

Lives and Costs Saved by Expanding and Expediting COVID-19 Vaccination

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Summary: Our study quantifies the potential value of decreasing vaccine hesitancy, increasing vaccination coverage, and how this may decrease with time it takes to achieve coverage, emphasizing the need to reach high coverage levels as soon as possible, especially before Fall/Winter.

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Conflicts of Interest

PJH and MEB codirect Texas Children's Center for Vaccine Development and with US are co-developers of vaccines against emerging and neglected diseases including coronaviruses such as COVID-19. Baylor College of Medicine non-exclusively licensed a COVID-19 vaccine construct to Biological E, Inc., an India-based manufacturing company. These authors have no financial stakes in any COVID-19 vaccine candidates under development. No other financial disclosures were reported by the authors of this paper.

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Abstract

Background: With multiple COVID-19 vaccines available, understanding the epidemiologic, clinical, and economic value of increasing coverage levels and expediting vaccination is important.

Methods: We developed a computational model (transmission and age-stratified clinical and economics outcome model) representing the US population, COVID-19 coronavirus spread (02/2020-12/2022), and vaccination to determine the impact of increasing coverage and expediting time to achieve coverage.

Results: When achieving a given vaccination coverage in 270 days (70% vaccine efficacy), every 1% increase in coverage can avert an average of 876,800 (217,000–2,398,000) cases, varying with the number of people already vaccinated. For example, each 1% increase between 40%-50% coverage can prevent 1.5million cases, 56,240 hospitalizations, 6,660 deaths, gain 77,590 QALYs, save \$602.8 million in direct medical costs and \$1.3 billion in productivity losses . Expediting to 180 days could save an additional 5.8 million cases, 215,790 hospitalizations, 26,370 deaths, 206,520 QALYs, \$3.5 billion in direct medical costs, and \$4.3 billion in productivity losses.

Conclusion: Our study quantifies the potential value of decreasing vaccine hesitancy and increasing vaccination coverage and how this value may decrease with time it takes to achieve coverage, emphasizing the need to reach high coverage levels as soon as possible, especially before the Fall/Winter.

Keywords: Coronavirus; COVID-19; Vaccination; Coverage; Rate

Introduction

With multiple COVID-19 vaccines available, decision makers need to better understand the epidemiologic, clinical, and economic value of attaining higher coverage levels and the speed at which people are vaccinated in order to set targets for how many people to vaccinate and by when this should be done. Recently, the US government has stated that the country will have a large enough supply of vaccines to make 90% of all adults eligible for vaccination by April 19, 2021 and offer the vaccine to all adults by May 1.[1, 2] However, these statements do not indicate target coverage levels or how quickly vaccinations will occur once the supply is available and people are made eligible. While the US is currently vaccinating at a rate of 1.75 million doses per day, which could result in a 70% coverage by mid-June if maintained[3], multiple obstacles, including vaccine hesitancy and refusal[4-6], anti-vaccine messaging[7-11], issues with vaccination scheduling and rollout[12-14], variations in state policies on who can receive a vaccine[15], and production, supply chain, and other logistical challenges[16-18], could delay how many people ultimately receive the vaccine and when. For example, polls by Kaiser Family Foundation shows vaccine hesitancy decreasing among those who would “wait and see” for vaccination from 39% to 17% (December 2020-March 2021), yet an additional 20% surveyed maintained that they would likely not get the vaccine.[6] A poll by Pew Research Center showed similar improvements in those who would get the vaccine (51% to 69% in September 2020-February 2021)[4, 5], yet it is possible that COVID-19 vaccine acceptance levels may remain below the fairly high coverage levels ($\geq 75\%$) needed to quell the pandemic to a point where social distancing and other non-pharmaceutical interventions (NPIs) can be relaxed[19]. As such, to better understand the epidemiologic, clinical, and economic value of increasing COVID-19 vaccine coverage levels and the rate at which these levels are achieved, we used a computational model of the U.S. population to represent the spread of COVID-19 coronavirus and a range of different COVID-19 vaccination scenarios.

Methods

Model Structure

Using Microsoft Excel (Microsoft Corporation, Redmond, WA) with the Crystal Ball add-in (Oracle Corporation, Redwood Shore, CA), we adapted a previously described computational model representing the U.S. population (327,167,434 persons), their interactions with each other, COVID-19 coronavirus spread, its potential health and economic outcomes,[19-21] and vaccination. The model advances in discrete, one-day time steps for 3 years (February 2020-December 2022). On any given day, each individual is in one of five mutually exclusive COVID-19 coronavirus compartments: 1) susceptible (S , not infected and able to become infected), 2) exposed (E , infected, but not able to transmit to others), 3) infectious and asymptomatic (I_a , infected, but without symptoms, and able to transmit to others), 4) infectious and symptomatic (I_s , infected, showing symptoms, and able to transmit to others), or 5) recovered/immune (R , not infected and unable to become infected). On day one, a set number of individuals start in the ' I_a ' and ' I_s ' compartments (i.e., seed coronavirus); the remainder start in the ' S ' compartment. Each day, individuals randomly interact with each other and an infectious person can potentially transmit the virus to a susceptible person. Individuals move through the compartments at various rates (Appendix). Each symptomatically infected person (i.e., COVID-19 case) travels through a probability tree of different sequential age-specific outcomes, accruing relevant costs and health effects (Appendix).[19-23]

Since different non-pharmaceutical interventions [NPIs (e.g., social distancing, wearing face masks, closures, curfews)] have been implemented to varying degrees (e.g., recommendations and mandates vary by state and local justifications and over time) through the course of the pandemic[24-27], scenarios represented the approximate use and effect of NPIs on a national level

through January 11, 2021[28]. The Appendix describes the model data sources, calibration, validation, input parameters, and values.

