



Budget Model

Epidemiological and Economic Effects of the COVID-19 Vaccine in 2021

Summary: This brief analyzes the epidemiological and economic effects of maintaining, increasing, or decreasing the current pace of daily COVID-19 vaccinations. PWBM projects that doubling the number of vaccine doses administered daily would boost employment by more than 2 million and real GDP by about 1 percent over the summer of 2021, with smaller effects later in the year.

Key Points

- The pace of the economic recovery in 2021 hinges on the pace of vaccination. PWBM projects that doubling the number of vaccine doses administered daily to 3 million per day would boost employment by more than 2 million and real GDP by about 1 percent over the summer, with smaller effects later in the year.
- The emergence of more transmissible variants of the virus means that cases are likely to rise later this year, regardless of the pace of vaccination. However, doubling the pace of vaccinations to 3 million per day would prevent a total of about 2 million cases in 2021.
- PWBM projects that by the end of the 2021, about 80 percent of the population will have immunity to COVID-19, either from vaccination or from having been previously infected. This result is about the same across vaccination scenarios, with a slower pace of vaccination leading to more of the population being immunized by previous infection.

Background

The COVID-19 pandemic and resulting widespread adoption of social distancing in March of 2020 led to the deepest recession on record—the continuation of the pandemic and social distancing represents the most significant drag on the economy in 2021. The pace of the economic recovery this year is therefore closely tied to the evolution of the pandemic, which in turn depends on the pace of vaccinations.

Since the first vaccine dose was administered on December 14th, 2020, around 50 million Americans have been at least partly vaccinated. Currently, around 1.5 million doses are administered daily, an increase of about 50 percent from a month ago. In this brief, we consider the epidemiological and economic implications

of maintaining, increasing, or falling from the current pace of daily vaccinations. We show that the speed of the rollout is critical for public health and for the economy this year, especially given the emergence of new and more transmissible variants of the virus. If the number of vaccinations administered per day remains around 1.5 million, we project a total of 26.5 million COVID-19 cases in 2021. If the number of daily doses rises to 3 million over the coming months, that total would fall to 24.5 million. The corresponding decrease in the need for social distancing would raise GDP by about 1 percent and increase the level of employment by more than 2 million over the summer, with smaller effects later in the year.

Modeling the Pandemic and the Pandemic Economy

To project the effects of vaccinations, we extend the integrated epidemiological-economic model described in a forthcoming contribution to the *Brookings Papers on Economic Activity*, [Arnon, Ricco, and Smetters \(2021\)](#), which we refer to here as ARS.¹ We provide a summary of the model in this section and a more detailed overview in the Technical Appendix below.

Infection Risk, Behavior, and Vaccination

The ARS model features a state-level compartmental epidemiological framework augmented to allow social and economic behavior to change in response to the severity of the pandemic. These behavioral responses are driven by perceptions of the risk of infection, which depend on the reported number of cases in one's community.² High or rising cases induce increased social distancing, which is economically costly but curbs growth in infections. The reverse occurs when cases fall and social distancing is relaxed, leading to a rise in both economic activity and the spread of infection.

Vaccination interrupts this risk response dynamic, because the risk of either infection or transmission is minimal for individuals who have been vaccinated. As the share of the population with immunity from vaccination rises, the epidemiological risk associated with relaxing social distancing diminishes, allowing a wide range of social and economic activity to safely resume.

Measuring Social and Economic Responses

To estimate and project the behavioral response to infection risk, we develop three daily, county-level measures of social and economic behavior. The first is an estimate of the contact rate – the frequency of close physical proximity between different individuals outside the home – which reflects the intensity of social distancing. The other two are daily proxies for county-level employment and GDP, which are designed to be comparable to official statistics for those indicators. Using these measures, we model the county-level relationship between social and economic activity and the number of new reported cases, which drives perceptions of infection risk.

The three measures of behavior are derived from more than twenty different indicators drawn from a range of nontraditional data sources, including mobile device location data, business and financial services software, payroll service providers, web search activity, and debit card transactions. Each measure is constructed as the first principal component of subset of these indicators, scaled into interpretable units. See the Technical Appendix for a comparison of these measures with the official statistics they proxy. For more detail on their construction, see Sections V and VI of ARS.

