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ABSTRACT

The Benefits and Costs of U.S. Employer COVID-19 Vaccine Mandates*

In 2021, the Biden Administration issued mandates requiring COVID-19 vaccinations for U.S. federal employees and contractors and for some healthcare and private sector workers. Although these mandates have been subject to legal challenges and some have been halted or delayed, rigorous appraisal of their benefits and costs accompanied neither the decision to implement them nor the efforts to terminate them. This paper aims to help fill that gap. We estimate the direct costs and health-related benefits that would have accrued if these vaccination requirements had been implemented as intended. Compared with the vaccination rates observed in January 2022, we find that the mandates could have led to 15 million additional vaccinated individuals, increasing the overall proportion of the fully vaccinated U.S. population to 68%. The associated net benefits depend on the evolution of the pandemic from the time of mandate enactment—information unavailable ex ante to analysts or policymakers. In scenarios involving the emergence of a novel, more transmissible variant, against which vaccination and previous infection offer moderate protection, the estimated net benefits reach more than $16,000 per additional vaccinated individual, with more than 20,000 total deaths averted in total. In scenarios involving a fading pandemic, existing vaccination-acquired or infection-acquired immunity provides sufficient protection, and the mandates' benefits are unlikely to exceed their costs. Thus, mandates may be most useful when the consequences of inaction are catastrophic. However, we do not compare the effects of mandates with alternative policies for increasing vaccination rates or promoting other protective measures, which may receive stronger public support and be less likely to be overturned by litigation.

JEL Classification: D61, H12, H43, I18

Keywords: benefit-cost analysis, COVID-19, vaccination, regulation, value per statistical life (VSL), willingness to pay (WTP)

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1. Introduction

The emergence of COVID-19 in the United States has been a massive health shock with enormous economic and social implications, precipitating numerous public and private adjustments at the individual and population levels, including biomedical and non-biomedical responses (e.g., development of medical prevention and treatment options, economic lockdowns, and masking requirements). Vaccination has been central to many of these efforts throughout the pandemic, with large public and private investments made into the rapid development, testing, production, and distribution of COVID-19 vaccines (Bloom et al. 2021b). Substantial effort has also been devoted to encouraging vaccine uptake. In this paper, we explore one such effort: the issuance of employer vaccination mandates by the U.S. federal government. We estimate the potential direct costs and health-related benefits of four mandates issued in September and November 2021, assuming they had been implemented as initially planned. Our results provide insights into the possible consequences of other mandates issued by firms, state or local governments, and national governments around the world, and the relative merits of mandates compared with other policy interventions.

The U.S. Food and Drug Administration granted the first emergency use authorization for a COVID-19 vaccine on December 11, 2020, and all U.S. adults were eligible to be vaccinated by April 19, 2021 (HHS 2022a). From the inception of public immunization efforts, the vaccination rate among adults grew steeply until mid-summer 2021, at which point it slowed notably (CDC 2022a). As of May 2022, 66.4% of the overall U.S. population was fully vaccinated, about 8 percentage points less than the average for high-income countries at 74.7% (Mathieu et al. 2021). Relative to high vaccination coverage, weak coverage translates to higher rates of COVID-19 infection, hospitalization, and mortality; increases the likelihood of a surge of infections overwhelming the health system; potentially allows the proliferation of new, possibly more dangerous variants; increases reliance on economically and socially costly nonpharmaceutical interventions (such as limiting capacity in indoor spaces or more extensive lockdowns); and threatens economic productivity and output (Bloom et al. 2021a).

Many organizations and government agencies have issued mandates requiring employee vaccination against COVID-19 to address concerns about worker health, virus transmission, operational efficiency, and the broader economic and social consequences of infection. In this paper, we focus on four of these mandates issued within the United States. The first is a presidential executive order requiring vaccination of federal executive agency employees (Biden 2021a). The second is an executive order requiring that federal contracts and subcontracts include safeguards against the spread of COVID-19 (Biden 2021b, SFWTF 2021). The third is a regulation issued by the Occupational Safety and Health Administration (OSHA) in the U.S. Department of Labor, applicable to private sector firms with 100 or more employees (OSHA 2021a). The fourth is a regulation issued by the Centers for Medicare and Medicaid Services (CMS) in the U.S. Department of Health and Human Services (HHS), requiring vaccination of Medicare and Medicaid providers and suppliers (CMS 2021).

Although these mandates have been subject to legal challenges and some have been halted or delayed, rigorous appraisal of their benefits and costs accompanied neither the decisions to implement them nor the efforts to terminate them. The objective of this paper is to help fill that gap. We estimate the gain in the number of individuals fully vaccinated due to the mandates, the costs associated with these additional vaccinations, the population-wide health benefits in terms of reduced COVID-19 cases and deaths, and the monetary value of these benefits, considering a range of possible pandemic paths.

Our analysis suggests that the overall net benefits of the mandates depend on the state of the pandemic at the time the mandates take effect. In particular, if a more transmissible variant (i.e., similar to Omicron) emerges, for which vaccines and previous infection are less protective, the net benefits of issuing mandates skyrocket. If not, existing vaccination-acquired or infection-acquired immunity may provide sufficient protection, and the net benefits of mandates decrease substantially. We do not address whether the net benefits of mandates are greater or less than the net benefits of other policies designed to encourage increased vaccination or other protective measures, however.

Although several of the mandates were suspended or prohibited prior to full enactment, assessing their benefits and costs yields valuable insight into the impacts of requiring vaccination in various relevant contexts, including state, local, and private sector settings in the United States and other countries. It also highlights key uncertainties worthy of further investigation, as discussed in more detail subsequently.

The paper is structured as follows. Section 2 provides background information on the mandates under investigation. Section 3 lays out the methodology to estimate the net benefits of the mandates, including use of a simulation model to estimate averted illnesses and deaths and their economic value. Section 4 discusses the results, and Section 5 concludes.

2. Background

The four mandates we address were issued in two waves. The two executive orders, covering federal employees and contractors, were published in September 2021. The two regulations, covering private sector employees and healthcare workers, were published in November 2021. The original deadlines by which covered employees were required to be fully vaccinated varied across the mandates.[1]

Each mandate has been challenged in court, delaying or preventing full implementation. The results of this litigation vary depending on the legal authority for the mandate, the basis for the challenge, the views of the court that considered the challenge, and other factors. As of April 2022, the mandates for federal employees and for healthcare workers remained in place, although some challenges continued to be heard, while mandates for federal contractors and private sector employees were blocked. However, by the time these two mandates were blocked, the vaccination requirements had been incorporated into several federal contracts and subcontracts, and many private sector employers had made significant progress on their implementation plans. Hence, these requirements may have had some effect despite their termination. Table 1 summarizes the current status of each mandate.

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[1] The mandates generally define an individual as "fully vaccinated" two weeks after having received a single dose of the Johnson & Johnson vaccine or the second dose of the Pfizer-BioNTech or Moderna vaccine.

Table 1. Status of vaccination mandates as of April 2022

Sector	Published	Initial "fully vaccinated" deadline	Status as of April 2022
Federal employees (Executive Order 14043)	Sept. 9, 2021	Nov. 22, 2021	Suspended, Jan. 21, 2022; reinstated April 7, 2022
Federal contractors (Executive Order 14042)	Sept. 9, 2021	Jan. 18, 2022	Blocked, Dec. 7, 2021; additional litigation ongoing
Private sector employees (OSHA regulation)	Nov. 5, 2021	Jan. 4, 2022	Stayed, Supreme Court; withdrawn Jan. 26, 2022
Healthcare workers (CMS regulation)	Nov. 5, 2021	Jan. 18, 2022	Allowed to proceed, Supreme Court, Jan. 13, 2022

Sources: Executive Order 14043: Biden (2021a), JDSupra (2022a); Executive Order 14042: Biden (2021b), National Law Review (2022); OSHA regulation: OSHA (2021a), OSHA (2022); CMS regulation: CMS (2021), JDSupra (2022b).

Notes: The status of the healthcare worker mandate currently varies by state, due to ongoing litigation and other factors (HHS 2022b).

While all four mandates allow exemptions from the vaccination requirements due to medical conditions or religious beliefs as required by law, only the OSHA regulation for private sector firms provides additional flexibility. While encouraging mandatory vaccination, OSHA allows employers to adopt policies that permit regular COVID-19 testing and wearing a face covering while at work as an alternative.

Although benefit-cost analysis is well established and widely used to inform policy decisions in the United States and elsewhere, these mandates were issued without a full understanding of their likely impacts due to the desire to act quickly. Benefit-cost analysis is not required for executive orders. It would normally be required for major regulations such as the OSHA and CMS mandates (Clinton 1993, U.S. Office of Management and Budget 2003), but analysis was limited due to these regulations' emergency nature. A feasibility analysis that focused on the costs to employers over a six-month period accompanied the OSHA mandate (OSHA

2021a), and estimates of a broader range of costs imposed on society at large over the first year of implementation accompanied the CMS mandate (CMS 2021).[2] While each agency provides some information on the number of people potentially affected by these regulations, they do not estimate the total value of the resulting benefits. This means that determining the extent to which the benefits of these mandates were likely to exceed their costs is not possible based on the agency analyses alone. We build on these analyses to provide a more comprehensive understanding of the impacts of the vaccination requirements.

3. Data and Methods

Our approach includes three steps. First, we estimate the expected increase in the number of vaccinated individuals attributable to the mandates. Second, we simulate the change in the number of COVID-19 nonfatal cases and deaths attributable to the change in vaccination rates using a standard compartmental epidemiological model. Finally, we estimate the monetary value of the illnesses and deaths averted and compare this value with the direct costs of vaccination. In the supplementary materials, we provide additional information on the data and assumptions used in the analysis.

Our viewpoint is *ex ante*, i.e., before the mandates were implemented. In particular, we regard the future course of the pandemic from the time of implementation as uncertain. We estimate the potential health impacts of the mandates under several pandemic trajectories that vary

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[2] These mandates impose several requirements in addition to those related to vaccination, including requirements for recordkeeping and reporting and face coverings and other protective measures. In our analysis, we focus narrowly on the vaccination requirements.

according to differences in the infectiousness of the dominant variant and in the effectiveness of vaccination- and infection-acquired immunity.