Vaccination

We represented a vaccine that can prevent infection. Vaccination moves a person into the 'V' compartment. After exposure to an infected person, these individuals have a probability of being infected equal to one minus the vaccine efficacy. Once an individual is vaccinated, protection lasts throughout the simulation duration (i.e., no waning immunity). Vaccination has a probability of causing minor (e.g., fever, soreness, headache) and major (e.g., Guillain-Barre Syndrome, allergic reaction/anaphylaxis, resulting in hospitalization) side effects events. Once vaccination begins, individuals in the population are vaccinated each day based on the daily vaccination rate to achieve the total vaccination coverage level within a given timeframe. Any individual in the population could be vaccinated, even those who have been already infected. We modeled vaccination onset (e.g., time point at which onset of protection occurs) to start on January 4, 2021, which was the first date a person could be fully vaccinated with the 2-dose vaccines available in December 2020 (i.e., 21-days days after the first dose administered on December 14, 2020[29]).

Economic Measures

The third-party payer perspective includes direct medical costs (e.g., vaccination, hospitalization), while the societal perspective includes direct and indirect (i.e., productivity losses due to absenteeism resulting from COVID-19 illness) costs. Hourly wage across all occupations[30] serves as a proxy for productivity losses. Absenteeism results in productivity losses for the symptom duration. All COVID-19 cases accrue productivity losses, regardless of age or employment status, as

everyone is assumed to contribute to society. All costs are reported in 2020 values, converting all past and future costs using a 3% annual rate.

For each scenario, we calculated the incremental cost-effectiveness ratio (ICER) as:

$$ICER = (Cost_{Vaccination\ Coverage\ A} - Cost_{Vaccination\ Coverage\ B}) / (Health\ Effects_{Vaccination\ Coverage\ A} - Health\ Effects_{Vaccination\ Coverage\ B})$$

where A and B represent vaccination scenarios with different coverage levels (described below) and health effects are measured in quality-adjusted life-years (QALYs) lost due to COVID-19. Each COVID-19 infection loses QALY values based on age-dependent healthy QALY value and infection-specific utility weights for their infection duration. Death results in the loss of the net present value of QALYs for the remainder of an individual's lifetime.[31] We considered increases in coverage to be cost-effective if the ICER was $\leq \$50,000/QALY$ and economically dominant if it saved costs and provided health effects (e.g., cost saving).

Experimental Scenarios

We evaluated the epidemiologic, clinical, and economic value of increasing COVID-19 vaccination coverage and decreasing the time it takes to achieve these levels, thus comparisons were made between various coverage levels and vaccination rates. Experiments consisted of Monte Carlo simulations of 2,000 trials, varying parameters throughout their range (Appendix Table 1). Scenarios consisted of vaccinating individuals to prevent infection on January 4, 2021 and varied the proportion of the population that have been infected before vaccination onset (20%-30%). This represents a range of total cases that had occurred by this date, capturing varying NPIs use and compliance, as well as underreporting of cases. Different scenarios represented what may happen

when varying vaccination coverage (10%-90%) and the time to achieve the coverage level (180-360 days). Sensitivity analyses varied vaccine efficacy (50%-90%) as real-world effectiveness under changing conditions may differ compared to clinical trials. Different scenarios also varied the reproduction number (February 2021-December 2022) representing different possible NPI use and compliance and seasonal differences in transmission (see Appendix). Additional analyses evaluated the impact of increasing coverage in example states.

Results

Figures 1 and 2 shows how varying the vaccination coverage and the days that it took to achieve that coverage level affected the number of cases and deaths and direct medical costs and productivity losses, while Figure 3 shows the impact per person vaccinated. Table 1 reports the differences in these cases and deaths. These Figures and Tables assume effective reproduction number values such that (in the absence of vaccination) cases decrease in February and continue downward in March, then start to go up in September, representing a situation in which NPIs continue with current compliance and a more transmissible variant's spread is slowed by NPI use, then humidity and temperatures start to decrease in September, increasing transmissibility of the virus. The Appendix reports results for example states.

Vaccination Protection Onset Starts When 20% of the Population Has Already Been Infected

Impact of Increasing Vaccination Coverage

As Figures 1 and 3 show, achieving a 50% coverage in 180 days (e.g., by early summer) with a 70% efficacious vaccine, resulted in a decrease of 20.9 million cases and 775,980 hospitalizations, 91,660 deaths, gained 977,730 QALYs (about a 15% relative reduction in these outcomes) compared to

achieving a 40% coverage in 180 days. This saved \$9.6 billion in direct medical costs \$19.8 billion in productivity losses. Therefore, every 1% increase in coverage in this range resulted in 2.1 million fewer cases, 77,590 fewer hospitalizations, 9,160 fewer deaths, and 97,770 QALYs gained, saved \$960.7 million in direct medical costs and \$1.9 billion in productivity losses. Dividing by the total population provides the outcomes per person in the population, which equates to a decrease of 0.06 cases and \$60 in productivity losses per person. Further increasing coverage to achieve 60% from 50% resulted in a decrease of 11.7 million cases (10% relative reduction), which translates to 1.2 million fewer cases and 5,140 fewer deaths, gained 52,650 QALYs, saving \$410.2 million more in direct medical costs and \$1.0 billion in productivity losses per 1% increase in coverage. Increases in coverage between 70%-90% coverage resulted in higher direct medical costs and were cost-effective, with increases in coverage costing \$2,978/QALY gained.

