average R_t 1.09 by just 0.01, we would expect to see over 100,000 fewer infections; 1,800 fewer deaths; and $265m less in overall direct medical costs. If a supported quarantine program could reduce the average R_t by even more, the savings are more pronounced. For example, if this intervention could reduce the average R_t by 0.03 to 1.06, the direct medical cost savings of ~$610m would exceed even the high end estimated cost of this universal program. If this supported quarantine program is as effective as we could hope – that is, if it could help drive the R_t to 1- it could result in almost 400,000 fewer infections; 6,700 fewer deaths; and $980m less in direct medical costs. These scenarios are included in the Appendix.

While we do not have quantitative evidence for how interventions impact R_t, given that R_t is estimated to have ranged from low of ~0.7 to highs in excess of 2.0 over the course of the pandemic,[44] it appears quite

[40] Johns Hopkins Coronavirus Resource Center. "Mortality Analyses." Accessed January 23, 2021. https://coronavirus.jhu.edu/data/mortality.

[41] Note: This estimate of ~$2,500 is derived from their conclusion that "If 80 percent of the US population were to get infected, the result could be ... $654.0 billion in direct medical costs over the course of the pandemic. If 20 percent of the US population were to get infected, there could be ...$163.4 billion in direct medical costs over the course of the pandemic." Dividing their cost estimate by the population represented yields ~$2,490 in healthcare expenses per infected person. Bartsch et al offer a higher estimate for the median cost of a *symptomatic* COVID-19 patient ($3,045), but because we do not know that all patients will become symptomatic, we use this more conservative inference.

[42] Bartsch, Sarah M., Marie C. Ferguson, James A. McKinnell, Kelly J. O'Shea, Patrick T. Wedlock, Sheryl S. Siegmund, and Bruce Y. Lee. "The Potential Health Care Costs And Resource Use Associated With COVID-19 In The United States." *Health Affairs* 39, no. 6 (April 23, 2020): 927–35. https://doi.org/10.1377/hlthaff.2020.00426.

[43] These costs are borne by the state and other payors. To consider costs borne by the state only, we can sum the % of population estimated to be on Medicare and Medicaid, or 43% of the population. This yields an estimated $470m in medical costs to the state. However, because it is possible this population is overrepresented in infections, 43% may be too low an estimate.

[44] "Massachusetts Rt." Accessed January 23, 2021. https://rt.live/us/MA.

possible that a time-tested, evidence-based intervention like supported quarantine could provide the marginal impact required to make it significantly offset the cost.

Counterfactual discussion

This exercise yields dramatic numbers for infection spread and associated costs. A few caveats that should be kept in mind:

- It is an oversimplification to treat R_t as an average constant when instead it has fluctuated over the course of the pandemic. But because we cannot predict the future behavior of R_t with accuracy, this is our second-best alternative to give context to the value of a supported quarantine intervention.
- It is unlikely the pandemic could continue to rage at these transmission rates without some new extreme public policy intervention, like a lockdown. But this too creates financial costs we do not assess here.
- This level of mass infection (440,000 more) in a state with a population of only 6.7 million could only occur if re-infections are possible, the frequency of which, based on available evidence, is unclear.
- Vaccine distribution is likely to reduce the overall population that is susceptible to infection. However, this factor, which will diminish the "infectable" population over time, is excluded from the estimation. If the state is able to ramp up vaccine distribution ahead of schedule, this would imply significant lower direct medical costs from future infections.
- Reducing the transmission rate and the number of cases is critical to preventing mutations in the virus that could pose threats to the current vaccines. To do this, the Commonwealth will need to invest resources in all the interventions that are effective, including a isolation and supported quarantine as well as vaccination.
  .

Even given these caveats, this exercise shows that an R_t above 1 produces exponential infection spread and related costs such that interventions that even marginally reduce R_t are likely cost effective. Although we do not have evidence about the unique and exact impact of particular interventions on R_t. most of the people diagnosed on "day 1" of this exercise (Feb 1) will be able to follow public health protocols and stay at home. But a certain percentage of individuals will not have this option, and they are disproportionately located in poorer and more marginalized communities where COVID19 has to date had highest transmission and mortality levels. It is likely that for them supported quarantine will make a difference, irrespective of the cost-benefit calculations.

From a practical perspective, this is a high price tag for an already constrained state budget. Policymakers must choose among a set of costly options for pandemic control. Testing, contact tracing, and supported quarantine are important on their own, but they also complement the goal of vaccine distribution by reducing the spread of infections. For this reason, supported quarantine and isolation is an important tool in the policymakers' toolkit and needs to be part of a comprehensive of a comprehensive mitigation strategy.

Conclusion

The important public health strategies of isolation and quarantine to mitigate disease transmission have been underutilized throughout the pandemic. We find that a statewide supported quarantine program would cost $300-570 million to cover individuals infected between February 1, 2021 and August 31, 2021. We base this cost estimate on the expectation that ~1.3m infected individuals and their contacts will require isolation and quarantine over the remaining duration of the pandemic. For those who cannot quarantine at home, this program would create centrally coordinated, professionally operated, and publicly available quarantine facilities. For those who can quarantine at home, this program would increase the likelihood of adherence, thus reducing transmission, the overall infection rate, and Covid-19 deaths. Finally, it is possible for this program to be cost effective for the state, medical payors, and other parties who bear the economic costs of infection spread, if it modestly reduces disease transmission.