In the simulation exercises, we begin our modeling on February 1, 2022, after the original deadlines for full vaccination of current employees under all four mandates. The choice of date is primarily for convenience, as explained subsequently. We consider impacts over a six-month period, given evidence that protection against severe disease remains high for at least six months after full vaccination (Andrews et al. 2022b).

We first describe the epidemiological model and its application to the mandates and discuss the calibration of the main parameters. Then, we describe the approach for estimating the value of the associated benefits and costs.

3.1. Epidemiological Model

To estimate the potential health impacts of the mandates, we use a susceptible, exposed, infectious, recovered (SEIR) epidemiological model—an approach often used to predict the evolution of the pandemic (e.g., IHME 2021).[3] We adopt an age-stratified model because age affects the intensity of social interactions (Prem et al. 2021), susceptibility to SARS-CoV-2 infection (Davies et al. 2020, Goldstein et al. 2021), and risk of severe disease and death from COVID-19 (O'Driscoll et al. 2021).

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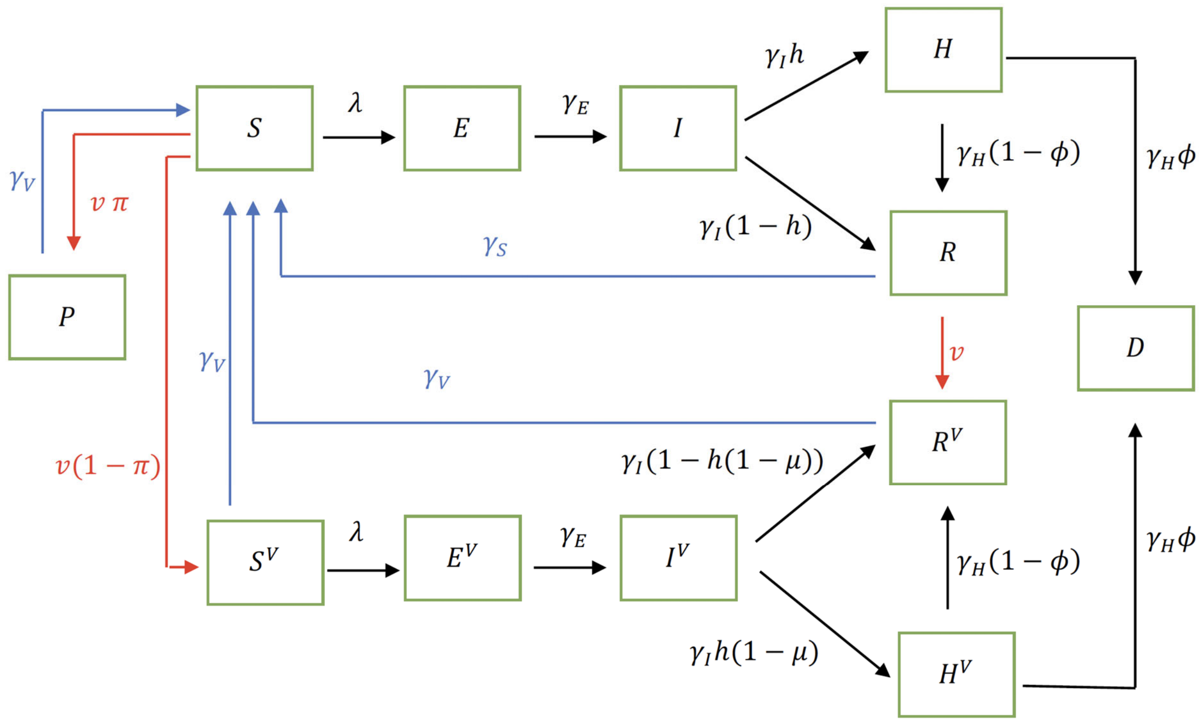
[3] Our approach considers only COVID-19 illnesses and deaths. We do not consider the effect of COVID-19 on other health conditions, e.g., when fears of infection or overburdening of the healthcare system prevent individuals from seeking care for other (potentially fatal) conditions.

Figure 1 represents the model schematically. Time is measured in days and is denoted by t. The U.S. population is partitioned into five age groups (0–17, 18–49, 50–64, 65–74, and 75+), with N_i denoting the number of individuals in age group i. Individuals are categorized as susceptible (S), exposed (E), infectious (I), hospitalized (H), recovered (R), dead (D), vaccinated and protected (P), vaccinated and susceptible (S^V), vaccinated and exposed (E^V), vaccinated and infectious (I^V), vaccinated and hospitalized (H^V), or vaccinated and recovered (R^V). The model assumes that the disease is transmitted with some probability when a susceptible individual enters into contact with an infectious one. The newly infected individual moves to an exposed compartment before becoming infectious. Most of those infected experience no or mild symptoms and recover after a short period, and a small proportion develop more serious health conditions that may require hospitalization and may lead to death. Infection-acquired immunity wanes over time, and recovered individuals move back to the susceptible compartment.

Figure 1. Diagram of the SEIR model.



Notes: S=susceptible; E=exposed; I=infectious; H=hospitalized; R=recovered; D=dead; P=vaccinated and protected; S^V=vaccinated and susceptible; E^V=vaccinated and exposed; I^V=vaccinated and infectious; H^V=vaccinated and hospitalized; R^V=vaccinated and recovered; γ_V=waning rate of vaccination-acquired immunity; γ_S=waning rate of infection-acquired immunity; γ_E=rate of transition out of exposed state; γ_I=rate of transition out of infectious state; γ_H=rate of transition out of hospitalization state; λ=infection rate; h=hospitalization rate; ϕ=hospitalization fatality rate; v=vaccination rate; π=vaccine effectiveness at reducing infection; μ=vaccine effectiveness at reducing severe disease.

Transition across compartments is described by the following set of equations, where dots denote derivatives with respect to time:

$$\dot{S}_{it} = -\lambda_{it}S_{it} - v_{it}S_{it} + \gamma_S R_{it} + \gamma_S R_{it}^V + \gamma_V S_{it}^V + \gamma_V P_{it} \qquad (1)$$

$$\dot{P}_{it} = \pi\, v_{it}S_{it} - \gamma_V P_{it} \qquad (2)$$

$$\dot{S}_{it}^{V} = (1-\pi)v_{it}S_{it} - \lambda_{it}S_{it}^{V} - \gamma_V S_{it}^{V} \tag{3}$$

$$\dot{E}_{it} = \lambda_{it}S_{it} - \gamma_E E_{it} \tag{4}$$

$$\dot{E}_{it}^{V} = \lambda_{it}S_{it}^{V} - \gamma_E E_{it}^{V} \tag{5}$$

$$\dot{I}_{it} = \gamma_E E_{it} - \gamma_I I_{it} \tag{6}$$

$$\dot{I}_{it}^{V} = \gamma_E E_{it}^{V} - \gamma_I I_{it}^{V} \tag{7}$$

$$\dot{H}_{it} = h_i \gamma_I I_{it} - \gamma_H H_{it} \tag{8}$$

$$\dot{H}_{it}^{V} = h_i(1-\mu)\gamma_I I_{it}^{V} - \gamma_H H_{it}^{V} \tag{9}$$

$$\dot{D}_{it} = \phi_i \gamma_H (H_{it} + H_{it}^{V}) \tag{10}$$

$$\dot{R}_{it} = (1-h_i)\gamma_I I_{it} + (1-\phi_i)\gamma_H H_{it} - \gamma_S R_{it} - v_{it}R_{it} \tag{11}$$

$$\dot{R}_{it}^{V} = v_{it}R_{it} + \big(1-h_i(1-\mu)\big)\gamma_I I_{it}^{V} + (1-\phi_i)\gamma_H H_{it}^{V} - \gamma_S R_{it}^{V} \tag{12}$$

The terms γ_E, γ_I, and γ_H represent, respectively, the rates of removal from the exposed, infectious, and hospitalized compartments, while γ_S and γ_V are the rates at which infection-acquired immunity and vaccination-acquired immunity wane over time. The parameter h_i represents the age-specific hospitalization rate, and ϕ_i is the age-specific hospitalization-fatality rate. The term v_{it} denotes the proportion of individuals who are newly vaccinated in period t.

The variable λ_{it} represents the infection rate and equals

$$\lambda_{it} = \beta_{it} \sum_{j=1}^{A} c_{ij} \frac{I_{jt} + I_{jt}^{V}}{N_j - D_{jt}} \tag{13}$$

where β_{it} is the susceptibility to transmission, i.e., the probability of transmission given contact with an infectious person; c_{ij} is the prepandemic number of contacts between an individual of age group i and an individual of age group j; and $\frac{I_{jt}+I_{jt}^V}{N_j-D_{jt}}$ is the probability that the member of age group j is infectious. The parameter β_{it} depends on the characteristics of the virus variant and on the presence of nonpharmaceutical interventions or changes in individuals' behavior (e.g., the use of masks or adherence to social and physical distancing practices). For a given set of contacts c_{ij}, β_{it} can be adjusted to match any effective reproductive number $\mathcal{R}_t$ for the virus.

We assume that the vaccine may affect the risk of infection, the risk of severe disease or death, or a combination of those endpoints (Peiris and Leung 2020). In each period, a fraction $\pi \in [0,1]$ of newly vaccinated individuals are 100% protected against the risk of infection and move to the vaccinated and protected compartment P. The remaining fraction of the newly vaccinated, 1-π, are not protected against the risk of infection and move to the vaccinated and susceptible compartment S^V. Vaccinated susceptible individuals face the same risk of infection λ_{it} as unvaccinated ones. However, if infected, they have a smaller probability of suffering from severe disease (here proxied by hospitalization) than unvaccinated people. Let $\mu \in [0,1]$ denote the effectiveness of the vaccine at preventing severe disease or death conditional on being infected. Thus, if $\pi = 1$, none of the vaccinated individuals get infected. If $\pi < 1$, some vaccinated individuals get infected after meeting an infectious person; however, if $\mu = 1$, none of them suffer severe disease.

The vaccine's effectiveness wanes over time, and vaccinated individuals move back to the susceptible compartment S. Both susceptible and recovered individuals are included among those who may be vaccinated. For individuals who are in the recovered state, the vaccine protects against future reinfection. Vaccination confers both direct and indirect protection: Vaccinated individuals are less likely to be infected, and they are less likely to develop serious health conditions if they are infected. In addition, by reducing the probability of being infected and infectious to others, vaccination provides population-wide benefits.