As the figures show, when it took longer to achieve vaccination coverage levels (270 days, by early fall), every 1% increase in coverage between 40%-50% with a 70% vaccine efficacy resulted in similar incremental reductions in outcomes; 2.3 million fewer cases, 87,990 fewer hospitalizations, 10,090 fewer deaths, 102,640 QALYs gained (about an 1.6% relative decrease in clinical outcomes), saving \$1.1 billion in direct medical costs and \$2.0 billion in productivity losses. Further increasing coverage from 50%-70% resulted in about an 0.9% relative decrease in clinical outcomes (1.0 million fewer cases, 38,470 fewer hospitalizations, 4,490 fewer deaths, and 44,890 QALYs gained), saved \$324.2 million in direct medical costs and \$886.3 million in productivity losses per 1% increase. As Figures 1-3 show, when it took 360 days to achieve vaccination coverage levels incremental reductions were similar. For example, every 1% increase in vaccination coverage resulted in a 1.8% and 0.9% relative decrease between 40%-50% and 50%-70% coverage, respectively.

With a 90% vaccine efficacy (180 days), achieving a 50% coverage compared to a 30% coverage resulted in about a 31.8% relative decrease in clinical outcomes (e.g., 2.3 million fewer cases per 1% increase in coverage) and saved \$2.9 billion in total costs, while increases from 50%-70% resulted in about a 7.3% relative decrease (e.g., 179,330 cases and 756 fewer deaths per 1% increase) and saved \$279.9 million. With a 50% vaccine efficacy, increasing coverage from 30%-50% resulted in a 24.9% relative decrease in clinical outcomes (2.6 million fewer cases and 11,342 fewer deaths per 1% increase in coverage), and saved \$69.8 billion, while increasing from 50%-70% coverage, also resulted in a 24% relative decrease and saved \$55.4 billion.

Impact of Achieving Coverage Levels Faster

The figures also show how shortening the duration in which vaccination coverage levels were achieved from 360 to 270 or 180 days reduced the number of cases, deaths, and costs. For example, reaching a 50% coverage level by 270 days instead of 360 days with a 70% efficacious vaccine decreased cases by 4.2 million and deaths by 18,500, saving \$4.5 billion in total costs (Figures 1 and 3). Further shortening to 180 days (vs. 270 days) decreased cases by 2.6 million and deaths by 11,300, saving by \$5.3 billion in total costs.

Vaccination Protection Onset Starts When 30% of the Population Has Already Been Infected

When 30% of the population had already been infected by vaccination start, increasing coverage resulted in larger incremental gains when increasing between 30% and 50% compared to an increase in coverage between 50% and 90% (Figures 2-3, Table 1). For example, when it took 180 days to achieve vaccination coverage levels, by early summer (70% vaccine efficacy), every 1% increase in coverage between 40%-50% resulted in 1.6 million fewer cases, 60,190 fewer hospitalizations, 7,135 fewer deaths, 78,200 QALYs gained (about a 1% relative decrease in clinical outcomes), saved \$674.2

million in direct medical costs and \$1.5 billion in productivity losses. While further increasing coverage between 50%-70%, every 1% increase resulted in 473,917 fewer cases, 17,550 fewer hospitalizations, 2,050 fewer deaths, 20,510 QALYs gained, and saved \$3.2 million in direct medical costs and \$534.2 million in productivity losses. Increases in coverage were cost saving, except between coverages of 70%-90%, when increases in coverage cost \$6,982/QALY (societal perspective).

When it took 270 days (early fall) to achieve vaccination coverage levels (70% vaccine efficacy), every 1% increase in coverage between 40%-50% resulted in similar incremental reductions in outcomes (approximately an 0.9% relative reduction), with 1.5 million fewer cases, 56,240 fewer hospitalizations, 6,660 fewer deaths, 77,590 QALYs gained, saving \$602.8 million direct medical costs and \$1.3 billion in productivity losses. Further increasing coverage from 50%-70% resulted in about an 0.3% relative decrease in clinical outcomes (460,360 fewer cases, 16,950 fewer hospitalizations, 1,960 fewer deaths, and 16,020 QALYs gained) and saved \$343.7 million in productivity losses but cost \$2.8 million more in direct medical costs per 1% increase. As Figures 2-3 show, trends were similar when it took 360 days (to early winter) to achieve vaccination coverage levels (e.g., every 1% increase in vaccination coverage resulted in an 0.9% and 0.3% relative decrease in clinical outcomes between 40%-50% and 50%-70% coverage, respectively).

Figure 4 shows the impact of increasing coverage with different vaccine efficacies. For a 90% efficacious vaccine (180 days), increasing coverage from 30%-50% resulted in about a 15% relative decrease in clinical outcomes and saved \$32.8 billion in total costs (\$1.6 billion per 1% increase), while increases between 50%-70% resulted in about a 4.7% relative decrease in clinical outcome and saved \$188.4 million in total costs (\$110.9 million per 1% increase). With a 50% vaccine efficacy,

increasing coverage from 30%-50% resulted in a 18.4% relative decrease in clinical outcomes (e.g., 2.1 million fewer cases per 1% increase) and saved \$50.7 billion (\$2.5 billion per 1% increase), while increasing from 50%-70% coverage, resulted in a 14.1% relative decrease and saved \$31.4 billion (\$1.6 billion per 1% increase). Increases in coverage resulted in greater gains than increases in efficacy (e.g., 70%-90% vaccine efficacy decreases cases by 7.1 million, while increasing coverage from 50%-70% with a 70% efficacy decreases cases by 9.2 million).