Projecting the Pandemic

The course of the pandemic in 2021 depends on several highly uncertain policy, behavioral, and biological outcomes. In addition to the pace of vaccinations, four factors will be key in determining the dynamics of COVID-19 over the rest of the year:

- Social distancing: We project that – independent of local infection risk and vaccinations – social distancing behaviors will be substantially relaxed over the course of the spring and summer.
- Seasonality: We assume a degree of seasonality in the likelihood of viral transmission, which declines in spring and summer and rises in fall and winter.
- B.1.1.7: We project that the more transmissible B.1.1.7 variant (or “UK variant”) will become dominant in the spring and eventually account for nearly all new infections.
- Herd immunity effects: As the share of the population with immunity rises and the share that remain susceptible to infection falls, viral transmission becomes less likely because there are fewer possible hosts. This effect holds whether immunity is obtained through vaccination or from natural resistance due to past infection.

We provide a more detailed discussion of these factors in the Technical Appendix.

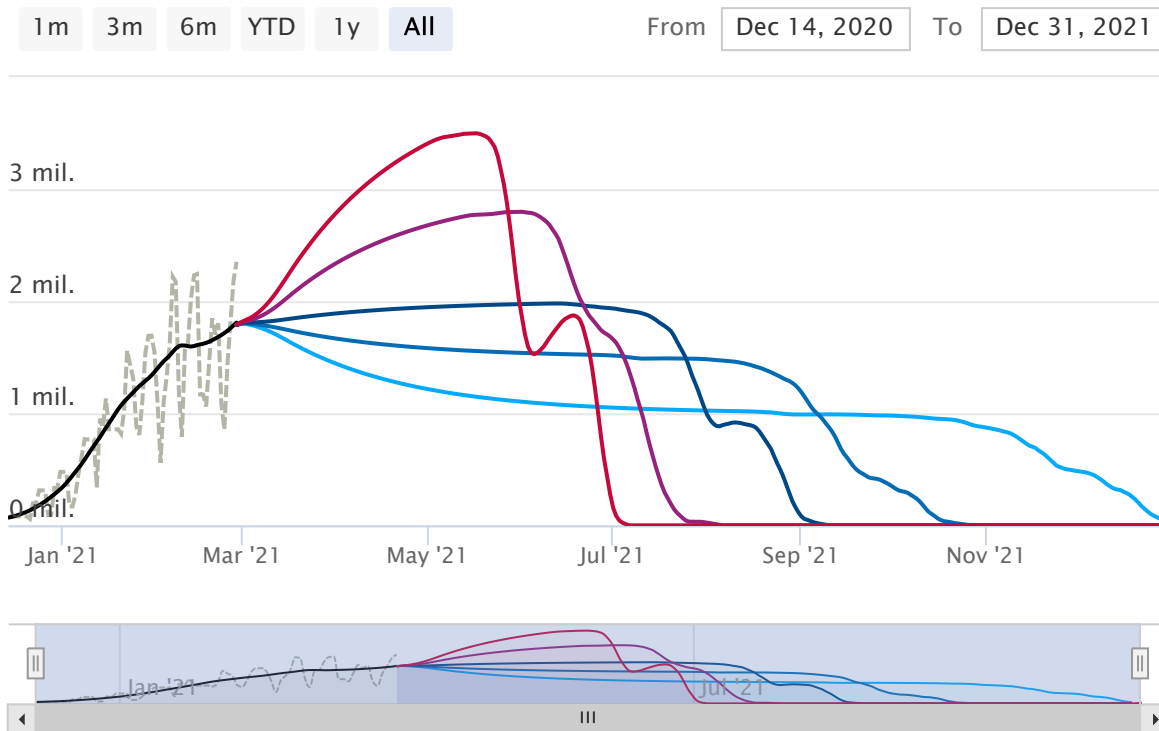
Five Paths to Vaccinating the Population

Around 1.5 million vaccine doses are currently administered daily across the United States. We consider five possible paths for how that number evolves over the coming year: a moderate decline to 1 million; remaining at 1.5 million; a moderate increase to 2 million; a large increase to 3 million; and a very large increase to 4 million. We assume that the specified number of daily doses would be made available nationally by mid-March but that additional time would be required to distribute them and, if necessary, scale up capacity to deliver shots into arms. Vaccines are distributed across states and counties initially in proportion to their priority populations as defined in CDC guidance and later in proportion to their total population aged 16 and over.