We also distinguish nonfatal cases based on symptom severity because the economic value of illness varies by severity. We consider four disease severity categories: asymptomatic cases, mild cases, severe cases, and critical cases (Robinson et al. 2021a). We assume that mild cases do not require hospitalization, severe cases are hospitalized but not admitted to an intensive care unit (ICU), and critical cases are admitted to the ICU.

The employer vaccine mandates increase the number of individuals who are fully vaccinated against COVID-19. We assume that individuals vaccinated because of the mandates reach full vaccination status at $t = 0$ (the beginning of the simulation). Thus, mandates only affect the initial number of individuals who are vaccinated. All other parameters are independent of whether vaccine mandates have been introduced. We interpret the period $t = 0$ as shortly after full vaccination is required under all four mandates (in the simulation we assume this date to be February 1, 2022).[4] By increasing the stock of individuals who are vaccinated at the beginning of the simulation, the mandates affect the evolution of the pandemic, in particular the number of COVID-19 cases and deaths that will occur in the simulated period among the entire population.

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[4] For simplicity, we assume all reach full vaccination status at the beginning of the simulation rather than at various times over the 2-4-month period from mandate publication to the implementation deadline. In the sensitivity analysis, we vary the share of the population that is susceptible at $t = 0$. This can be interpreted as starting the simulation at a date other than February 1.

3.2. Calibration of the Epidemiological Model

This section discusses the most important parametric assumptions. Appendix A includes details on the calibration of the remaining parameters. In particular, we focus on the characteristics of the vaccines, assumptions about the initial conditions in the epidemiological model, and the reproduction number.

3.2.1. Vaccination

The COVID-19 vaccines available in the United States have been very effective (90–100%) against severe disease and death with respect to all virus variants as of spring 2022.. In contrast, effectiveness against infection varies considerably across variants: Effectiveness against infection with the Delta variant is about 90% in the early weeks after full vaccination (Andrews et al. 2022a, Lopez Bernal et al. 2021, Tartof et al. 2021), while effectiveness against infection with the Omicron variant is substantially lower (65–75% in the first weeks after the second dose) and wanes at a faster pace (Andrews et al. 2022a). In the simulations, we assume the vaccine is 95% effective at preventing severe disease (here proxied by hospitalization) for all age groups. To account for *ex ante* uncertainty about the characteristics of the dominant variant, we vary the effectiveness of the vaccine at preventing infection from 90% to 20% (with 90% representing the Delta variant that was dominant when the mandates were issued and 20% representing a hypothetical variant for which vaccines are not very effective).

The durations of both infection- and vaccination-acquired immunity are not definitively known, although evidence exists of immune memory several months after infection or vaccination

(Dan et al. 2021, De Giorgi et al. 2021), and infection with one variant confers protection against other variants to some extent (Harvey et al. 2021, Planas et al. 2021), although cross-protection against the Omicron variant appears to be considerably reduced (Ferguson et al. 2021, McCallum et al. 2022). To simplify, we assume that both infection-acquired and vaccination-acquired immunity have the same mean duration, and we set this equal to nine months to be conservative.

We do not model the presence of booster doses, and, as previously explained, we assume that the only difference between the with-mandates and without-mandates scenarios concerns the proportion of individuals who are vaccinated at the beginning of the simulation. We assume additional vaccinations will be minimal during the simulation period and set $v_{it} = 0$, for all $i, t > 0$.

3.2.2. *Initial conditions*

The epidemiological model requires specifying the proportion of the population that is in each compartment at $t = 0$. For the sake of simplicity, we set $E_{i0} = I_{i0}$ and $H_{i0} = h_i I_{i0}$. In addition, we assume that no exposed, infectious, or hospitalized individuals are present among any who are vaccinated. We set the population share with active infection at $t = 0$ equal to 0.5%. To simplify, we assume that the distribution of active infections across age groups is the same as the distribution of population across age groups.

According to estimates from the Centers for Disease Control and Prevention (CDC) of infection-induced seroprevalence antibodies, by the end of January 2022 about 43% of the population had been infected with SARS-CoV-2 (31% by the end of November 2021, before the spread of the Omicron variant) (CDC 2022b). Seroprevalence rates are considerably higher for children and younger adults than for older individuals (58% in the 0–17 age group versus 23% in the 65+ age group by the end of January 2022, and 42% in the 0–17 age group versus 17% in the 65+ age group by the end of November 2021). This is likely due to differences in vaccination rates and contact patterns among age groups.

Even though about 40% of the population has infection-induced seroprevalence antibodies, not everyone in this group is necessarily immune to reinfection, either because of waning immunity over time or because their antibodies do not protect against a new variant. Thus, we vary the percentage of the population that is in the recovered state from 10% to 40% depending on the characteristics of the dominant variant (with 10% representing a hypothetical new variant for which past infection is barely protective). This percentage determines the overall number of vaccinated or unvaccinated individuals who are in the recovered state. We use the aforementioned CDC data to determine the distribution of recovered individuals by age group and vaccination status (details in Appendix A).

Because the increase in vaccination attributable to the mandates, ΔVax, occurs only among susceptible and recovered individuals, the age-specific initial number of exposed, infected, and hospitalized individuals in the with-mandates scenario is the same as in the without-mandates one. We assume that the distribution of additional vaccinated individuals across the susceptible and recovered compartments is proportional to the initial distribution in the without-mandates scenario, i.e., $v_{i0} = \frac{\Delta Vax}{S_{i0}+R_{i0}}$.

3.2.3. Reproduction number

The effective reproduction number represents the degree of infectiousness of the virus given the presence of vaccination or other policies to control the virus' spread (e.g., physical distancing requirements or school and business closures). The more infectious a virus variant is, or the less effective the control policies, the larger the reproduction number. In the simulation, we vary the initial reproduction number from one to three to capture different transmissibility levels. A reproduction number equal to one represents a situation in which the pandemic is under control. A reproduction number equal to three represents a situation in which the pandemic is rapidly intensifying, perhaps due to the emergence of a new, more transmissible variant for which existing vaccines and control measures are less effective at preventing contagion. Appendix A provides details on the computation of the reproduction number.

3.3. Economic Values

To estimate the net benefits of the mandates, we rely on the conventional benefit-cost analysis framework, as described in the HHS (2016) *Guidelines for Regulatory Impact Analysis* and elsewhere. We compare conditions without the mandates to conditions with the mandates, estimate the benefits associated with reducing the risk of incurring both fatal and nonfatal cases of COVID-19, and compare them with the direct costs associated with the additional vaccinations.

For fatal cases, consistent with the benefit-cost analysis framework, we rely on estimates of the value per statistical life (VSL) to value a change in the risk of death from the perspective of the affected individual. VSL is derived from the rate at which individuals are willing to trade small changes in their own income for small changes in their own risk of death within a defined time period.[5] This individual willingness to pay presumably includes both any reduction in earnings and averted costs associated with the risk reductions and the value of continuing to experience the joys of life itself for a longer time period.

In the benchmark case, we assume that the value of preventing a COVID-19 death is equal to the central population-average VSL estimate recommended by the HHS: $11.4 million in 2020 US$ and at 2020 income levels (HHS 2021). The effects of personal characteristics (such as age) and risk characteristics (such as dread) on VSL are uncertain and may be counterbalancing (Hammitt 2020; Robinson et al. 2021a,b). We test the effects of applying higher and lower VSL estimates to reflect uncertainty in the underlying empirical studies. We apply a low value of $5.3 million and a high value of $17.4 million based on the HHS (2021) *Guidelines*.

We likewise value nonfatal cases based on estimates of the willingness of those affected to exchange their own money for a change in their own risk. This willingness to pay captures both the intrinsic value of being in better health and the averted out-of-pocket costs of medical treatment and lost work and leisure time. Because estimates of willingness to pay are not available for COVID-19 cases of varying severity, we approximate these values using the approach recommended in the HHS (2016) *Guidelines*. This approach involves estimating the increase in quality-adjusted life years (QALYs) associated with averting nonfatal cases of illness and multiplying these gains by a constant monetary value per QALY. We use estimates of QALY gains

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[5] For example, if an individual is willing to pay $1,000 to reduce their risk of death by one-in-10,000 in a given year, that willingness to pay can be converted into a VSL of $10,000,000 by dividing by the risk change. This does not mean that the individual can or will pay $10,000,000 to guarantee their own survival. At a population level, if each individual in a group of 10,000 is willing to pay $1,000 out of their own income for a 1-in-10,000 reduction in their own risk of death over a defined time period, in the aggregate they would be willing to pay $10,000,000 to avert one expected death over that time.

per nonfatal COVID-19 case averted by age and disease severity based on Robinson et al. (2021a), who estimate the change in QALYs based on conditions similar to COVID-19 cases of differing severity. We value these gains using a constant value per QALY derived from a population-average VSL estimate.[6] Assuming a 3% discount rate, the value per QALY ranges from $270,000 (if the VSL is $5.3 million) to $880,000 (if the VSL is $17.4 million), with the central estimate equal to $580,000 (if the VSL is $11.4 million) (HHS 2021).

We do not assign a value to reducing the risk of an asymptomatic case.[7] While asymptomatic individuals may need to quarantine if they receive a positive test result, they also benefit from an increase in immunity without experiencing the adverse health effects initially associated with illness. The value of these impacts and the extent to which they are counterbalancing is difficult to ascertain. In addition, the long-term impacts of asymptomatic COVID-19 are largely unknown or uncertain (Boyton and Altmann 2021). Thus, we exclude averted asymptomatic cases from our benefit calculations.

In addition to the value of preventing a death or a case of illness from the perspective of the affected individual, we include costs that other members of society would pay. Specifically, we include the costs of outpatient and inpatient medical treatment borne largely by private or government insurers. To estimate these costs, we rely on research on COVID-19 medical costs for fee-for-service Medicare patients (Tsai et al. 2021), which provides detail on the average costs for different types of inpatient and outpatient care. To extrapolate these costs to other insurers and age

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[6] The constant value per QALY is equal to the VSL divided by the present value of quality-adjusted life expectancy, calculated at the average age of the individuals included in the studies that underlie the VSL estimates. See HHS (2016, 2021) for more details.