Impact of Achieving Coverage Levels Faster

Again, shortening the duration in which vaccination coverage levels were achieved reduced the number of cases, deaths, and total costs (Figures 2-4). For example, reaching a 50% coverage level by 270 days instead of 360 days decreased cases by 6.6 million, hospitalizations by 252,260, deaths by 29,380, direct medical costs by \$4.0 billion, and productivity losses by \$8.0 billion (70% vaccine efficacy, approximately a 4.4% relative decrease in all outcomes). Further shortening this to 180 days (vs. 270 days) decreased cases by 5.8 million, hospitalizations by 215,790, deaths by 24,370, and direct medical costs by \$3.5 billion and productivity losses by \$4.3 billion (approximately a 3.8% relative decrease in all outcomes).

The Appendix presents the results for scenarios in which COVID-19 transmission was higher in February and March.

Discussion

As we have demonstrated, the impact and value of available COVID-19 vaccines will depend heavily vaccination coverage and the speed at which different coverage levels are achieved. Our results

show that even a 1% increase in vaccination coverage can avert several thousands to millions of cases, save thousands of lives, gain thousands of QALYs, and save millions in direct medical costs and productivity losses, depending on the initial coverage level, days to achieve that coverage level, the proportion of the population already infected by vaccination start, and vaccine efficacy. Even if the high coverage levels needed to completely “return-to-normal” are not achieved, increasing coverage levels still has substantial value with the greatest gains being achieved between 0% and 50% vaccination coverage. Further, the cost savings generated by increasing vaccination coverage represents the amount that could be invested to increase coverage and still break even. The numbers generated can give decision-makers a sense of the value of making vaccines more available and accessible, as well as increasing people’s acceptance of and confidence in COVID-19 vaccines.

Our study also shows how increasing vaccination coverage can be as important as or even more important than having a higher efficacy vaccine. For example, increasing vaccination coverage from 50% to 70% will prevent 9.2 million cases (70% vaccine efficacy) while going from a 70% efficacious vaccine to 90% prevent 7.1 million cases (50% coverage). This will be important to consider should the real-world vaccine effectiveness numbers for particular vaccines dip below the 90%-plus vaccine efficacy numbers that have been reported in trials. Initial studies report that these vaccines may actually have an 86%-92% effectiveness at preventing infection.[32-35] While the emergence of new variants[36, 37] could further reduce the effectiveness of currently available vaccines[38, 39] and raises concerns about the emergence future variants adversely affecting vaccine effectiveness, our results show that even with a lower efficacy (e.g., 50%), small increases in vaccination can still avert thousands of cases, even at higher coverage levels.

Our results also show how the time it takes to reach different coverage levels can affect the impact and value of the COVID-19 vaccine, showing the importance of achieving high coverage levels as soon as possible, especially by the summer. Even a 90-day delay in achieving a 50% coverage (e.g., achieving by early fall vs. early summer) will result in 5.8 million additional cases, 24,370 more deaths, and cost \$3.5 billion more in direct medical costs. Thus, it will be especially important to achieve high coverage levels before the Fall/Winter, when relative humidity and temperatures begin to drop which may be related to an increase the virus's transmissibility.[40, 41] This is because the more widespread the virus becomes the more difficult it will be to prevent its spread, even with vaccination. This underscores not only the importance of getting people vaccinated as quickly as possible (when pre-existing immunity is lower and before further spread of variants) but also the importance of using NPIs (e.g., social distancing, face mask use) to slow the virus's spread as much as possible until the vaccines become more widely available and accessible.

While there may be variations in COVID-19 coronavirus spread and NPI use throughout the US, our results show that general trends hold at different scales, such that increases in vaccination coverage in specific states will have similar relative impacts on clinical outcomes and costs as at the national level. Currently, most vaccine deployment decisions are occurring at the state level and there is wide variation in how many people are being reached in each state, the percentage of people that are hesitant to receive vaccine, and who is able and eligible to receive vaccines.[3, 15] Our results highlight the value of a coordinated national strategy that ensures and supports an adequate supply of vaccines to all states, identifies clear and consistent eligibility guidelines, and provides education and incentives for increasing coverage and doing so faster.

Our findings emphasize the importance of expanding and expediting COVID-19 vaccinations in 2021. They also provide a rationale for working to reach vaccine hesitant populations and groups in the U.S., in order to communicate a pro-vaccination agenda.

Limitations

All models, by definition, are simplifications of real-life and cannot account for every possible outcome.¹⁶ Model inputs drew from various sources and time points during the pandemic, and new data on COVID-19 coronavirus continues to emerge. Since the epidemic course may not be predictable, we explored a range of possible scenarios and parameter values. Our scenarios explore a vaccine protecting against infection based on evidence to date[32-35]; however, the specific efficacy levels for how a vaccine works (e.g., reduce severe disease, prevent infection) are still being studied and the data is subject to change. As waning immunity is not yet well understood, our study did not consider natural nor vaccine-induced immunity.[42, 43] Our analyses did not incorporate all costs that vaccines can avert such as other productivity losses (e.g., time required for quarantine), easing other interventions (e.g., school closures) or declines in general economic activity (e.g., job losses, business closures). Our scenarios assume coverage of the entire population; however, some populations may not be eligible for vaccination (e.g., children, immunocompromised). Additionally, we held the daily vaccination rate for each coverage level and duration of time to achieve that coverage, however, in reality, this may vary from day to day.

