Mandated Bacillus Calmette-Guérin (BCG) vaccination predicts flattened curves for the spread of COVID-19

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The current analysis is based on data available on April 1, 2020. It will be updated every two weeks and made available at MedRxiv (https://www.medrxiv.org/). Address correspondence to Martha Berg or Shinobu Kitayama at Department of Psychology, University of Michigan, Ann Arbor, MI 48109 USA. Emails: bergmk@umich.edu and kitayama@umich.edu.

One sentence summary

The presence of national policies for universal BCG vaccination is associated with flattened growth curves for confirmed cases of COVID-19 infection and resulting deaths in the first 30-day period of country-wise outbreaks.

Abstract

Prior work suggests that BCG vaccination reduces the risk of different infectious diseases. BCG vaccination may thus serve as a protective factor against COVID-19. Here, we drew on day-by-day reports of both confirmed cases and deaths and analyzed growth curves in countries that mandate BCG policies versus countries that do not. Linear mixed models revealed that the presence of mandated BCG policies was associated with a significant flattening of the exponential increase in both confirmed cases and deaths during the first 30-day period of country-wise outbreaks. This effect held after controlling for median age, gross domestic product per capita, population density, population size, geographic region, net migration rate, and various cultural dimensions (e.g., individualism and the tightness vs. looseness of social norms). Our analysis suggests that mandated BCG vaccination can be effective in the fight against COVID-19.

Introduction

The current pandemic of COVID-19 began in December 2019 in Wuhan, China. Since then, it has rapidly spread across the globe. Currently, there is no end in sight. The present work is motivated by prior evidence that Bacillus Calmette-Guérin (BCG) vaccination (typically given at birth and/or during childhood) offers a long-lasting protective effect not only against tuberculosis (the intended target of BCG), but also against various other infectious diseases (*1*–*3*). We tested whether the curves for the spread of COVID-19 might be flattened in countries with mandated BCG policies, compared to those that do not.

The BCG vaccine is used primarily against tuberculosis (*4*). One review has found that BCG vaccination reduces the risk of tuberculosis by 50% (*5*). A follow-up of an earlier BCG clinical trial performed on native Americans show that BCG protects people from both tuberculosis and lung cancer for up to several decades, throughout each person's life (*2, 3*). A more recent meta-analysis of a broader range of observational studies and clinical trials (*1*) suggests that the effectiveness of BCG could extend to all-cause mortality. Several controlled trials provide consistent results, showing that the reduced mortality is attributable to protection against respiratory infections, as well as neonatal sepsis (*6*–*8*). Altogether, the available evidence suggests that BCG has beneficial effects on immunity against a range of lung-related infections that go beyond tuberculosis, which makes it a promising candidate for defending against COVID-19. As for mechanisms, recent experimental work (*9*) finds that BCG vaccination causes genome-wide epigenetic reprogramming of human monocytes, which in turn predicts protection against experimental viral infection.

Over the last century, many countries adopted universal policies of mandatory BCG vaccination to fight against tuberculosis, which was then a major threat. Since then, many countries maintained such a policy at least until very recently (e.g., China, Ireland, Finland, and France). Some other countries terminated the policies as tuberculosis ceased to be a threat (e.g., Australia, Spain, Ecuador). Of note, some countries never mandated BCG vaccination (e.g., U.S., Italy, and Lebanon). Therefore, there is sufficient variability in the presence or absence of such policies distributed across different regions of the world, which makes it possible to draw a systematic comparison. A cross-national analysis, however, is inherently challenging. Among others, in this particular case, different countries have varying onsets in the current pandemic, which makes it problematic to test the absolute number of confirmed cases or deaths (as in, for example, (*10, 11*)).

To overcome this challenge, we examined day-by-day reports of both confirmed cases and deaths and analyzed growth curves in countries with mandated BCG policies versus those without. The growth curves illuminate the process of the viral spread in each country, which in turn shapes the total number of cases or deaths. The start of the growth curves was set to be equal across countries. Following prior work, we focused on a time period either after the first 100 confirmed cases (as in (*12*)) or after one confirmed COVID-caused death. Of note, we limited our analysis to the first 30 days of the onset of country-wise outbreaks. This will enable us to capture the initial, exponential spread of the virus, while minimizing any effects of country-dependent coping actions (e.g., stay-home mandates by the state).

