By Sarah M. Bartsch, Marie C. Ferguson, James A. McKinnell, Kelly J. O'Shea, Patrick T. Wedlock, Sheryl S. Siegmund, and Bruce Y. Lee

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The Potential Health Care Costs And Resource Use Associated With COVID-19 In The United States

ABSTRACT **With the coronavirus disease 2019 (COVID-19) pandemic, one of the major concerns is the burden COVID-19 will impose on the United States (U.S.) health care system. We developed a Monte Carlo simulation model representing the U.S. population and what can happen to each person who gets infected with severe acute respiratory syndrome coronavirus 2 (SARS-CoV2). We estimate resource use and direct medical costs per infection and at the national level, with various "attack rates" (infection rates) to understand the potential economic benefits of reducing the burden of the disease. A single symptomatic COVID-19 infection would cost a median of $3,045 in direct medical costs incurred only during the course of the infection. Eighty percent of the U.S. population getting infected could result in a median of 44.6 million hospitalizations, 10.7 million ICU admissions, 6.5 million ventilators used, and 249.5 million hospital bed days, costing $654.0 billion in direct costs over the course of the pandemic. If 20% were to become infected, there would be a median of 11.2 million hospitalizations, 62.3 million hospital bed days, and 1.6 million ventilators used, costing $163.4 billion. [*Editor's Note: This fast-track Ahead-of-Print article is the accepted version of the peer-reviewed manuscript. The final edited version will appear in an upcoming issue of* Health Affairs.]**

Sarah M. Bartsch is a project director at Public Health Informatics, Computational and Operations Research (PHICOR), City University of New York, in New York City.

Marie C. Ferguson is a project director at PHICOR, City University of New York.

James A. McKinnell is an associate professor of medicine in the Infectious Disease Clinical Outcomes Research Unit, Los Angeles Biomedical Research Institute, Harbor-UCLA Medical Center, in Los Angeles, California.

Kelly J. O'Shea is a senior research analyst at PHICOR, City University of New York.

Patrick T. Wedlock is a senior research analyst at PHICOR, City University of New York.

Sheryl S. Siegmund is director of operations at PHICOR, City University of New York.

Bruce Y. Lee (bruceleemdmba@gmail.com) is a professor of health policy and management and executive director of PHICOR, City University of New York.

With the coronavirus disease 2019 (COVID-19) pandemic, one of the major concerns is the burden COVID-19 will impose on the United States (U.S.) health care system. Elected officials, health professionals, and health care systems have raised concerns that the demand will exceed existing capacity and they have requested additional resources and financial support.[1–3] One of the goals of social distancing measures is to reduce the percentage of the population who get infected to avoid overburdening the health care system.[4,5] Conversely, others have advocated for "herd immunity" strategies that allow certain proportions of the population to become infected (e.g., at least 60–70%) until the virus can no longer spread.

All of this calls for an urgent need to better understand the potential health care costs and demand for resources due to COVID-19 in the U.S. when different percentages of the population become infected. Computational models have helped quantify the potential impact of and guide decision making for epidemics and outbreaks in the past, such as the 2009 H1N1 pandemic,[6–16] the ongoing Ebola outbreak that emerged in 2018,[17] and the 2015–2016 Zika outbreak.[18,19] Therefore, we developed a computational model to represent what may happen to each patient infected with severe acute respiratory syndrome coronavirus 2 (SARS-CoV2) and quantify potential resource use and direct medical costs (i.e., costs directly attributable to health care resource use for interventions and care that are specific to COVID-19 illness and would typically be paid out by third-party payers) in the U.S. under various conditions.

Study Data And Methods

MODEL STRUCTURE We developed a Monte Carlo simulation model using Microsoft Excel (Microsoft Corporation, Redmond, WA) with the Crystal Ball add-in (Oracle Corporation, Redwood Shore, CA) representing the entire population of the U.S. and what can happen to each patient who ends up getting infected with SARS-CoV2. At the beginning of each simulation run, we determine what percentage of the population ends up getting infected (i.e., the attack rate) with the age distribution of cases matching the reported age distribution of COVID-19 cases. Each infected person then travels through a probability tree of different possible sequential clinical outcomes. Below we describe these probabilistic events and the associated health care needs for a simulated person in our model.