Conclusions

Our study quantifies the potential value of decreasing vaccine hesitancy and increasing vaccination coverage and how this value may decrease with the time it takes to achieve coverage, emphasizing the need to reach high coverage levels as soon as possible, especially before the Fall/Winter.

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Table 1. Mean (95% confidence interval) number of COVID-19 coronavirus cases (in millions) and deaths (in thousands) averted when increasing vaccination coverage when varying the days needed to achieve a given vaccination level (vaccine efficacy of 70%)

Days needed to achieve vaccination coverage level	Increasing coverage from 30% to 50%		Increasing coverage from 50% to 70%		Increasing coverage from 70% to 90%	
20% of Population Had Already Been Infected by Vaccination Onset						
		Relative decrease (%)		Relative decrease (%)	Cases averted (millions)	Relative decrease (%)
180 days	67.5 (66.8-68.3)	36.3%	23.5 (22.3-24.7)	19.9%	3.9 (2.2-5.5)	4.1%
270 days	67.0 (66.4-67.6)	35.6%	20.8 (19.8-21.8)	17.2%	3.9 (2.6-5.3)	3.9%
360 days	63.4 (62.8-64.0)	33.6%	21.4 (20.6-22.3s	17.1%	4.9 (3.7-6.1)	4.7%
		Relative decrease (%)		Relative decrease (%)	Deaths averted (thousands)	Relative decrease (%)
180 days	291.8 (287.5-296.2)	36.3%	102.9 (97.6-108.3)	20.1%	15.6 (8.5-22.7)	3.8%
270 days	290.3 (286.4-	35.7%	89.9 (85.2-	17.2%	17.8 (11.5-	4.1%

	294.1)		94.6)		24.0)	
360 days	272.9 (269.2- 276.6)	33.5%	93.3 (89.2- 97.4)	17.2%	20.8 (15.1- 26.4)	4.6%
30% of Population Had Already Been Infected by Vaccination Onset						
	<i>Cases averted (millions)</i>	<i>Relative decrease (%)</i>	<i>Cases averted (millions)</i>	<i>Relative decrease (%)</i>	<i>Cases averted (millions)</i>	<i>Relative decrease (%)</i>
180 days	40.4 (39.6-41.2)	22.2%	9.5 (8.6-10.3)	6.7%	4.4 (3.3-5.4)	3.3%
270 days	39.1 (38.2-39.9)	20.9%	9.2 (8.4-10.0)	6.2%	4.3 (3.4-5.3)	3.1%
360 days	38.4 (37.5-39.2)	19.9%	11.2 (10.4- 11.9)	7.2%	5.1 (4.2-5.9)	3.6%
	<i>Deaths averted (thousands)</i>	<i>Relative decrease (%)</i>	<i>Deaths averted (thousands)</i>	<i>Relative decrease (%)</i>	<i>Deaths averted (thousands)</i>	<i>Relative decrease (%)</i>
180 days	174.9 (170.5- 179.4)	22.2%	41.0 (36.7- 45.4)	6.7%	18.8 (13.8- 23.9)	3.3%
270 days	171.4 (165.7- 177.1)	21.2%	39.2 (32.3- 46.1)	6.1%	18.0 (10.6- 25.5)	3.0%
360 days	165.8 (161.1- 170.6)	19.9%	48.0 (43.8- 52.2)	7.2%	23.5 (19.0- 27.9)	3.8%

Note: cases and deaths are through December 31, 2022. Scenarios assume reproductive number values in the absence of vaccination such that cases decrease in February and continue downward in March, then start to go up in September, and the following year NPIs are discontinued.

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Figure Legends

Figure 1: Impact of increasing vaccination coverage for COVID-19 vaccines when 20% of the population has already been infected by vaccination onset (on January 4) with a 70% vaccine efficacy when varying the days needed to achieve different coverage levels on (A) the number of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) cases; (B) the number of deaths; (C) direct medical costs; and (D) productivity losses due to absenteeism. Assumes an \$85 vaccination cost. Note: cases and deaths simulated through December 31, 2022; scenarios assume reproductive number values such that cases decrease in February and continue downward in March, then start to go up in September, and the following year NPIs are discontinued.

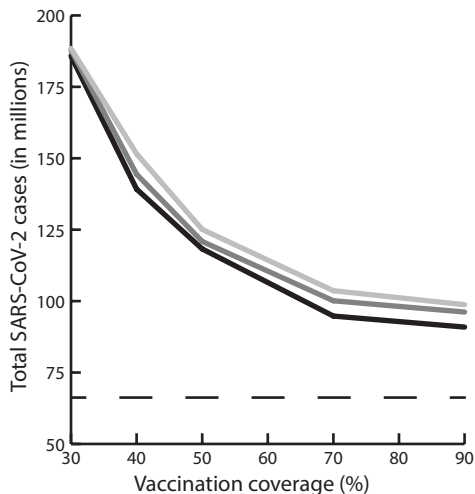
Figure 2: Impact of increasing vaccination coverage for COVID-19 vaccines when 30% of the population has already been infected by vaccination onset (on January 4) with a 70% vaccine efficacy when varying the days needed to achieve different coverage levels on (A) the number of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) cases; (B) the number of deaths; (C) direct medical costs; and (D) productivity losses due to absenteeism. Assumes an \$85 vaccination cost. Note: cases and deaths simulated through December 31, 2022; scenarios assume reproductive number values such that cases decrease in February and continue downward in March, then start to go up in September, and the following year NPIs are discontinued.