Figure 1. Daily Vaccinations

(millions)

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Daily vaccinations:

-- Actual
 — Actual, Smoothed
 — 1m
 — 1.5m
 — 2m
 — 3m
 — 4m

Figure 1 shows the number of daily doses administered over time under each scenario. Vaccinations continue until all eligible adults who wish to be vaccinated have received a full course. Based on surveys of attitudes to towards COVID-19 vaccines, we assume that 25 percent of those eligible will decline vaccination. Consistent with recent statements from federal officials, we also assume that a vaccine for children under 16 will not be available before the end of 2021. Between these two groups, about 40 percent of the population remains unvaccinated at the end of the year under any scenario.

We include only vaccines that require two doses for full vaccination and assume that the vast majority of persons who receive one dose eventually receive a second. The average number of days between doses initially varies by state according to the latest data but gradually converges to 28 days across the nation. We assume that individuals scheduled to receive a second dose are prioritized above those who have not yet received a first dose.

Public Health Effects of Alternative Vaccination Paths

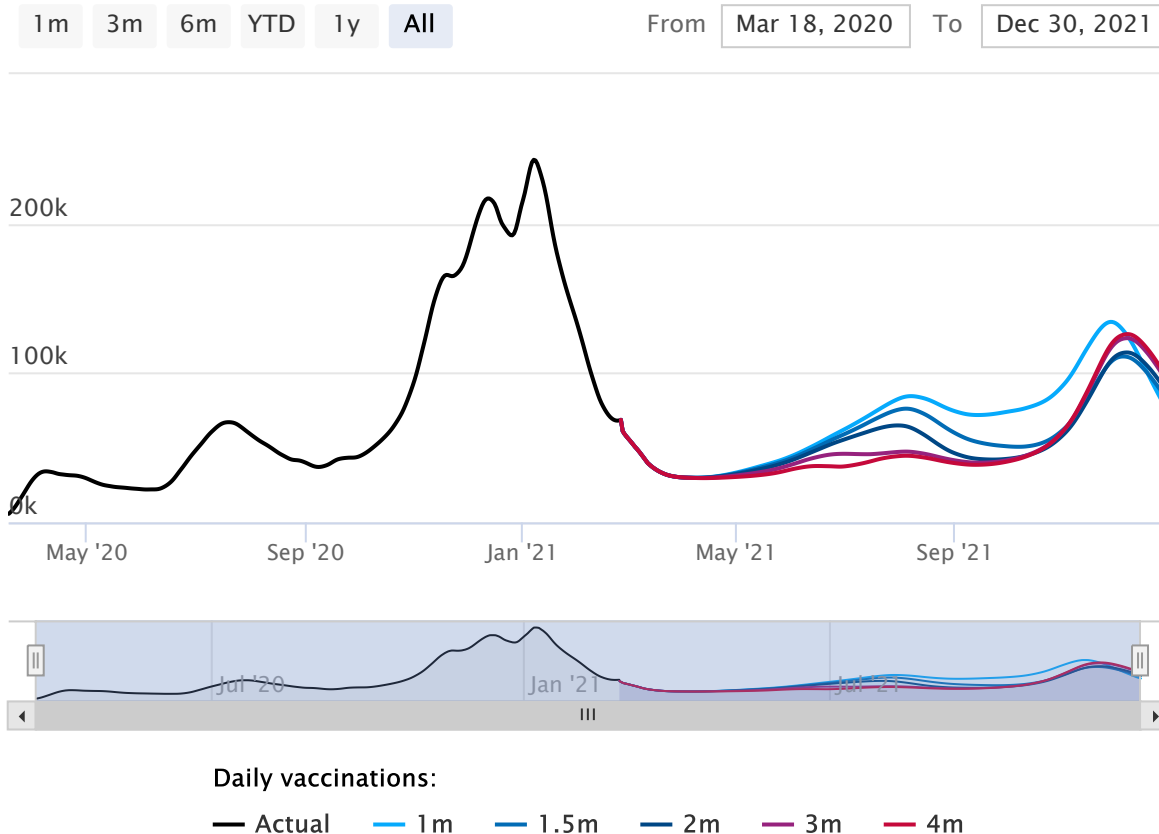
Figure 2 shows PWBM’s projections for the daily number of new confirmed cases under each of the five paths for daily vaccinations. We project that the number of new cases will continue to decline through the spring but begin to rise again over the summer as B.1.1.7 becomes the dominant SARS-CoV-2 strain circulating in the United States. We expect that the effects of increased transmission due to the prevalence of the B.1.1.7

variant, combined with a relaxation of social distancing as the weather improves, will more than offset a seasonal decline in contagiousness.