[7] Asymptomatic rates vary by age group and range from 60% for children to 33–34% for older adults (see Appendix A).

groups, we multiply by an adjustment factor based on data on average hospitalization costs across insurers (Avalere Health 2020).[8] Further, we assume that not all symptomatic mild cases will seek care; based on estimates of the proportion of symptomatic cases that are reported (CDC 2021),[9] we assume 29% of mild cases incur outpatient medical costs (such as testing or provider office visits). These estimates do not include medical costs incurred after the initial acute COVID-19 episode, which may be substantial especially for those with more severe acute disease and those who develop long COVID.

Table 2 summarizes the overall values of averting fatal and nonfatal cases of illness, including estimates of individual willingness to pay and insured medical costs. Appendix B provides additional details.

Table 2. Value per illness and death averted (2020 US$)

	Central VSL Estimates	**Low VSL Estimates**	**High VSL Estimates**
Fatal COVID-19 Cases	$11.45 million	$5.35 million	$17.45 million
Symptomatic Nonfatal COVID-19 Cases			
Mild	$5,450–$6,440	$2,660–$3,200	$8,150–$9,650
Severe	$38,730–$40,800	$32,710–$33,670	$44,560–$47,700
Critical	$711,290–$2.51 million	$370,420–$1.21 million	$1.04–$3.78 million

Sources: Authors calculations based on Robinson et al. (2021a), HHS (2021), Tsai et al. (2021), and Avalere Health (2020).

Notes: For nonfatal cases, the exhibit provides the minimum and maximum estimates across age groups; Appendix B provides age-specific values for individual willingness to pay and insured medical costs. The monetary values reflect a 3% discount rate and 2020 income levels based on HHS (2021).

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[8] We adopt an adjustment factor equal to 1.49 calculated by dividing the weighted average cost across all insurers by the average cost for Medicare fee-for-service patients.

[9] CDC estimates that from February 2020 to September 2021, one in 3.4 COVID-19 symptomatic illnesses were reported (CDC 2021).

The direct costs of the mandates include those associated with the vaccine itself and its administration and associated time losses. We assume two doses per vaccinated individual, given that more than 97% of the U.S. population has chosen one of the available two-dose options (the Pfizer-BioNTech or Moderna vaccine) (CDC 2022c). Based on CMS (2021), we assume a cost of $40 per dose for the vaccine and its administration plus $50 in staff time to plan and arrange for vaccination, for a total of $130 per additional vaccinated individual.

In addition, we include two types of time losses that accrue to the employee. The first is time spent getting the vaccine, which we assume is one hour per dose or two hours total, including scheduling, transportation, and wait time. The second is the time lost to adverse reactions. OSHA (2021a) estimates that these reactions lead to 0.36 days of administrative leave per vaccinated individual across both doses on average. We apply this rate to all waking hours (16 hours) to represent the loss in leisure, unpaid (household) labor, and paid work for a loss of 5.76 hours on average. Thus, the time loss per additional vaccinated employee totals 7.76 hours.

The value of changes in time use depends on the extent to which the change is pleasurable or unpleasurable and on the extent to which the time would otherwise be used for paid work or other activities (Baxter et al. 2017). For simplicity, we value these time losses at the U.S. average hourly wage rate of $27.07 as of May 2020, as reported by the U.S. Bureau of Labor Statistics (2021). The overall value of time losses thus averages $210 per vaccinated individual. Adding these losses to the costs of administering the vaccine itself, the total cost per vaccinated individual is $340. Note that these estimates include direct costs only; as discussed later, we do not estimate likely additional economic consequences of the vaccination requirements—some of which may be positive and some negative.

4. Net Benefits of Employer Vaccine Mandates

To determine the potential net benefits of the U.S. employer vaccination mandates, we compare the benefits of averting COVID-19 cases and deaths to the costs of increased vaccination. We simulate disease dynamics over a six-month period (from February 1, 2022, to July 31, 2022), without and with the mandates, estimating the potential health impacts of the mandates under several pandemic trajectories.

In the following, we first discuss the increase in the number of fully vaccinated adults potentially attributable to the mandates. We then present our estimates of the health impacts of the mandates and the total costs and benefits.

4.1. Increase in Vaccinated Workers

Evaluating the impacts of the mandates requires estimating the number of people likely to be vaccinated without the mandates over the period assessed for comparison. Although research on other COVID-19 vaccine mandates finds that they spur increased vaccination rates (Karaivanov et al. 2022, Oliu-Barton et al. 2022), the size of the effect varies depending on the share of the population already vaccinated, the degree to which individuals and organizations comply with the requirements, the details of the requirements and the allowed exemptions, and the pandemic trajectory (Mills and Rüttenauer 2022). Even without mandates, additional people will likely be vaccinated, e.g., because of concerns about the emergence of a more dangerous variant, the implementation of vaccine mandates at the local or firm level, or requirements to be vaccinated to participate in certain activities (such as attending a concert) or visit certain venues (such as some restaurants). In addition, social norms may play an important role. As more people become vaccinated, vaccine hesitancy may decrease.

We estimate that the mandates covered 86.7 million workers, based on federal workforce data from the U.S. Office of Personnel Management (OPM 2021), healthcare worker data from CMS (2021), and federal contractor and private sector employer data reported by OSHA (2021a,b). Most (85%) of the covered workers were subject to the private sector employer mandate (age distribution in Appendix B).

In the without-mandate scenario, we assume that vaccination rates among non-healthcare workers, including federal employees, federal contractors, and private sector employees, are equal to population-level rates. Vaccination rates among healthcare workers are typically higher, although significant disparities in vaccine uptake exist among different subgroups (CMS 2021, OSHA 2021a, Farah et al. 2022). Based on reports of vaccination coverage among hospital-based healthcare personnel (Reses et al. 2021), we estimate that healthcare workers were about 12% more likely to be vaccinated than the rest of the working-age population when the mandates were announced; we assume that this relationship persists under the without-mandates scenario.[10] As of October 2021 (i.e., around the time the mandates were announced), about 64% of the U.S.

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[10] According to Reses et al. (2021), by mid-September 2021, 30% of hospital-based healthcare workers were not vaccinated, compared with 37.6% of the general working-age population. Thus, $\frac{70}{62.4} \simeq 1.12$.

working-age population (18–64) was fully vaccinated (CDC 2022a). This is likely an underestimate of the vaccination rates that could have been expected by the time the mandates were fully in effect. Thus, we use the age-specific vaccination rates observed on January 31, 2022, as the "benchmark" estimate of the rates for non-healthcare workers in the "without-mandates" scenario, with the 12% upward adjustment in the case of Medicare and Medicaid providers and suppliers. We recognize that observed rates as of January 31, 2022, include some vaccinations attributable to the mandates, but expect the effect of the mandates was small given that (as noted earlier) all had been subject to challenges and the largest (the OSHA regulation) had been withdrawn.[11]

We rely on research reported in OSHA (2021a) and CMS (2021) to determine the additional number of federal contractors, private sector employees, and healthcare workers that will be vaccinated under the with-mandates scenario (see details in Appendix C). We use OSHA estimates for both private sector employees and federal contractors, given uncertainty about the extent to which individual firms will be covered by the OSHA regulation or by the contractor executive order. Based on estimates of vaccine confidence, religious and medical exemptions, the coverage of existing state- or firm-level mandates, and the extent to which firms will allow testing in lieu of vaccination,[12] OSHA projects that 89.4% of all covered workers will be vaccinated under the mandate. CMS projects that 98.9% of healthcare workers will be vaccinated in the with-mandate scenario based on the impact of previous state and organizational COVID-19 vaccination

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[11] Only the federal employee mandate was fully implemented as of January 31, accounting for only 2% of the population covered by the mandates and about 0.6% of the overall U.S. population. The observed vaccination rate as of January 31 is also below the rate that would have been projected *ex ante* at the time the mandates were published, given that vaccination rates slowed significantly over time.

[12] Private sector employers covered by the OSHA regulation may also choose to require testing and face coverings in lieu of vaccination.

requirements for these workers. For federal workers we rely on vaccination rates provided by the White House in December 2021, according to which 92.5% of covered federal employees were estimated to have received at least one COVID-19 vaccination dose as of December 8, 2021 (White House 2021). We stratify these overall projections by age group by assuming that the age-specific increase in vaccination is proportional to the proportion of unvaccinated individuals in the without-mandates scenario.[13]

In total, we estimate the mandates will increase the vaccination rate among covered employees by 18.2 percentage points, or about 15.8 million individuals. When added to the estimated number of adults vaccinated nationally as of January 31, 2022, overall coverage increases from 74.7% to 79.4% of the U.S. population aged 18 and older. Most of this increase is attributable to the OSHA mandate for private sector employees, which covers a much larger population than the other mandates. Table 3 summarizes the overall number of vaccinated employees with and without mandates by employee category. Appendix B reports the percentage of vaccinated individuals by age group in the without-mandates and with-mandates scenarios.

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[13] We cap all age-specific vaccination rates estimated under the without-mandates and with-mandates scenarios at 99.5%.

Table 3. Projected change in the number of vaccinated employees

Mandate	Covered employees	Vaccinated employees, without mandate	Vaccinated employees, with mandate	Change in vaccinated employees
Federal employees	2.02 million	1.47 million (72.6%)	1.87 million (92.5%)	402,000 (19.9%)
Private sector and contractor employees	74.26 million	52.94 million (71.3%)	66.39 million (89.4%)	13.44 million (18.1%)
Healthcare employees	10.39 million	8.29 million (79.8%)	10.27 million (98.9%)	1.99 million (19.2%)
Total	86.67 million	62.70 million (72.4%)	78.53 million (90.6%)	15.84 million (18.2%)

Sources: Authors calculations based on OPM (2021), OSHA (2021a,b), CMS (2021) for the number of covered employees; CDC (2022c), Reses et al. (2021) for the number of vaccinated employees without mandates; OSHA (2021a), CMS (2021), White House (2021) for the number of vaccinated employees with mandates.