Figure 3: Impact of increasing vaccination coverage for COVID-19 vaccines per person vaccinated with a 70% vaccine efficacy when varying days needed to achieve different coverage levels on (A) the number of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) cases and (B) direct medical costs

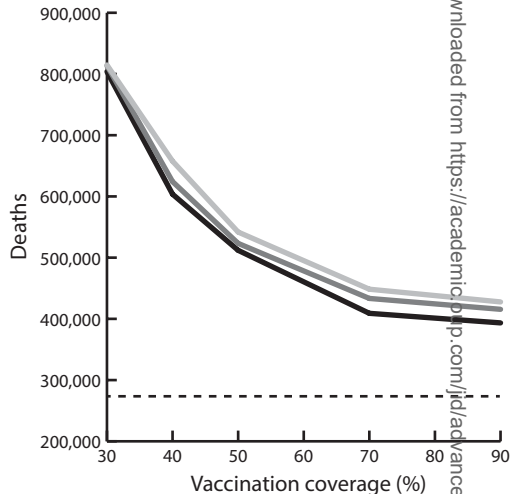
when different proportions of the population have already been infected by vaccination onset (on January 4). Assumes an \$85 vaccination cost. Note: cases and costs are simulated through December 31, 2022; scenarios assume reproductive number values such that cases decrease in February and continue downward in March, then start to go up in September, and the following year NPIs are discontinued.

Figure 4: Impact of increasing vaccination coverage for COVID-19 vaccines when varying days needed to achieve different coverage levels on (A) the total number of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) cases when vaccination onset starts once 30% of the population has already been infected with a 50% vaccine efficacy and a 90% vaccine efficacy, and (B) on the number of SARS-CoV-2 cases per person vaccinated with a 50% vaccine efficacy, and a 90% vaccine efficacy. Note: cases are modeled through December 31, 2022; scenarios assume reproductive number values such that cases decrease in February and continue downward in March, then start to go up in September, and the following year NPIs are discontinued.