Figure 2. Daily New Cases

(thousands)

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Notably, even a dramatic increase in the pace of vaccinations over the coming months would not completely avert a resurgence of COVID-19 in the summer. By July, however, the effects of different vaccination rates on the course of the pandemic begin to emerge clearly. Doubling the pace of daily vaccinations to 3 million reduces the peak of the late summer wave by about half, amounting to a cumulative difference of 1.8 million cases through the end August.

Projected new cases begin declining by September, as the rise in contact rates from diminished social distancing tapers off and in some places reverses due to increased perceptions of infection risk. After a brief reprieve in the fall, however, we project a surge in new cases in the winter, driven by a combination of the prevalence of the B.1.1.7 variant and a seasonal increase in infectiousness observed across coronaviruses. This surge occurs regardless of the pace of vaccination over the course of the year and is in fact somewhat sharper for higher vaccination rates. This counterintuitive outcome reflects the smaller share of the population that was infected during the smaller late summer wave and thus gained natural immunity.³

Herd immunity effects begin to dominate by late December, and daily new confirmed cases start to fall under each vaccination scenario. Figure 3 shows the projected share of the population with COVID-19 immunity by

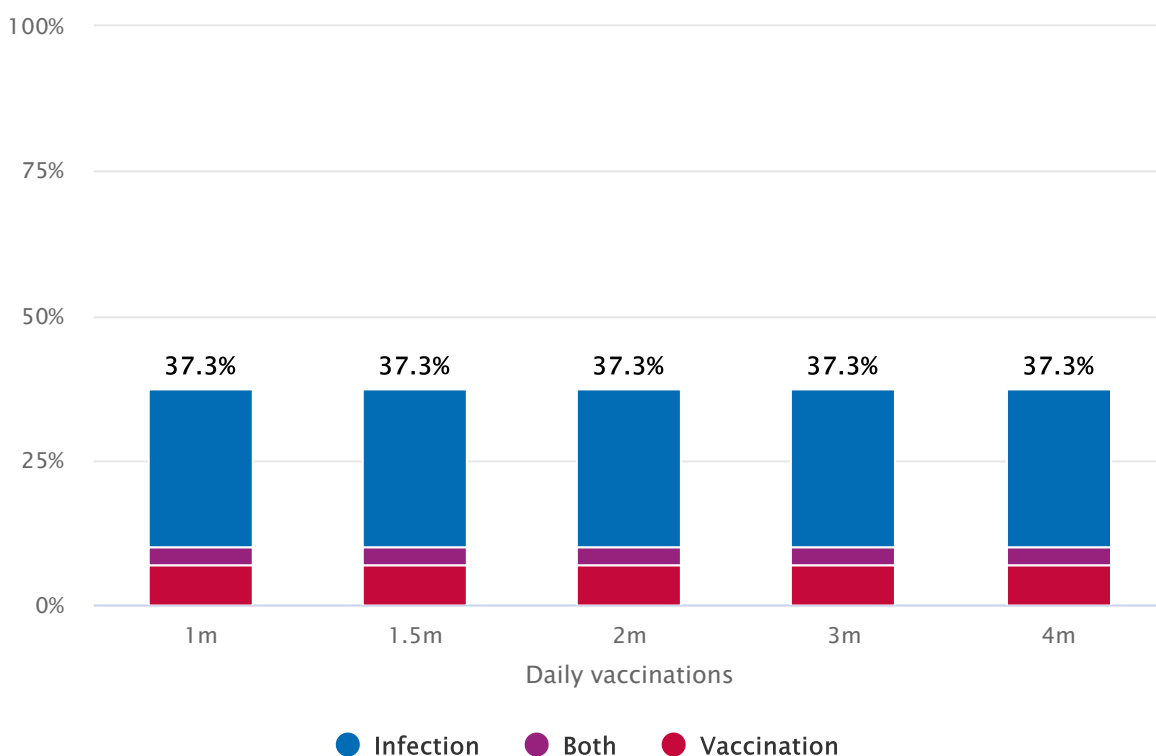
source (infection, vaccination, or both). Note that by the end of 2021, the relatively-larger summer waves in the slower vaccination scenarios lead to a larger immune fraction of the population. Critically, we assume that reinfection risk is negligible during the timeframe of analysis; the durability of immunity from both infection and vaccination remains uncertain. Rather than a categorical threshold, herd immunity is best thought of as a headwind acting against future waves, the force of which depends on reinfection risk.