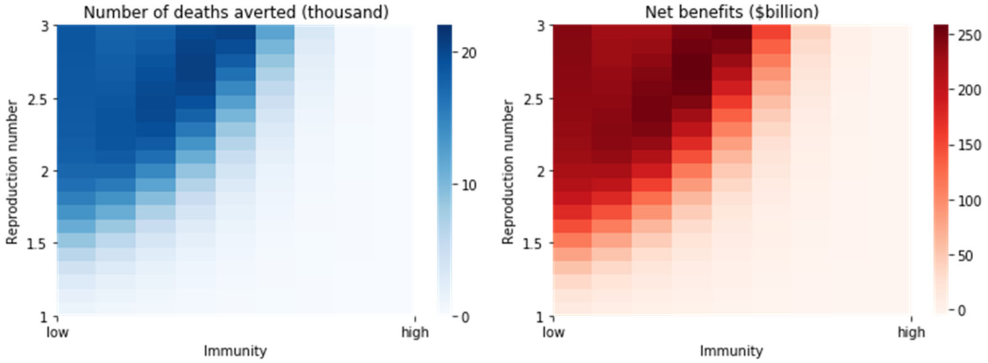
Notes: Vaccinated employees as a percentage of covered employees are reported in parentheses.

4.2. Health Impacts

As discussed earlier, we estimate the number of COVID-19 cases of differing severities and deaths averted due to the increase in the number of individuals fully vaccinated over a six-month period. Because the future path of the pandemic was perhaps the most significant uncertainty at the time the mandates were issued, we vary associated parameters to illustrate the effects of this uncertainty. We vary the reproduction number from one to three, vaccine effectiveness against infection from 20% to 90%, and the share of the population with infection-acquired immunity from 10% to 40%.

Figure 2 (left panel) and Appendix Figure B1 summarize the simulation results in terms of, respectively, deaths and cases of illness averted as a function of the reproduction number (y-axis) and of the proportion of the population with either infection-acquired or vaccination-acquired immunity (x-axis). The proportion of the population with immunity depends on the effectiveness π of the vaccine and on the proportion of the population in the recovered states at the beginning of the simulation, R_0. We vary these variables linearly and simultaneously from their respective lower bounds to their respective upper bounds. Thus, the "low" immunity case corresponds to $\pi = 20\%$ and $R_0 = 10\%$, while the "high" immunity case corresponds to $\pi = 90\%$ and $R_0 = 40\%$. The middle point in the x-axis corresponds to $\pi = 55\%$ and $R_0 = 25\%$, and so on. The number of deaths averted goes from a few dozen, if the reproduction number is low and the share with immunity is high, to almost 23,000 if the variant is very infectious and the share of the population with immunity is low. The number of total cases averted ranges from a few hundred to 5 million.

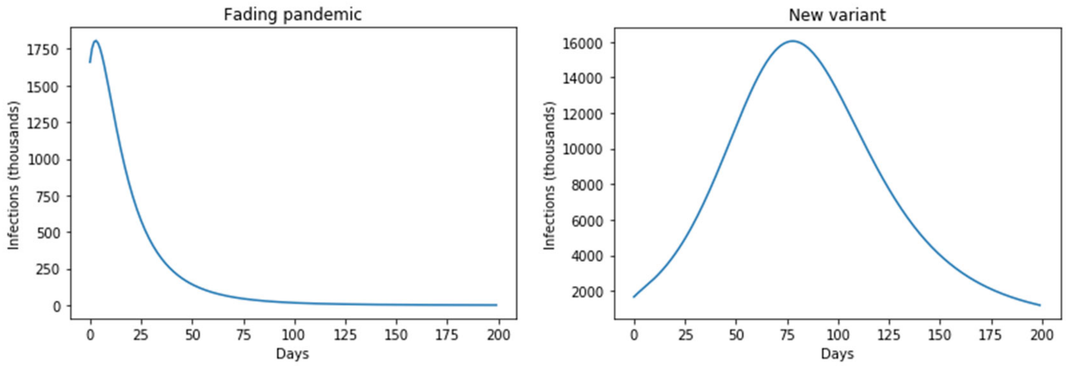
Figure 2. Deaths averted (in thousands) and corresponding net benefits (in $ billions) with the mandates as a function of the reproduction number (y-axis) and of the proportion of the population with vaccination-acquired or infection-acquired immunity (x-axis)



Notes: "Low" immunity corresponds to 20% vaccine effectiveness against infection and 10% of the population protected against re-infection because of past infection. "High" immunity corresponds to 90% vaccine effectiveness against infection and 40% of the population protected against re-infection because of past infection.

To highlight the importance of uncertainty in the pandemic trajectory on the net benefits of the mandates, we consider two illustrative pandemic paths. Our first assumes that at the beginning of the simulation, the pandemic is fading toward an endemic state. A large share of the population has infection- or vaccination-acquired immunity ($R_0 = 35\%$, $\pi = 80\%$, and $\mathcal{R}_0 = 2$); a small surge of infections occurs, and as a result the health benefits of the mandates are limited. The second assumes that at the beginning of the simulation period, a new variant emerges that is more infectious and for which existing vaccines and past infection are less protective (e.g., an Omicron-type variant; $R_0 = 15\%$, $\pi = 40\%$, and $\mathcal{R}_0 = 3$). Figure 3 depicts the number of active infections over time without the mandates for the two illustrative scenarios.

Figure 3. Number of active infections over time without mandates in two illustrative scenarios



Notes: Fading pandemic: $R_0 = 35\%$, $\pi = 65\%$, and $\mathcal{R}_0 = 2.1$. New variant: $R_0 = 15\%$, $\pi = 40\%$, and $\mathcal{R}_0 = 3$.

The emergence of a new variant leads to a large surge of infections, and the health benefits of the mandates are substantial. Table 4 reports the number of cases and deaths averted by age group for each pandemic scenario over the six-month simulation period. Overall, with a fading pandemic only a few hundred deaths are prevented, while with the emergence of a new variant, 15,000 deaths are avoided. Table 4 also reports the number of additional vaccinations by age group. In absolute terms, most of the health benefits accrue to individuals in the 50–64 age group due to their relatively high risk of severe illness and death from COVID-19 and the estimated increase in vaccination uptake in this group with the mandates. Although relatively few additional vaccinations occur among individuals in the 65–74 age group (given that many in this age group are no longer employed), these individuals accrue the largest reduction in mortality risk, especially in the presence of a more dangerous variant. Non-working-age populations (0–17 and 75+) benefit from the mandates as well, due to the indirect protection conferred by a higher vaccination rate in the population.

Table 4. Number of cases and deaths averted by age group in two illustrative pandemic scenarios

	Age 0–17	**Age 18–49**	**Age 50–64**	**Age 65–74**	**Age 75+**	**All Ages Total**
Fading pandemic						
Cases	5,200	49,300	12,300	2,700	600	70,100
Deaths	0	30	70	60	80	240
New variant						
Cases	403,300	2.46 million	728,700	224,200	100,800	3.92 million
Deaths	20	3,100	7,300	3,800	770	15,000
Number of additional individuals vaccinated	0	12.5 million	3 million	244,000	0	15.8 million

4.3. Net Benefits

Figure 2, right panel, shows the net benefits of the mandates (in billions of dollars) as a function of the reproduction number and of the proportion of the population with infection-acquired or vaccination-acquired immunity, using our central estimates of benefit values from Table 2 and estimated costs of $340 per additional vaccinated individual. Nonfatal illnesses dominate the number of averted cases, which are mostly asymptomatic or relatively mild. The value per death averted is an order of magnitude greater than the value for even the most critical nonfatal case. Thus, a close correlation exists between the number of deaths averted and the size of the net benefits.

The pandemic trajectory substantially affects net benefits, suggesting that the timing of the mandates relative to this path is an important determinant of the results. However, this timing is particularly difficult to predict for a relatively unfamiliar virus like SARS-CoV-2. If, by the time the mandates are fully enforced, the reproduction number is low and the share of the population with vaccination- or infection-acquired immunity is high, few cases and deaths are averted, and the mandates yield very small, and possibly negative, net benefits. By contrast, if a new viral strain emerges that is more transmissible (has a high reproduction number) and for which existing immunity is not very protective, then the net benefits from the mandates are substantial (about $260 billion from Figure 2). A simple back-of-the-envelope calculation using the central VSL estimate suggests that if the per-person cost of vaccination is $340 and we ignore nonfatal cases, the mandates would need to prevent at least 470 deaths to break even (i.e., to yield zero net benefits). If the per-capita cost doubles (to $680), the breakeven point is 941 deaths.

Table 5 summarizes the net benefits for the two illustrative pandemic scenarios. With a fading pandemic, net benefits are negative, but they reach $201.4 billion with a new, more dangerous variant. Table 5 also highlights the sensitivity of net benefits to the high and low VSL estimates discussed earlier and tests the effects of increasing vaccination costs to account for potential unforeseen factors. Not surprisingly, with the threat of a new variant, the net benefits of the mandates are substantial, regardless of which cost and benefit values are adopted (see also Appendix Figure B2).

Table 5. Estimated net benefits

Scenario	Fading Pandemic			Pandemic with new variant		
	Cases averted	**Deaths averted**	**Net benefits**	**Cases averted**	**Deaths averted**	**Net benefits**
Baseline: VSL=$11.4 mil; $340 cost	70,100	240	-$2.2 billion	3.9 million	15,000	$201.4 billion
Low VSL: VSL=$5.3 mil; $340 cost	70,100	240	-$3.8 billion	3.9 million	15,000	$93.0 billion
High VSL: VSL=$17.4 mil; $340 cost	70,100	240	-$0.5 billion	3.9 million	15,000	$307.8 billion
Higher vaccination costs: VSL=$11.4 mil; $680 cost	70,100	240	-$7.5 billion	3.9 million	15,000	$196.1 billion

Because COVID-19 deaths occur disproportionally among older adults, some previous analyses of lockdowns, social distancing, and other policies (e.g., Greenstone and Nigam 2020) have adjusted VSL for age and ignored other, potentially counterbalancing factors. As discussed in Robinson et al. (2021b), the relationship between age and VSL is uncertain. They find that alternative approaches to this adjustment lead to average VSL estimates that are 42% and 78% of the central estimate, given the distribution of COVID-19 deaths throughout the U.S. population. Thus, our low value for VSL (which is 46% of our central estimate) leads to results that resemble the results if we solely adjusted VSL for age.