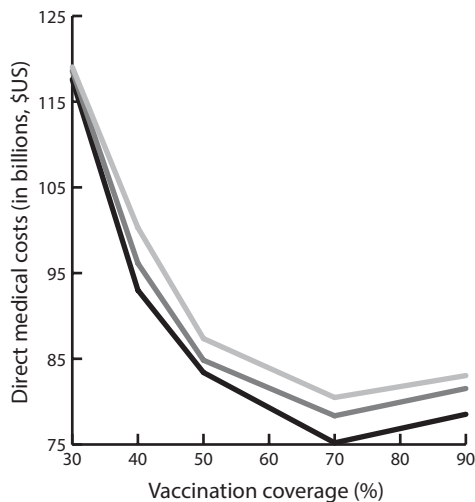
A. Total SARS-CoV-2 cases



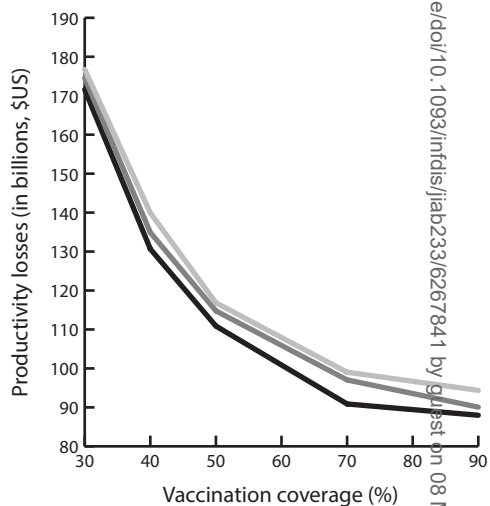
B. Total deaths



C. Total direct medical costs



D. Total productivity losses



Cases before vaccination onset — — —

Deaths before vaccination onset

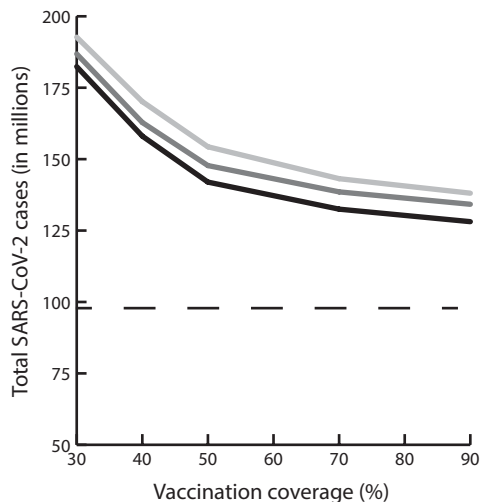
Duration of vaccination

180 days

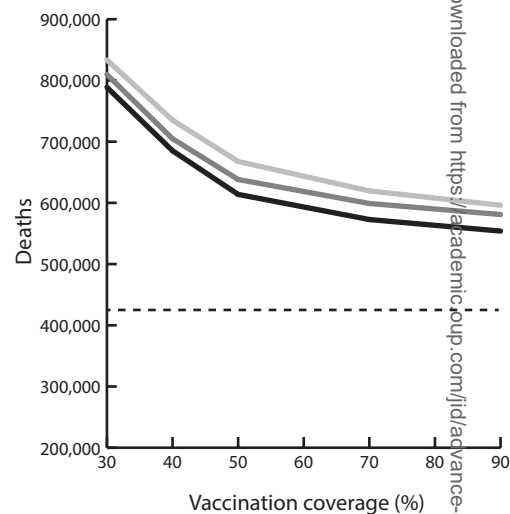
270 days

360 days

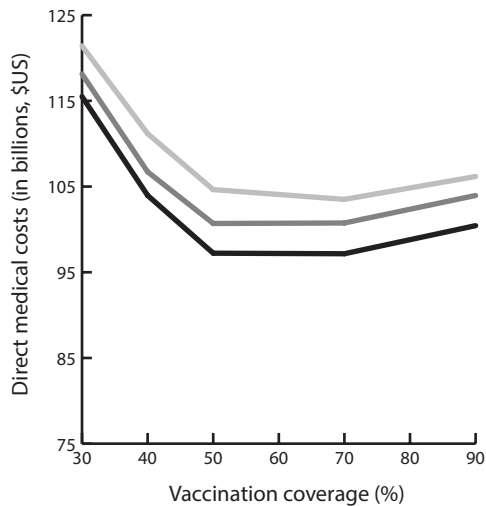
A. Total SARS-CoV-2 cases



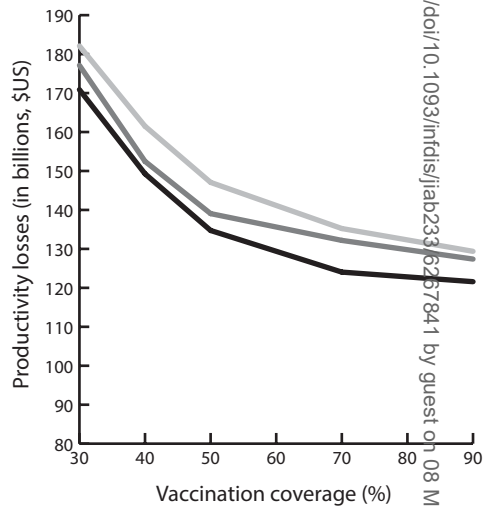
B. Total deaths



C. Total direct medical costs



D. Total productivity losses

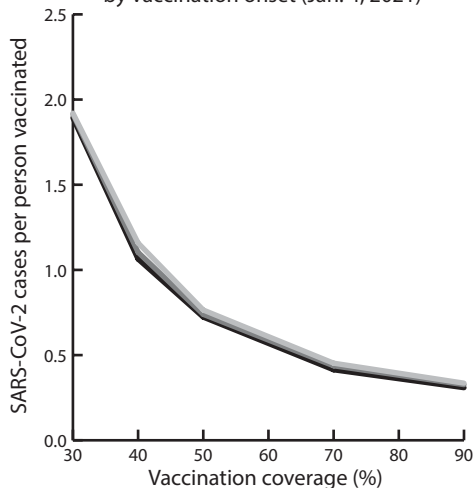


Cases before vaccination onset — — — — —
Deaths before vaccination onset - - - - -

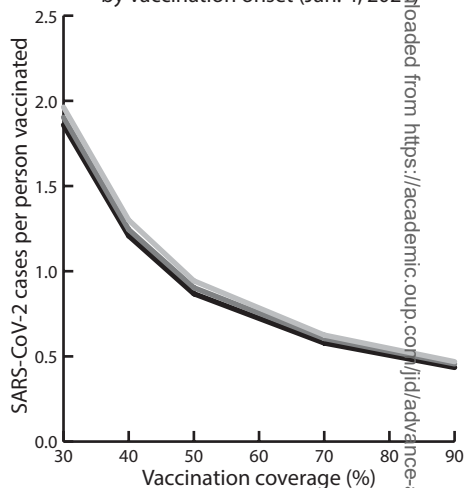
Duration of vaccination
180 days — 270 days — 360 days —

A. SARS-CoV-2 cases per person vaccinated

20% of population already infected by vaccination onset (Jan. 4, 2021)

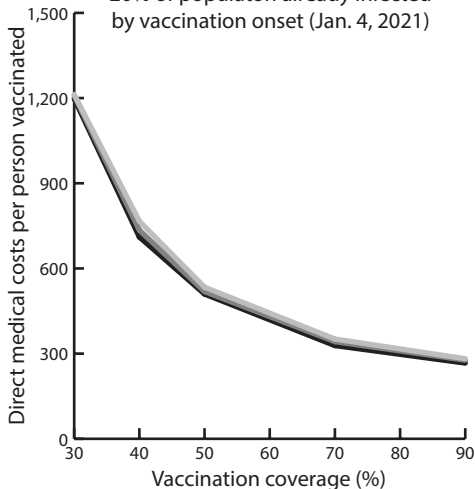


30% of population already infected by vaccination onset (Jan. 4, 2021)

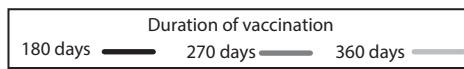
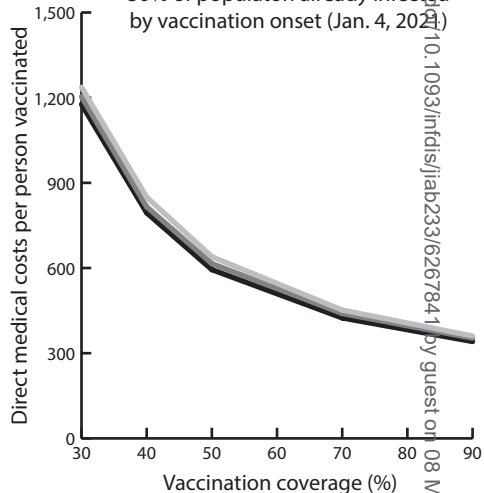