First, the person has a probability of being asymptomatic throughout the entire course of the infection. If this person is symptomatic, we assume that the person would start with a mild infection, and then has probabilities of either seeking ambulatory care or calling his/her physician (i.e., telephone consult). Next, this person has a probability of progressing to severe disease and requiring hospitalization. If this person is not hospitalized and has only a mild illness he/she self-treats with over-the-counter (OTC) medications (e.g., acetaminophen, ibuprofen). If hospitalized, this person then has a probability of having severe pneumonia or having severe non-pneumonia symptoms. After hospital admission, this patient has a probability of being admitted to the intensive care unit (ICU). This patient then has a probability of having either sepsis or acute respiratory distress syndrome (ARDS), with or without sepsis. If this patient has ARDS, he/she requires the use of a ventilator. If hospitalized, this patient has a probability of dying, and if surviving, he/she could require additional care after hospital discharge (e.g., ARDS or sepsis care).

For each of the aforementioned steps and possible outcomes, the person accrues different associated costs. If a person only has a mild illness, these costs include either ambulatory care or a telephone consult, and OTC medications. If a person is hospitalized, these costs include either ambulatory care or a telephone consult, hospitalization, and post-discharge care. This patient incurs the cost of hospitalization associated with the highest ward level of care he/she receives (e.g., if admitted to the ICU, incurs the cost of only the ICU-related diagnosis, sepsis or ARDS, but not the general ward stay) and his/her most severe clinical outcome (e.g., if the patient has ARDS, incurs the cost of ARDS to account for ventilator use, regardless of sepsis). After hospital discharge, this patient accrues outcome-specific post-discharge costs for associated health care use for one year.[20,21] If this patient has ARDS, he/she incurs the reported median direct medical cost per patient, which includes additional hospitalization, skilled nursing facility stays, rehabilitation stays, and outpatient visits (including specialist, primary care provider, and occupational therapist visits).[21] If this patient has sepsis, he/she incurs the median cost paid to the providers for all-cause emergency department visits, outpatient visits, inpatient stays, and pharmacy costs for a patient surviving severe sepsis.[20]

DATA SOURCES Online appendix exhibit 1 shows the model input parameters, values, and data sources, and is divided into costs, probabilities, and population.[22] All inputs are age-specific when available and come from the scientific literature or nationally representative data sources, which are listed in the appendix.[22] The cost section of appendix exhibit 1 includes the costs associated with an ambulatory visit, a telephone consult, total cost of OTC medications (based on age-specific dosing), age- and outcome-specific hospitalization costs, and outcome-specific post-discharge costs.[22] Hospitalization costs came from the Healthcare Cost and Utilization Project,[23] which includes the cost for the entire hospital stay, excluding professional (e.g., physician) fees. In the absence of data on COVID-19-specific and SARS-specific hospitalization costs, the cost of pneumonia due to *Streptococcus pneumoniae* served as a proxy for COVID-19 hospitalization with severe pneumonia symptoms, as these patients present with similar symptoms and would require a similar level of care. Similarly, influenza due to an unidentified virus with other manifestations served as a proxy for hospitalization with non-severe pneumonia symptoms. We performed a literature search (searching PubMed and Google Scholar) to identify papers reporting direct medical costs for the year after hospital discharge for patients with an ARDS and sepsis diagnosis, excluding the index hospitalization. We report all costs in 2020 values, using a 3% discount rate.

The probabilities section of appendix exhibit 1 reports the probability of the various outcomes as a person travels through the SARS-CoV2 probability tree.[22] This includes the probability of developing symptoms, seeking ambulatory care, hospitalization, subsequent ICU admission, the different clinical outcomes (e.g., pneumonia, ARDS), and death. The probability of being symptomatic came from a recent study which conducted daily time series laboratory testing of cases on board the Diamond Princess cruise ship.[24] In the absence of COVID-specific data, the probability of ambulatory care for influenza served as a proxy for seeking ambulatory care.[25] Age-specific COVID-19 probabilities for hospitalization and ICU admission came from a recent report from the Centers for Disease Control and Prevention (CDC) and are specific to the U.S. context as of March 16, 2020.[26] We used this data to calculate relevant COVID-19 probabilities because at the time of conducting this study, it was the only up-to-date and age-specific data available for the U.S. context. Other COVID-19-specific data came from peer-reviewed literature, and incorporated all studies reporting the input available at the time of the search (published prior to March 10, 2020). Other inputs include the total number of persons in the U.S. population, which uses the 2018 population estimate.[27]