In the previous sections, we explore the effects of uncertainty in the pandemic pathway and in the benefit and cost values. Several other model parameters are also subject to high uncertainty. Table 6 reports the results of additional sensitivity tests. In particular, we focus on the without-mandate population-wide vaccination rates, the vaccination rates among children, the effectiveness of the vaccine, and the length of immunity. Our estimate of vaccine uptake due to the mandates (15 million additional vaccinated individuals) depends in part on the assumptions about vaccination rates in the without-mandates scenario. If vaccination rates without mandates were lower (e.g., if we used the rates observed in October 2021 rather than those observed in January 2022), but we use the same approach to estimate the change in rates due to the mandates, the associated increase in vaccinated individuals is 21 million. Under this scenario, estimated benefits would substantially increase even if no new variant emerged. When predicting the without-mandates vaccination rates, the largest uncertainty concerns vaccination uptake among young children because they became eligible only in the fall of 2021 (HHS 2022a). Although the mandates do not directly affect children, the rates at which they are vaccinated affects the spread of infection throughout the population under each scenario. However, assuming lower vaccination rates among children does not substantially affect the benefits of the mandates.

Table 6. Additional sensitivity analyses

Scenario	Fading pandemic			Pandemic with new variant		
	Cases averted	**Deaths averted**	**Net benefits**	**Cases averted**	**Deaths averted**	**Net benefits**
Baseline values + low vaccination rate without mandates	338,600	1,300	\$9.5 billion	7.3 million	29,900	\$404.3 billion
Baseline values + low vaccination rate among children	78,100	270	-\$1.8 billion	3.8 million	14,900	\$201.2 billion
Baseline values + lower effectiveness of the vaccine at preventing severe disease ($\mu = 0$)	70,100	250	-\$2.1 billion	3.9 million	30,300	\$354.0 billion
Baseline values + mean duration of immunity equal to six months	84,700	320	-\$1.2 billion	3.4 million	15,500	\$203.2 billion

Throughout the analysis, we assume that vaccines are very effective at preventing severe disease independently of the dominant variant. If the vaccines do not confer additional protection against severe disease ($\mu = 0$), i.e., if protection against severe disease were reduced to the same level as protection against infection, we find that net benefits would increase. This is due to the nonlinearities in the epidemiological model and in particular to the result that, compared with a scenario with $\mu > 0$, when $\mu = 0$ the number of deaths increases faster with low vaccination rates (without-mandate scenario) than with higher overall vaccination rates (with-mandate scenario).

Paradoxically, this suggests that the benefits of increasing vaccination rates through mandates are larger with a vaccine that is less effective at inducing direct protection against death.

Finally, we test the importance of our assumption that mean duration of immunity is nine months. If vaccination- and infection-acquired immunity wanes after six months, the net benefits of the mandates are slightly larger due mostly to the increase in the number of deaths averted. Due to the chosen time horizon (six months), the simulations capture only one wave of infections. If the length of immunity shortens, a larger wave of infections occurs because more people are likely to have lost their immunity. Consequently, the potential benefits of increasing the number of vaccinated individuals increase.

5. Discussion and Conclusions

This paper investigates the COVID-19-related health benefits and direct costs of the employer vaccination mandates issued by the U.S. federal government in September–November 2021 as if they had been implemented as intended. Our analysis suggests that the benefits exceed the direct costs under various assumptions regarding the pandemic trajectory, except under a scenario in which the mandates are implemented when the pandemic is fading. The net benefits are particularly large in the presence of a new variant that is more infectious and for which vaccines and previous infection are less effective at preventing contagion. Thus, the main benefit of the mandates may be to prevent the potential catastrophic consequences that a new variant could pose.

Based on the results of Figure 2, we estimate that the gross benefits of the mandates range from \$10 to more than \$16,000 per additional vaccinated person, depending on the status of the pandemic. Most of the benefits accrue to the newly vaccinated individuals (direct protection from vaccination). However, the mandates also confer indirect protection to individuals not covered by the mandates (e.g., children and older adults) by reducing transmission.

We do not compare the effects of the mandates with other policies that encourage vaccinations or with policies that provide other types of protection. The primary difference between mandates and other vaccine promotion efforts is that mandates require rather than encourage vaccination. As such, they likely spur faster and perhaps greater increases in vaccination rates. However, as ongoing litigation illustrates, mandates may also increase social discord and raise issues about government use of coercive tactics. Our analysis does not account for these concerns, which likely counterbalance the positive benefits to an unknown extent.

We also do not compare vaccination with other policies, such as masking, testing, social distancing, ventilation and filtration, or activity limitations (such as lockdowns). Such policies may be useful supplements to vaccination requirements or substitutes. More work is needed to assess the costs and benefits of these policies so they can be compared with the impacts of vaccination mandates or promotion efforts. One challenge is that differences in analytic approach can obscure or exaggerate differences in impacts. Applying consistent analytic methods and assumptions across a suite of policy options will aid in determining the most desirable combination of actions.

The analysis has other limitations. While we consider various scenarios, we lack data on the likelihood of those scenarios. We also make several simplifying assumptions. For example, we assume that the change in the number of people vaccinated occurs at a single point in time, rather than being spread out over time; we ignore the role of booster shots; and we do not address spatial variations in vaccination and infection rates (Beleche et al. 2021).

More generally, our estimates likely understate the net benefits of the mandates given that we limit the analysis to a six-month time frame and consider a limited set of effects. Additional benefits of increased vaccination may include reduced public and private expenditures on outbreak containment and response, lower likelihood that other variants will emerge, increased resources available to treat other health conditions, and improved mental health. Increased vaccination rates may also improve educational outcomes by permitting schools to stay open, spur economic activity and growth by reducing business closures and increasing consumer confidence and demand, and improve social wellbeing by decreasing isolation (Bloom et al. 2021a).

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Supplementary Materials

Appendix A. Calibration of the Epidemiological Model

Table A1 summarizes the selected values for the epidemiological model parameters and the sources supporting these assumptions. Table A2 reports the age distribution of the age-varying parameters. The pre-COVID-19 age-specific contact matrix is divided into five age bins (Prem et al. 2021). Using population-weighted averages, we combine these age bins into the broader age groups used in the simulation (Table A3).

Table A1. Parameters of the epidemiological model

Parameter	Description	Value	Reference
$1/\gamma_E$	Mean latent period	3 days	Based on median incubation period of 5 days and assuming that infectiousness starts two days before symptoms (Lauer et al. 2020).
$1/\gamma_I$	Mean duration of infectiousness	5 days	Based on the assumption that infectiousness decreases rapidly after onset of symptoms even though viral shedding may last longer (Cevik et al. 2021).
$1/\gamma_H$	Mean duration of hospitalization	12 days	Based on Centers for Disease and Control (CDC) estimates of median number of days from symptom onset to death of about 2 weeks (CDC 2021).
$1/\gamma_S$	Mean duration of infection- and vaccination-acquired immunity	270 days	Based on evidence that both fully vaccinated and previously infected individuals have a low risk of subsequent infection for at least 6 months (Dan et al. 2021, De Giorgi et al. 2021).
r_i	Relative susceptibility to infection for age-i individuals	See Table A2	Davies et al. (2020).

Parameter	Description	Value	Reference
c_{ij}	Average number of age-j individuals contacted by an age-i individual per day	See Table A3	Prem et al. (2021).
N_i	Number of individuals in age group i	Total population: 331,890,000 See Table A2 for age distribution	U.S. Census Bureau (2020) and https://www.census.gov/quickfacts/fact/table/US/PST045221.
α_i	Share of infections that are asymptomatic	Age-dependent (see Table A2)	Ma et al. (2021). Estimates for ages 0–20 were used to approximate the percentage asymptomatic among the 0–17 age group; results for ages 20–39 were used to estimate the percentage among the 18–49 age group; results for ages 40–59 were used to approximate the percentage for the 50–64 age group; results for ages 60 and over were used to approximate the percentage for the remaining age groups.
h_i	Share of infected individuals who are hospitalized	Age-dependent (see Table A2)	Based on Salje et al. (2020) and adjusted for U.S. population pyramid.
icu_i	Share of hospitalizations requiring admission to ICU	Age-dependent (see Table A2)	Based on Salje et al. (2020) and adjusted for U.S. population pyramid.
ϕ_i	Share of hospitalized individuals who die	Age-dependent (see Table A2)	Based on infection fatality rates from Levin et al. (2020), Table 3, and adjusted for U.S. population pyramid.
R_{i0}, R_{i0}^V	Number of people with infection-acquired immunity, by age and vaccination status $R_0 \equiv \sum_i (R_{i0} + R_{i0}^V)$	$R_0 \in [10\%, 40\%]$ Age- and vaccination- profile in Table A2	The 40% figure is based on estimates of infection-induced seroprevalence antibodies from the CDC (2022a) and baseline vaccine effectiveness assumptions. Sensitivity analysis with $R_0 < 40\%$
$\mathcal{R}_0$	Basic reproduction number	[1,3]	Assumption
π	Effectiveness of the vaccine against infection	[20%–90%]	Based on likely estimates of vaccine effectiveness against infections of the Delta and Omicron variants (Andrews et al. 2022a, Lopez Bernal et al. 2021, Tartof et al. 2021) and sensitivity analysis.
μ	Additional effectiveness of the vaccine against severe disease (here proxied by hospitalization)	[50%–94%]	Total effectiveness T_s of the vaccine against severe disease is defined as $T_s = \pi + (1 - \pi)\mu$. We set $T_s = 95\%$ and derive the corresponding μ. 95% effectiveness is based on estimates of vaccine effectiveness against severe disease and death (Andrews et al. 2022a,b).

Table A2. Age-specific demographic and epidemiological data

Age group	Population share[a] (%)	Asymptomatic rate[b] (%)	Hospitalization rate[c] (%)	ICU rate[c] (%)	Infection-fatality rate[d] (%)	Relative susceptibility[e]	Initial infection-acquired immunity share[f] (%)	Percentage recovered vaccinated (%)[g]
0–17	22.4	60.2	0.15	17.34	0.004	0.39	29.7	7.2
18–49	42.0	49.5	0.86	16.04	0.057	0.79	45.3	28.1
50–64	19.3	32.5	3.70	31.79	0.581	0.84	16.0	43.7
65–74	9.8	33.8	8.40	28.00	2.500	0.82	5.4	66.2
75+	6.5	33.8	19.20	10.25	13.995	0.74	3.6	54.3

Sources: a. U.S. Census Bureau (2020); b. Ma et al. (2021); c. Salje et al. (2020); d. Levin et al. (2020); e. Davies et al. (2020); f. CDC (2022a); g. own estimation.