Figure 3. Population Immunity Status in 2021

(percent)

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****Please view online for additional dates.****



2/28/2021



One important feature of our projections is the changing age composition of new infections over time. The United States has currently not approved COVID-19 vaccine use for children aged 16 and under. As the vaccinated share of the adult population increases, the median age of new infections will fall. Age is a key determinant of COVID-19 severity: children are less likely to show symptoms and are far less likely to experience severe disease. As a result, future waves of COVID-19 infections will be associated with lower rates of hospitalization and mortality than previous waves.

Economic Effects of Alternative Vaccination Paths

Figure 4 shows PWBM’s projections for daily economic activity under each of the five paths for daily vaccinations. Tables 1 and 2 present them in terms consistent with the reporting of official statistics (see Figure A3 in the Technical Appendix for a historical comparison with these statistics). These projections reflect both the direct effects of vaccination on economic behavior – as vaccinated individuals are able to safely engage in a range of economic activity that requires physical proximity – and the indirect effects through reduced transmission and prevalence – which mitigates the infection risk faced by non-vaccinated individuals.

Figure 4. Economic Projections

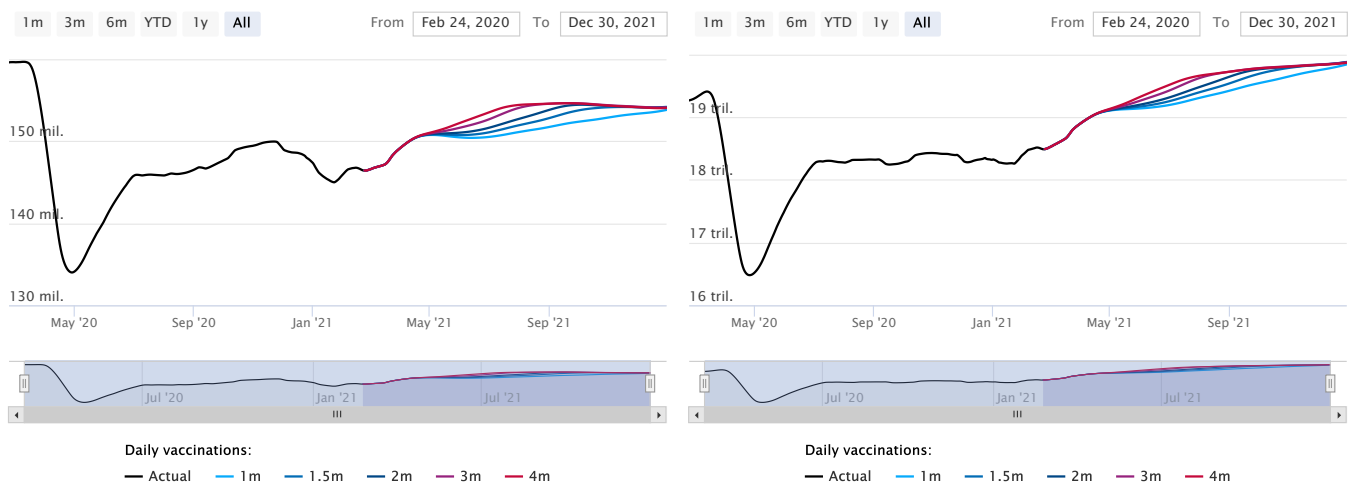
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A. Daily Employment

(millions, 30-day average)

B. Daily Real GDP

(tril. of chained 2012 dollars, annual rate, 30-day average)



Note: Estimates and projections of employment are not seasonally adjusted.

We project that the rate of vaccination will have a significant effect on economic activity in 2021, especially in the late spring and summer. At the current pace of around 1.5 million doses per day, we expect the economic recovery to continue but proceed gradually through the middle of year, with employment rising to nearly 152 million in July and four-quarter real GDP growth of around 5 percent in the third quarter. Increasing the pace of vaccinations to 3 million would sharply accelerate the rate of recovery, boosting employment by 2 million in July and raising GDP growth by a percentage point in third quarter.