SCENARIOS AND SENSITIVITY ANALYSES For each scenario, we ran Monte Carlo simulations consisting of 1,000 trials varying each parameter throughout its range (appendix exhibit 1).[22] Scenarios consisted of varying the attack rate from 20% to 80%. Given that new data on SARS-CoV2 continues to emerge, as well as variability and uncertainty in currently available data, we performed sensitivity analyses, varying several key parameters to determine their impact on results. Specifically, we varied the type of initial care received (from all persons having a telephone consult with their physician to all having a probability of a doctor's visit or telephone consult), the probability of severe disease requiring hospitalization (decreasing the reported values by a relative 20%–50% and increasing the reported values by a relative 20%), the probability of ICU admission (varying the reported values by a relative +/−20%), and the probability of death given hospitalization (decreasing the currently reported values by a relative 95%). We also varied the post-discharge costs to 50% of the reported values, such that they were comparable to values reported for other high-income countries.[28]

LIMITATIONS All models, by definition, are simplifications of real-life and cannot account for every possible outcome.[29] Our model inputs drew from various sources, and new data on SARS-CoV2 continues to emerge. For example, our clinical probabilities derived from data based on testing regimens that capture live infections and may not be representative of the population. As such, these probabilities may be lower than what is reported given these data may be subject to selection bias with a lack of seroprevalence studies. Additionally, we used existing data for hospitalization costs that are not necessarily specific to COVID-19. For example, the cost of ARDS decreased with age (since mortality increases with age,[30] older patients have a shorter hospital stay and therefore lower hospitalization costs),[31] which may not necessarily be the case for COVID-19. As another example, the studies that measured post-discharge costs for ARDS and sepsis included all health care costs and not just those specific to ARDS and sepsis. Thus, we explored a large range of values in sensitivity analyses, which helped determine the impact of uncertainty and variability in the available data. The purpose of this study was not to evaluate the value of specific interventions such as social distancing, but to determine the direct impact of the pathogen itself. Therefore, costs of various epidemic responses were not included.

Study Results

DIRECT MEDICAL COSTS PER COVID-19 CASE Appendix Exhibit 2 shows the median cost per COVID-19 case.[22] A single symptomatic SARS-CoV2 infection would cost a median of $3,045 [95% uncertainty interval (UI): $2,873–$3,205] in direct medical costs when only including costs that accrue during the course of the infection (this estimate is based on a symptomatic case traveling through the probability tree). When adding costs that may be incurred after the infection, such as outpatient visits and hospitalization, the cost per case increases to $3,994; when decreasing post-discharge costs by 50%, a single case would cost a median of $3,517 (95% UI: $3,355–$3,695) (data not shown). A person with mild illness (i.e., that does not require hospitalization) who either has an in-person doctors visit or a telephone consult costs a median of $57 to $96, varying with age (appendix exhibit 2).[22] If a person only uses a telephone consult, the median cost decreases to $32 (95% UI: $19–$56) for a 0–17 year old and $17 (95% UI: $16–$67) for a person 18 years and older (data not shown).

A single hospitalized case would cost a median of $14,366 (95% UI: $13,545–$15,129) when including only costs during the course of the infection (appendix exhibit 2).[22] Appendix exhibit 2 provides the break-down of cost by age-group. The costs begin to decline for those 65 years and older because of their lower hospitalization costs and probabilities for accruing these costs (e.g., those 85 years and older have a lower probability of ICU admission and lower ICU hospitalization costs than those 45–64 years). Decreasing post-discharge costs by 50% decreases the age-specific cost per case by a relative 0%–14%, with the largest decrease for a 65–84 year old (median of $17,682) (data not shown).

For any given symptomatic case, decreasing the probability of hospitalization by a relative 50% of the reported values decreases the cost to a median of $1,529 (95% UI: $1,450–$1,608) (data not shown). Decreasing the probability of ICU admission by a relative 20% decreases the cost to a median of $2,895 (95% UI: $2,746–$3,066), while for a single hospitalized case it decreases costs to a median of $13,708 (95% UI: $12,838–$14,515). For any given hospitalized case, increasing the probability of ICU admission by a relative 20% increases costs to a median of $14,991 (95% UI: $14,236–$15,812), while decreasing the probability of death has little impact on costs including those that may be incurred post-discharge (median $18,629; 95% UI: $17,643–$19,666).