Notes: The "initial infection-acquired immunity share" refers to the age distribution of the number of people with infection-acquired immunity. For example, if 100 people have infection-acquired immunity, 30 of them are in the 0–17 age group, 45 in the 18–49 age group, etc. The "percentage recovered vaccinated" denotes the age-specific proportion of recovered individuals who are vaccinated. Continuing the previous example, if 30 individuals with infection-acquired immunity are in the 0–17 age group, 2 of them (i.e., 7.2% of them) have been vaccinated.

Table A3. Pre-pandemic age-specific expected daily contacts

Age of the person making the contact	Age of the person contacted				
	0–17 years	18–49 years	50–64 years	65–74 years	75+ years
0–17 years	12.14	4.34	1.56	0.24	0.07
18–49 years	3.64	8.31	3.20	0.24	0.06
50–64 years	2.92	6.17	4.73	0.52	0.11
65–74 years	3.29	3.67	2.53	1.41	0.24
75+ years	2.09	1.65	1.51	0.65	0.27

Source: Prem et al. (2021).

Initial Number of Recovered Individuals by Age and Vaccination Status

Let $R_0 = \sum_i (R_{io} + R_{io}^V)$ be the initial number of recovered individuals. To determine the distribution of recovered individuals R_0 by age group, we use data from the Centers for Disease Control and Prevention (CDC) on infection-induced seroprevalence (CDC 2022a). Based on the CDC estimates and accounting for the age distribution of the U.S. population, the age distribution of individuals with infection-induced seroprevalence antibodies was stable during Fall-Winter 2021–2022: About 30% of individuals with antibodies were younger than 17, 45% were in the 18–49 age group, 16% were in the 50–64 age group, and the rest were in the 65+ age group (see Table A2, "initial infection-acquired immunity share"). We assume that the age distribution of individuals with infection-induced seroprevalence antibodies is a good representation of the initial age distribution of recovered individuals.

Next, we determine the proportion of recovered individuals who are vaccinated for each age group. Because of the protection conferred by vaccination, unvaccinated individuals are more likely to have been infected with SARS-CoV-2 than vaccinated individuals.[14] Furthermore, unvaccinated infected individuals are more likely to be hospitalized and die than vaccinated infected ones, thereby reducing the observed proportion of unvaccinated recovered individuals. We derive the proportion of vaccinated/unvaccinated recovered individuals in the without-mandate scenario using the following approximation:

$$R_i \simeq x_i(1 - ifr_i)Unvax_i + (1 - \pi)x_i(1 - (1 - \mu)ifr_i)Vax_i,$$

where R_i is the total number of recovered individuals in age group i, ifr_i is the infection-fatality ratio, x_i is the proportion of unvaccinated individuals who have been infected, π and μ represent the effectiveness of the vaccine at reducing infection and severe disease, and $Unvax_i$ and Vax_i are the number of unvaccinated and vaccinated individuals in group i, respectively. The first term is the number of recovered unvaccinated individuals, and the second term is the number of recovered vaccinated individuals. The only unknown variable in the expression is x_i. Using model

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[14] For example, before the spread of the Omicron variant, the number of reported COVID-19 cases was about five times larger among unvaccinated than vaccinated individuals (https://covid.cdc.gov/covid-data-tracker/#rates-by-vaccine-status).

assumptions about infection-fatality ratios (Table A2), baseline vaccine effectiveness,[15] the CDC estimate of individuals with infection-induced seroprevalence antibodies (40%), and vaccination shares as of January 2022,[16] we solve for x_i and determine the proportion vaccinated and proportion unvaccinated among recovered individuals in each age group. Table A2 shows the results. For example, 54.3% of recovered individuals aged 65 and above have been vaccinated.

We apply those age-specific proportions of vaccinated/unvaccinated recovered individuals to all scenarios, independently of the overall number of recovered individuals (regardless of whether it is 40% of the population or less) and of the percentage of the population that is vaccinated at the beginning of the simulation.

Reproduction Number

We assume that susceptibility to infection is age specific, with children and adolescents being less susceptible than adults (Goldstein et al. 2021). We set $\beta_i = \beta r_i$, where r_i denotes the relative susceptibility to infection, taken from Davies et al. (2020), while β is a scale factor calibrated to obtain the reproduction number of interest. To compute the scale factor β, we use the next-generation matrix method (see, e.g., Towers and Feng 2012). Let $M_{ij} = \frac{r_i}{\gamma_I} c_{ij} \frac{N_i}{N_j}$ be the ith-row and jth-column of the next-generation matrix M. The reproduction number is $\mathcal{R}_0 = \beta\ eval(M)$, where $eval(M)$ is the real part of the largest eigenvalue of M. As a consequence, $\beta =$

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[15] We assume that the baseline vaccine effectiveness against infection is 80% to account for some waning over time compared with the anticipated effectiveness against the Delta variant (about 90%).

[16] We assume that the observed number of vaccinated/unvaccinated individuals nets out those who have been infected and died. Thus, $Unvax_i = \frac{Observed\ Unvax_i}{1 - x_i ifr_i}$ and $Vax_i = \frac{Observed\ Vax_i}{1 - x_i(1-\pi_i)(1-\mu) ifr_i}$.

$\frac{\mathcal{R}_0}{eval(M)}$. We vary the reproduction number $\mathcal{R}_0$ from one to three to capture different transmissibility levels across variants and different levels of control.

Appendix B. Additional Tables and Figures

Table B1. QALY gains per nonfatal case averted by age range and severity category

Age group	Mild	Severe	Critical
0–17	0.011	0.023	4.209
18–49	0.011	0.023	3.622
50–64	0.009	0.022	2.481
65–74	0.009	0.021	1.859
75+	0.009	0.019	1.100

Sources: Authors' calculations based on Robinson et al. (2021), 3% discount rate.

Table B2. Medical costs averted per case by severity category

	Mild	Severe	Critical	Fatal
Medicare fee-for-service average costs[a]	\$154[i]	\$18,460[ii]	\$49,441[iii]	\$32,015[iv]
Estimated average costs for all insurers[b,v]	\$230	\$27,457	\$73,538	\$47,619

Sources: a. Tsai et al. (2021). b. Authors' calculations based on Tsai et al. (2021) estimates and an adjustment factor derived from data published by Avalere Health (2020).

Notes: i. Average cost per outpatient visit multiplied by average number of outpatient visits. ii. Average hospitalization costs excluding deaths and cases involving ventilators. iii. Average costs among cases involving ventilators. iv. Cases involving death. v. Adjustment factor (1.49) calculated by dividing the weighted average cost across all insurers by the average cost for Medicare fee-for-service patients.

Table B3. Individual willingness to pay per case averted by age range and severity category, central VSL estimate

Age group	Mild	Severe	Critical	Fatal
0–17	\$6,380	\$13,340	\$2,441,220	\$11,400,000
18–49	\$6,209	\$13,169	\$2,100,763	\$11,400,000
50–64	\$5,220	\$12,569	\$1,439,244	\$11,400,000
65–74	\$5,220	\$11,921	\$1,078,393	\$11,400,000
75+	\$5,220	\$11,276	\$637,753	\$11,400,000

Notes: VSL=\$11.4 million; value per QALY = \$580,000.

Table B4. Individual willingness to pay per case averted by age range and severity category, low VSL estimate

Age group	Mild	Severe	Critical	Fatal
0–17	$2,970	$6,210	$1,136,430	$5,300,000
18–49	$2,890	$6,130	$977,741	$5,300,000
50–64	$2,430	$5,851	$669,993	$5,300,000
65–74	$2,430	$5,549	$502,011	$5,300,000
75+	$2,430	$5,249	$296,885	$5,300,000

Notes: VSL=$5.3 milion; value per QALY = $270,000.

Table B5. Individual willingness to pay per case averted by age range and severity category, high VSL estimate

Age group	Mild	Severe	Critical	Fatal
0–17	$9,680	$20,240	$3,703,920	$17,400,000
18–49	$9,420	$19,980	$3,187,365	$17,400,000
50–64	$7,920	$19,071	$2,183,360	$17,400,000
65–74	$7,920	$18,087	$1,636,183	$17,400,000
75+	$7,920	$17,108	$967,625	$17,400,000

Notes: VSL=$17.4 million; value per QALY = $880,000.

Table B6. Estimated number of covered workers by sector and age group

Age group	Private employers and federal contractors	Federal employees	Healthcare workers	Total
18–49	49,773,098	1,151,421	6,964,167	57,888,686
50–64	20,396,678	762,966	2,853,868	24,013,513
65–74	4,087,849	107,581	571,965	4,767,395
Total	74,257,625	2,021,968	10,390,000	86,669,594

Sources: Authors' calculations based on OPM (2021), OSHA (2021a,b), CMS (2021), and age-specific labor force participation data (U.S. Bureau of Labor Statistics 2022).

Table B7. Employee vaccination rates without and with mandates

Age group	**Vaccination rate without mandates (%)**		**Vaccination rate with mandates (%)**	
	Low	**Benchmark**	**Low**	**Benchmark**
0–17	17.1	28.3	17.1	28.3
18–49	59.9	66.7	71.8	73.5
50–64	75.0	80.0	81.6	83.6
65–74	87.1	91.0	88.3	92.1
75+	81.8	85.2	81.8	85.2
Population average	57.3	64.2	63.7	67.9
18+	69.0	74.7	77.2	79.4

Notes: The "benchmark" scenario uses the actual vaccination rates as of January 31, 2022, as a proxy for the vaccination rates in the without-mandates scenario (with a 12% upward adjustment in the case of Medicare and Medicaid providers and suppliers). The "low" scenario uses the vaccination rates as of October 1, 2021, as a proxy for the vaccination rates in the without-mandates scenario (with the aforementioned adjustment).