Table 1. Projected Civilian Employment in 2021

(millions)

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	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	2021
Daily vaccinations:											
1m	149.0	150.7	150.5	150.5	151.1	151.7	152.3	152.9	153.3	153.8	150.7
1.5m	149.0	150.8	150.7	151.1	151.9	152.8	153.7	154.1	154.1	154.2	151.2
2m	149.0	150.8	151.0	151.6	152.7	153.8	154.4	154.3	154.1	154.1	151.5
3m	149.0	150.9	151.6	152.6	154.0	154.5	154.6	154.4	154.2	154.1	151.9
4m	149.0	151.0	152.2	153.5	154.4	154.6	154.6	154.3	154.1	154.0	152.0

The differences between alternative rates of vaccination diminish over the second half of the year. We project that, unless the number of doses administered daily declines from the current pace, employment and real GDP will be similar in December across all paths for vaccinations. The main reason for this convergence is that even at rate of 1.5 million per day, everyone who wishes to be vaccinated will be by late fall. Another factor is that differences in the number of people vaccinated do not translate directly to differences in the number of people with immunity. As discussed in the previous section, a slower pace of vaccination in the coming months leads to a larger increase in new infections and cases over the summer. Individuals infected over the summer who recover will have natural immunity at the end of the year, whether or not they have been vaccinated.

Table 2. Projected Real GDP Growth in 2021

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	Four-quarter percent change				Year-over-year
	Q1	Q2	Q3	Q4	
Daily vaccinations:					
1m	-2.1	10.7	4.4	5.1	5.4
1.5m	-2.1	10.8	5.1	5.6	5.8
2m	-2.1	11.0	5.5	5.6	5.9
3m	-2.1	11.4	6.0	5.6	6.1
4m	-2.1	11.7	6.0	5.6	6.2

Averaging over the full year, we project that raising the rate of daily vaccinations to 3 million or more would increase employment in 2021 by nearly 1 million and real GDP growth by about a third of a percentage point in 2021.

Technical Appendix

Epidemiological Framework

Our epidemiological projections begin with an augmented version of the canonical compartmental model in epidemiology, wherein the population is divided into groups and a series of differential equations describe how each group interacts with one another, and changes, over time. We define the following compartments at the state level: *Susceptible*, *Exposed*, *Infectious*, *Resistant*, *Vaccinated*, and *Resistant & Vaccinated*.

The differential equations and parameter values governing movement between compartments are the same as those described in [Arnon, Ricco, and Smetters \(2021\)](#) (ARS). We model vaccination as a removal from the *Susceptible* and *Resistant* groups. New vaccinations are assumed to be delivered proportionally across these compartments; that is, the likelihood of vaccination is assumed to be independent of past infection. We assume that immunity is achieved three weeks after the first vaccine shot, and that vaccination reduces transmission by 90 percent.⁴

Projecting the course of the pandemic requires projecting future values for the average number of secondary infections caused by each infection per day, represented by β . We do so using a ground-up approach. We begin by estimating historical values of the effective reproduction number R using an approach developed in [Cori et. al. \(2013\)](#).⁵

As described in ARS, we model R as the product of four components:

$$R_{it} = \kappa_{it} \zeta_{it} \gamma_{it}^{-1} S_{it}$$

where κ represents the contact rate, ζ represents the average probability of viral transmission per contact, γ represents the reciprocal of the average duration of infectiousness, and S is the share of the population susceptible to COVID-19 (all indexed by state i at time t).

Note that $\beta_{it} = \kappa_{it} \zeta_{it}$. Historically, R , κ , and S are measured or estimated and γ is assumed; ζ can therefore be inferred as a residual. We find that variation in ζ over 2020 and early 2021 is consistent with the strong evidence of seasonal patterns in other coronaviruses. We estimate state-specific time patterns in ζ and – interpreting them as seasonal factors – use them to project ζ over the remainder of 2021.

As in ARS, we model the contact rate κ at the county level as a function of a demographic, economic, and political characteristics as well the response to perceived infection risk. We assume that populations with similar characteristics exhibit common patterns of behavior but impose no further restrictions and allow the effect of each characteristic on behavior to vary flexibly over time. We estimate the response to local infection risk using the number of new cases reported in a county. While true infection risk depends on the number of active infections and not the number of reported cases, infections are not observed by the public, and perceptions of risk are driven by publicly reported information like confirmed case counts. Our analysis suggests that about one third of new infections are currently being confirmed. Because children are more

likely to be symptomatic when infected, we assume that children have a case confirmation rate that is one-half that of adults.⁶ See Section IV of ARS for a description of how we estimate the share of infections confirmed via diagnostic test.