HEALTH CARE RESOURCE USE AND COSTS WHEN 80% OF THE US POPULATION GETS INFECTED Appendix exhibit 3[22] shows the number of cases and their resource use (e.g., hospital bed days, ventilator days) in the U.S. when various example percentages of the population get infected with SARS-CoV2. In a scenario using the currently reported values for key parameters, an 80% attack rate would result in 215.0 million (95% UI: 208.7–221.2 million) symptomatic COVID-19 cases in the U.S., with 44.6 million total hospitalizations.

Appendix exhibits 4 and 5[22] show the median direct medical costs of COVID-19 in the U.S. incurred during the course of the infection and in the year following hospital discharge when different percentages of the population get infected with SARS-CoV2. The band depicts the range in the median direct medical cost when varying key parameters. An 80% attack rate corresponds to a median cost of $654.0 billion (95% UI: $615.8–$692.8 billion) (appendix exhibit 4) including only costs during the course of the infection and $859.6 billion (95% UI: $809.5–$911.7 billion) when including costs for a year post-discharge (appendix exhibit 5)[22] [$756.1 (95% UI: $712.5–$802.6 billion) if post-discharges costs were 50% lower (data not shown)]. When decreasing the probability of severe disease leading to hospitalization by a relative 50% of the values reported in the literature, costs incurred during the course of the infection decrease by a relative 49.7% to $328.9 billion (data not shown). Decreasing the reported value for the probability of death by a relative 95% had no impact on cost when including those that may be incurred post-discharge [median $859.6 billion (95% UI: $813.7–$909.1 billion) (data not shown)].

HEALTH CARE RESOURCE USE AND COSTS WHEN 50% OF THE US POPULATION GETS INFECTED A 50% attack rate would result in 134.4 million (95% UI: 130.6–138.2 million) symptomatic COVID-19 cases in the U.S. (appendix exhibit 3).[22] This results in a median of $408.8 billion (95% UI: $385.4–433.5 billion) in direct medical costs during the course of the infection (appendix exhibit 4)[22] and a median of $536.7 billion (95% UI: $507.6–$570.8 billion) when including post-discharge costs (appendix exhibit 5),[22] and $472.5 billion (95% UI: $447.0–$501.3 billion) when post-discharge costs are 50% the reported values (data not shown).

HEALTH CARE RESOURCE USE AND COSTS WHEN 20% OF THE US POPULATION GETS INFECTED With an attack rate of 20%, there would be 53.8 million (95% UI: 52.2–55.3 million) symptomatic COVID-19 cases in the U.S. (appendix exhibit 2),[22] costing $163.4 billion (95% UI: $154.5–$173.1 billion) in direct medical costs including only costs occurring during the course of the infection (appendix exhibit 4).[22] Including costs for a year post-discharge, cases cost a median of $214.5 billion (95% UI: $202.4–$227.9 billion) (appendix exhibit 5).[22] When decreasing post-discharge costs by 50%, COVID-19 cost a median of $188.6 billion (95% UI: $178.8–$199.8 billion) (data not shown). Decreasing the currently reported values for the probability of death by a relative 95%, had little impact on the total cost ([median $214.9 billion (95% UI: $202.8–$227.2 billion) (data not shown)].

Discussion

Our results show that, even when only considering the costs during the acute infection and not the costs of follow-up care after the infection, the direct medical costs of a symptomatic COVID-19 case tend to be substantially higher than other common infectious diseases. For example, the cost on average is four times that of a symptomatic influenza case ($696 in medical costs in 2020 values)[25] and 5.5 times that of a pertussis case ($412–$555 in 2020 values).[32] The cost of a hospitalized case in infants was greater for COVID-19 than for infants with respiratory syncytial virus ($7,804 in 2020 values),[33] but for older adults, the cost per hospitalized case was similar ($20,463 in 2020 values).[34] The direct medical costs are higher than other common infectious diseases because COVID-19 infection can have a higher probability of hospitalization and mortality compared to seasonal influenza[25] and other pathogens. While the COVID-19-specific probabilities are based on emerging data, our results were robust to varying the probability of

ICU admission and death. Additionally, a potential lingering medical cost after the acute infection has run its course is the cost of caring for those who have survived major complications such as ARDS and sepsis. Existing studies have shown that the cost of such care can be considerable,[20,21] often requiring follow-up care and potentially re-hospitalization because long-lasting damage has been done, making the person susceptible to other problems such as other infections. These costs further increased the cost of a single case, in particular a hospitalized case, by approximately $4,000.