Figure B1. Number of cases averted (by severity category) with the mandates as a function of the reproduction number (y-axis) and of the proportion of the population with infection-acquired or vaccination-acquired immunity (x-axis)

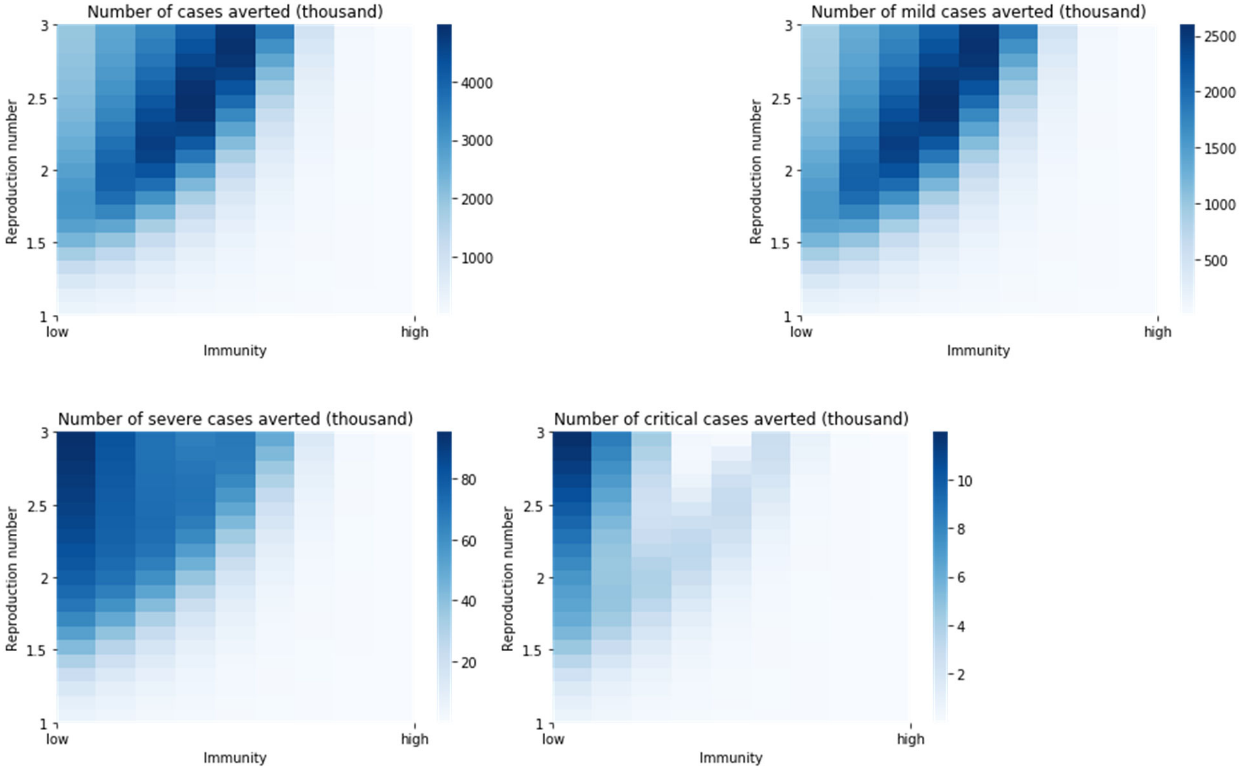
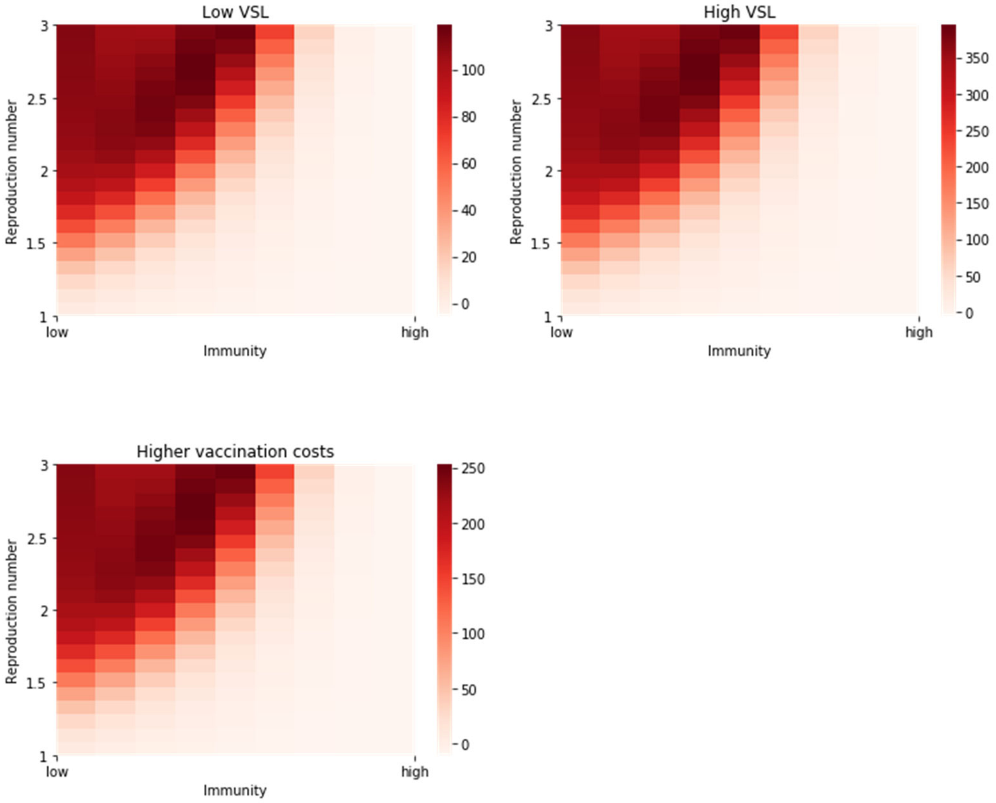


Figure B2. Sensitivity of net benefits to benefit and cost estimates as a function of the reproduction number (y-axis) and of the proportion of the population with infection-acquired or vaccination-acquired immunity (x-axis), various scenarios.



Appendix C. Estimation of with-Mandates Vaccination Rates among Federal Contractors, Private Sector Employees, and Healthcare Workers

As discussed in the main text, with-mandates vaccination rates for federal employees are taken directly from data reported by the White House. For the other sectors, we rely on estimates from OSHA (2021a) and CMS (2021). The following summarizes the agencies data sources and calculations.

Under the with-mandates scenario for covered private sector workers and federal contractors, we apply assumptions from the OSHA *Federal Register* notice concerning which unvaccinated workers are likely to become vaccinated under the mandates (OSHA 2021a, pp. 61470–61473). To inform its assumptions, OSHA begins with CDC vaccine confidence data from October 2021 (CDC 2022b), which indicate that 13.8% of the population "probably or definitely will not" get the vaccine; OSHA categorizes these individuals as "vaccine-hesitant." OSHA further estimates that 5% of covered workers are vaccine-hesitant for religious or medical reasons and will be granted exemptions under any employer policy in compliance with the mandates. Four percent of all workers are assumed to pursue religion exemptions based on data from Vermont tracking the share of kindergarten students with religious exemptions from general (i.e., not COVID-19) vaccination requirements (Graham 2021). One percent of these workers are assumed to pursue medical exemptions based on the share of respondents to the U.S. Census's Household Pulse Survey who indicated that they would not receive a COVID-19 vaccine because their "doctor has not recommended it" (U.S. Census Bureau 2021).

OSHA's projections are also based on assumptions concerning the share of covered firms that are likely to require vaccination of employees with only limited exemptions versus the share of covered firms that are likely to recommend vaccination but not require it (with testing and masking permitted as an alternative). Based on several surveys of employers, OSHA estimates that 25% of firms (employing 25% of covered workers) already required vaccination before the imposition of the mandate and that 60% (employing 60% of covered workers) will require vaccination once the mandate is in effect (Willis Towers Watson 2021, Mishra and Hartstein 2021, ASU COVID-19 Diagnostic Commons 2021). For the 35% of firms that did not already require vaccination but will under the mandate, OSHA assumes that the 5% of employees seeking religious or medical exceptions will be exempt. For the 25% of firms that already required vaccination, OSHA assumes that vaccine-hesitant workers other than those seeking religious or medical exemptions would have already been vaccinated. For the remaining 40% of firms that will recommend vaccination but not strictly require it, OSHA assumes that the majority of the 13.8% of employees who identify as vaccine-hesitant for any reason will opt out of vaccination. However, OSHA also assumes that some vaccine-hesitant workers (roughly 5% of all covered workers, including some of those seeking exemptions and those not) at both firms requiring vaccination and those recommending it will return to teleworking and therefore not vaccinate.

Taken together, these assumptions lead OSHA to project that 89.4% of all covered workers will be vaccinated under the mandate. We apply this overall vaccination rate to covered OSHA workers and federal contractors in the with-mandates scenario and stratify the increase in vaccination rate by age based on the age distribution of unvaccinated people in the without-mandates scenario.

For healthcare workers, we assume that 95% of those who were unvaccinated in each age group when the mandate was imposed will eventually become vaccinated, based on discussion in the CMS *Federal Register* notice (CMS 2021, p. 61608). This assumption results in an overall with-mandates vaccination rate of 98.9% for healthcare workers as a central estimate (98.6% in the low estimates scenario and 99.3% in the high estimates scenario). While this figure may seem high on its face, it is in line with vaccination rates achieved in healthcare settings that had implemented their own vaccination requirements prior to the announcement of the CMS mandate. The CMS *Federal Register* notice points to three examples (CMS 2021, p. 61569). First, a hospital system in Texas achieved a vaccination rate of 99.5% among staff after imposing a requirement (Emanuel and Skorton 2021). Second, in a Detroit-based health system that instituted a mandate, 97% of workers were fully or partially vaccinated when the mandate went into effect (Erb 2021). Third, a vaccination requirement imposed by a long-term care company across more than 250 facilities resulted in a vaccination rate of 95% (Emanuel and Skorton 2021). In addition to the examples cited by CMS, New York imposed a state-level mandate that resulted in a vaccination rate of 99% among healthcare workers (New York State 2021).

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