Part IV. Appendices

Appendix 1. Cost model sensitivities

Table 1. Sensitivity of support quarantine program cost to contacts per case (shows est. cost range depending upon program efficacy)

(B) Contacts per case	Program cost
2.25	$ 347,000,000
3.25	$ 475,000,000
4.25	$ 572,000,000
5.25	$ 701,000,000
6.25	$ 798,000,000
7.25	$ 895,000,000
8.25	$ 1,023,000,000
9.25	$ 1,120,000,000
10.25	$ 1,249,000,000
11.25	$ 1,345,000,000
12.25	$ 1,442,000,000

Table 2. Sensitivity of support quarantine program cost to daily case count

(A) Daily case counts	Program cost (low end)	Program cost (high end)
1200	$ 347,000,000	$ 572,000,000
700	$ 215,000,000	$ 328,000,000
800	$ 242,000,000	$ 371,000,000
900	$ 268,000,000	$ 445,000,000
1000	$ 294,000,000	$ 487,000,000
1100	$ 320,000,000	$ 530,000,000
1200	$ 347,000,000	$ 572,000,000
1300	$ 373,000,000	$ 615,000,000
1400	$ 431,000,000	$ 657,000,000

Table 3. Sensitivity of support quarantine program cost to duration of pandemic

(C) Days remaining of pandemic	Program cost (low end)	Program cost (high end)
211	$ 347,000,000	$ 572,000,000
120	$ 211,000,000	$ 321,000,000
150	$ 256,000,000	$ 393,000,000
180	$ 300,000,000	$ 497,000,000
210	$ 345,000,000	$ 570,000,000
240	$ 390,000,000	$ 642,000,000

Table 4. Sensitivity of support quarantine program cost to location of quarantine

(D) Share quarantining at home (vs facility)	Program cost (low end)	Program cost (high end)
95.0%	$ 347,000,000	$ 572,000,000
90.0%	$ 408,000,000	$ 633,000,000
92.5%	$ 378,000,000	$ 603,000,000
95.0%	$ 347,000,000	$ 572,000,000
97.5%	$ 347,000,000	$ 542,000,000
100.0%	$ 316,000,000	$ 511,000,000

Table 5. Sensitivity of support quarantine program cost to cost of at-home quarantine

(E) At-home cost per individual per day	Program cost (low end)	Program cost (high end)
$ 54.9	$ 347,000,000	$ 572,000,000
$30	$ 210,000,000	$ 352,000,000
$40	$ 265,000,000	$ 440,000,000
$50	$ 320,000,000	$ 529,000,000
$60	$ 374,000,000	$ 617,000,000
$70	$ 429,000,000	$ 705,000,000

Appendix 2. Counterfactual sensitivities

Table 6. Sensitivity of cost estimates to daily cast count

(A) Daily case counts	Program cost (low end)	Program cost (high end)	Direct medical costs
1200	$ 347,000,000	$ 572,000,000	$ 1,100,000,000
700	$ 215,000,000	$ 328,000,000	$ 642,000,000
800	$ 242,000,000	$ 371,000,000	$ 733,000,000
900	$ 268,000,000	$ 445,000,000	$ 825,000,000
1000	$ 294,000,000	$ 487,000,000	$ 917,000,000
1100	$ 320,000,000	$ 530,000,000	$ 1,008,000,000
1200	$ 347,000,000	$ 572,000,000	$ 1,100,000,000
1300	$ 373,000,000	$ 615,000,000	$ 1,192,000,000
1400	$ 431,000,000	$ 657,000,000	$ 1,284,000,000

Table 7. Sensitivity of expected infections from one-day of new cases over course of pandemic to R_t

R_t	Infections	Direct medical costs
1.09	442,000	$ 1,100,000,000
0.9	11,000	$ 26,000,000
0.95	20,000	$ 49,000,000
0.975	30,000	$ 74,000,000
0.98	33,000	$ 81,000,000
0.99	39,000	$ 98,000,000
1	48,000	$ 119,000,000
1.01	59,000	$ 147,000,000
1.02	74,000	$ 184,000,000
1.03	93,000	$ 232,000,000
1.04	119,000	$ 295,000,000
1.05	152,000	$ 379,000,000
1.06	197,000	$ 490,000,000
1.07	256,000	$ 638,000,000
1.08	336,000	$ 836,000,000
1.09	442,000	$ 1,100,000,000
1.1	584,000	$ 1,454,000,000
1.11	775,000	$ 1,929,000,000
1.12	1,031,000	$ 2,566,000,000
1.13	1,375,000	$ 3,422,000,000
1.14	1,836,000	$ 4,570,000,000
1.15	2,455,000	$ 6,112,000,000
1.16	3,286,000	$ 8,180,000,000
1.17	4,401,000	$ 10,955,000,000
1.18	5,895,000	$ 14,675,000,000
1.19	7,897,000	$ 19,657,000,000
1.2	10,575,000	$ 26,325,000,000
1.25	45,133,000	$ 112,351,000,000