The significant difference in medical costs by attack rate show the value of any strategies that can keep the attack rate as low as possible and, conversely, the potential cost of any "herd immunity" strategies that allow people to get infected. As can be seen, the difference between 80% and 50% of the population getting infected is 80.6 million symptomatic cases, 16.7 million hospitalizations, and $245.4 billion in direct medical costs (incurred during the course of the infection), which is 11.7% versus 18.7% of the 2017 total national health expenditures ($3.5 trillion).[35] Similarly, the difference between 50% and 20% of the population being infected is 161.2 million cases, 33.4 million hospitalizations, and $490.7 billion. Currently, the primary strategy to keep the attack rate lower is social distancing, which includes maintaining physical space from other persons and avoiding group gatherings and crowds. Any discussion regarding the cost or burden of social distancing should include the costs on the other side of the equation such as health care costs, which are the costs that such approaches are potentially reducing. The alternative, or in many ways the opposite to social distancing, are herd immunity strategies, which have been considered in the United Kingdom.[36] These would involve having certain proportions of the population be exposed to the virus until it no longer spreads. However, it must be kept in mind that this strategy is not without its cost.

Our study also provides an idea of the magnitude of resources needed to take care of COVID-19 cases. Various state and local leaders have been calling for assistance, such as more hospital beds and ventilators to bolster existing capacity. Companies such as General Motors are repurposing factories to make emergency ventilators, stadiums are being converted into make shift hospitals to increase capacity, tents to treat cases are popping up, and Navy ships are aiding in the care of non-COVID-19 patients.[37–40] Even a quick look at the numbers shows that current health care system capacity is falling well below what is needed. For example, there are approximately 96,596 ICU beds and 62,000 full-featured mechanical ventilators in U.S.,[41] which are orders of magnitude lower than what would be needed, even with a 20% attack rate. Available ICU beds would, of course, depend on the timing of COVID-19 patient admissions.

Our study focused on direct medical costs and therefore did not include the potentially substantial non-medical costs that may be associated with COVID-19, such as productivity losses due to absenteeism and premature mortality, as well as declines in economic activity (e.g., decreased production, equity losses, business closures). In fact, our results may even underestimate direct medical costs given our interest to remain conservative in calculating costs. For example, we did not include additional costs that may result from COVID-19 and its health care impact exacerbating other medical conditions (e.g., respiratory illnesses can worsen other chronic health issues).[42] Our analysis drew from costs accrued during situations that were not public health emergencies and did not account for the possibility that costs could change during a pandemic. In actuality, the scarcity of critical supplies could drive up costs, as suppliers may increase prices or charge higher premiums (e.g., hospitals are paying up to 15 times the price of personal protective equipment and medical supplies).[43,44] Moreover, our analysis did not include indirect medical costs or effects such as reductions in elective procedures decreasing revenue,[45] or potential costs from worse disease outcomes due to increases due to postponement of preventive care and diagnosis. Additionally, recruiting health care professionals to focus on COVID-19 could lead to shortages for other patients.[46] Thus, health care systems that lack extra capacity could experience increases in operating costs.

Conclusion

Our study suggests that over the course of the pandemic, COVID-19 coronavirus in the U.S. could result in direct medical costs incurred during the course of the infection from $163.3 billion if 20% of the population gets infected to $654.0 billion if 80% of the population gets infected. Even when only considering the costs during the acute infection and not those of follow-up care after infection, the direct medical costs of a symptomatic COVID-19 case tends to be substantially higher than other common infectious diseases. The significant difference in costs by attack rate across the U.S. population show the value of strategies that keep the attack as low as possible and, conversely, the potential cost of any "herd immunity" strategies that allow people to get infected. Our study also highlights the magnitude of resources needed to take care of COVID-19 cases. ■

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22 To access the appendix, click on the Details tab of the article online.

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