Key Epidemiological Assumptions

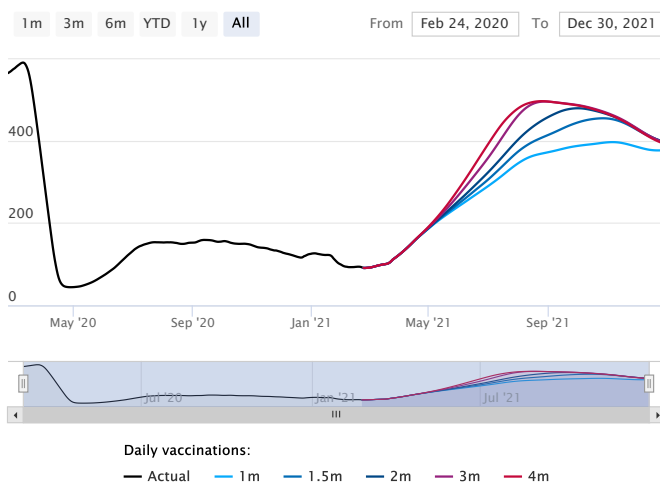
Panel A of Figure A1 plots historical estimates and projections of the contact rate k . Across all scenarios, we project a substantial rise in the contact rate over the spring and summer of 2021, reflecting our expectation of a relaxation of social distancing measures. The extent of the rise varies across the different scenarios for vaccinations, however, due to the endogenous risk response induced by each scenario’s epidemiological outcomes (which in turn depend on the contact rate).

Figure A1. Components of Viral Transmission

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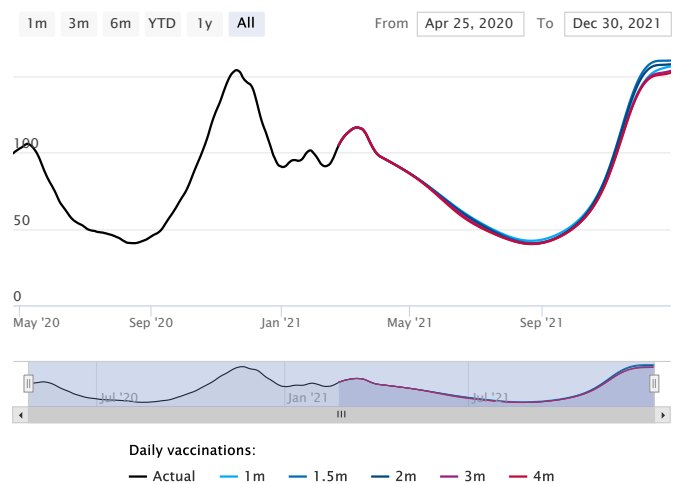
A. Contact Rate

(index, January 2021 = 100, 30-day average)



B. Average infectiousness

(index, January 2021 = 100, 30-day average)