B. Direct medical costs per person vaccinated

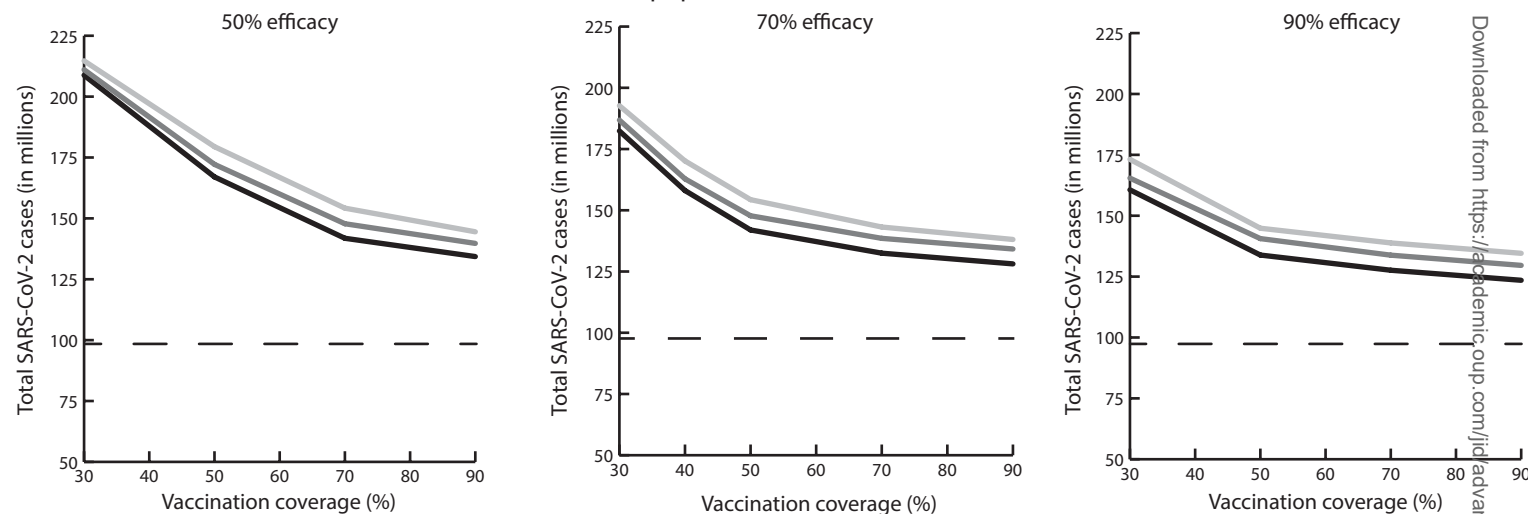
20% of population already infected by vaccination onset (Jan. 4, 2021)



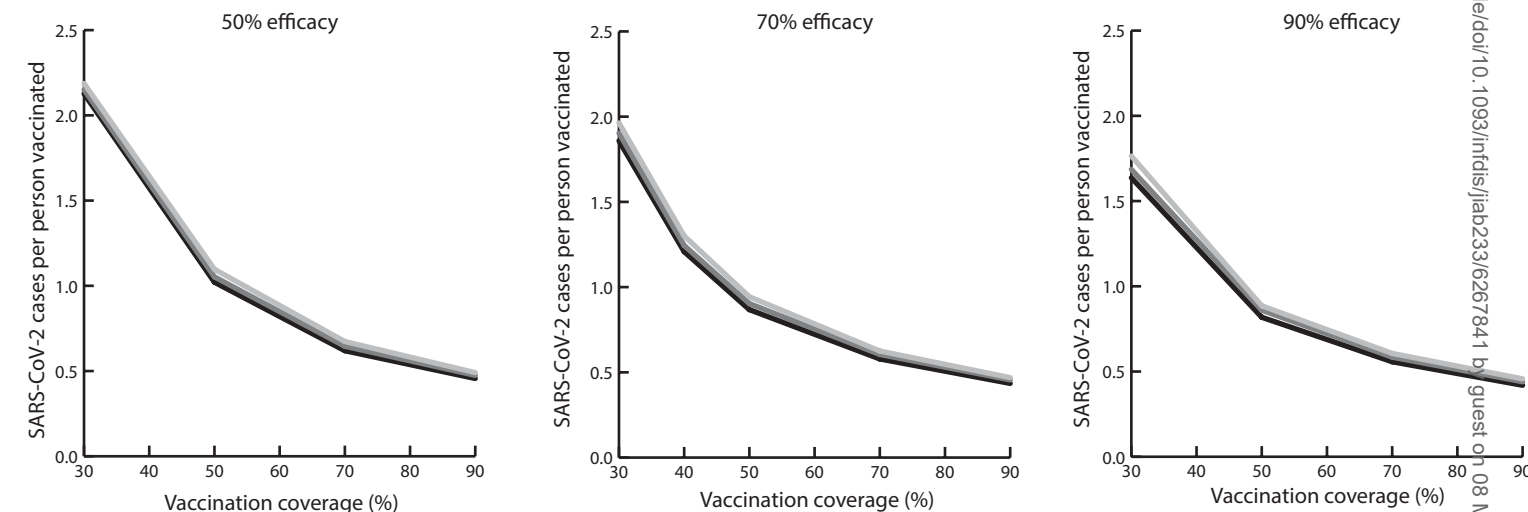
30% of population already infected by vaccination onset (Jan. 4, 2021)



A. Total SARS-CoV-2 cases (vaccination onset after 30% of population have been infected)



B. SARS-CoV-2 cases per person vaccinated (vaccination onset after 30% of population have been infected)



Cases before vaccination onset — — — — — Duration of vaccination
 180 days — 270 days — 360 days —