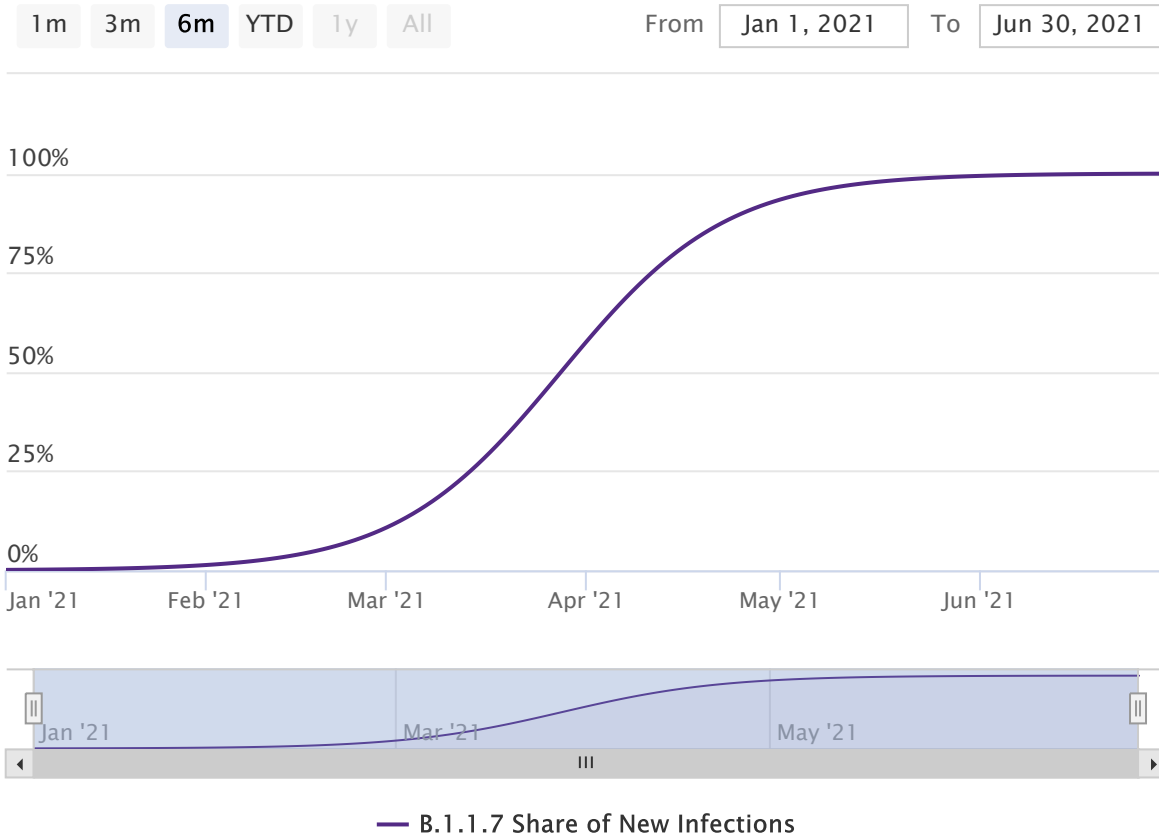


Panel B of Figure A1 plots the product of the average transmission probability ζ and the duration of infectiousness γ^{-1} , which we refer to as average infectiousness. Average infectiousness reflects the probability that an infected individual transmits the virus to susceptible individuals over the course of their infection, conditional on their contact rate. Two factors lead to the sharp increase in average infectiousness in the second half of the year: the seasonal pattern in ζ described above and the emergence – and eventual dominance – of the B.1.1.7 SARS-CoV-2 variant (commonly referred to as “the UK variant”). As shown in Figure A2, we project that B.1.1.7 will be the most common virus strain by March 23rd. Following [recent evidence](#), we assume that B.1.1.7 is 50 percent more transmissible than the traditional variant and that this effect operates through a longer duration of infectiousness. We assume current isolation practices generally continue such that only asymptomatic infections lead to higher transmissibility.

Figure A2. B.1.1.7 Share of New Infections

(percent)

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Daily Economic Activity Measures

Figure A3 plots 7-day averages of our daily index measures of employment and real GDP against the traditional economic statistics they are intended to track. Indexes are constructed for each county (excluding those with insufficient coverage in our sources) and then rescaled linearly to match the mean and standard deviation of the target indicator. Note that the scaling does not affect the information contained in the indexes and is merely a transformation of units, not a forecast of the indicator. The employment index is scaled to PWBM’s estimate of monthly, not seasonally adjusted county employment-population ratios in 2020, which use employment estimates from the Bureau of Labor Statistics’ (BLS) Local Area Unemployment Statistics. The real GDP index is scaled to PWBM’s estimate of county-level quarterly real GDP through the third quarter of 2020, which is based on county and state GDP data from the Bureau of Economic Analysis.

Figure A3. Daily Economic Activity Indexes

[DOWNLOAD DATA](#)

A. Employment

(millions)



B. Real GDP

(tril. of chained 2012 dollars, annual rate)



Note: Estimates of employment are not seasonally adjusted.

In Figure A3, county-level indexes are aggregated to US totals and plotted against headline measures of total employment and real GDP.

This analysis was conducted by [Alex Arnon](#) and [John Ricco](#). Directed by [Richard Prisinzano](#). Prepared for the website by [Mariko Paulson](#).

1. This framework was first developed last spring for PWBM's [analysis of reopening](#) after the initial wave of social distancing restrictions. ↩
2. Actual risk of infection depends on the number of active infections rather than the reported number of cases, which includes only infections that are detected through a test. However, the true number of infections is unknown and perceptions are driven by publicly reported counts. ↩
3. This pattern does not hold for the slowest vaccination scenario, wherein a large enough level of baseline community spread leads to a higher peak. ↩
4. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3790399. ↩
5. <https://academic.oup.com/aje/article/178/9/1505/89262> ↩
6. <https://www.nature.com/articles/s41591-020-0962-9> ↩