Since vaccination may become effective at the population level only when a vast majority is made resistant against a target virus(es), a phenomenon known as "herd immunity" (*13*), we first tested whether the growth curves would be significantly less steep in countries that have continued to mandate BCG vaccination at least until very recently, as compared to countries that do not currently require it. We then explored whether there might be any difference between those that never had such a policy and those that had one during the 20th century but have since terminated the policy for at least a few decades. Lastly, we tested whether the groups of the countries that vary in the BCG policy status might vary on various cultural dimensions, such as individualism vs. collectivism (*13*, *14*) and the tightness vs. looseness of social norms (*14*).

Results

Confirmed Cases

All countries that had reported at least 15 days of at least 100 total confirmed cases, and that had available data on BCG policy and covariates (median age, gross domestic product per capita, population density, population size, net migration rate, and geographical region) were included (52 countries in total). For each country, day 1 was set to be the first day of at least 100 confirmed cases. See Column 2 of Table S1 for the date of day 1 for each included country.

To model exponential growth of confirmed cases, we estimated a linear mixed model of the natural log-transformed number of confirmed cases. We entered two contrast-coded variables designating BCG policy status (current vs. [past and none] combined and past vs. none). The effect of BCG policy status on growth rate is reflected by the interactions between day and each BCG policy status contrast. .

As shown in Table 1-A., we found a significant main effect of day, $b = 0.190$, $p < .001$, reflecting an exponential increase in cases over time. This increase was qualified by a significant interaction between day and BCG policy status. Specifically, the growth rate of COVID-19 cases was significantly slower in countries with mandated BCG vaccinations, compared to countries without mandated BCG vaccinations, $b = -0.025$, $p = .020$ (see Fig. 1-A and B).[1] This effect was not accounted for by the cultural dimensions of individualism vs. collectivism, power distance, and tightness/looseness (see Supplementary Results 1-A). Countries that once had such policies but terminated them before 2000 were not significantly different in growth rate from those that never instituted mandatory BCG vaccinations, $b = -0.019$, $p = .143$. Fig. 2-A shows the distribution of the country-wise regression coefficients. There is a substantial variation in the mandatory BCG group. See Supplementary Results 2-A and 3-A for the effects of the control variables and a robustness check, respectively.

Deaths

All countries that had reported at least 15 days of at least 1 total death from COVID-19, and that had available data on BCG policy and covariates (54 countries in total) were included in this analysis. For each country, day 1 was set to be the first day of at least 1 confirmed death. See column 3 of Table S1 for the date of day 1 for each included country.

We estimated a linear mixed model of the natural log-transformed number of deaths, controlling for the same control variables as above. As in the analysis on confirmed cases, we found a significant main effect of day, $b = 0.211$, $p < .001$, reflecting an exponential increase in deaths over time (Table 1-B). This increase was qualified by a significant interaction between day and BCG policy status. Specifically, the growth rate of COVID-19 related deaths was significantly less in countries with mandated BCG vaccinations, compared to countries without mandated BCG vaccinations, $b = -0.078$, $p < .001$ (Fig. 1-C and D). This effect was independent of the cultural dimensions mentioned above (Supplementary Results 1-B). Countries that once had such policies but terminated them before 2000 were no different in growth rate from those that never instituted mandatory BCG, $b < 0.001$, $p = .993$. Fig. 2-B shows the distribution of the country-wise regression coefficients. See Supplementary Results 2-B and 3-B for the effects of the control variables and a robustness check, respectively.

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[1] The main effect of the current BCG policy contrast in each analysis shows that there are fewer total cases and deaths in BCG-mandated countries, compared to those that do not currently mandate BCG vaccination. However, this is a necessary consequence of the rate of increase being more gradual in the former than in the latter.

Discussion

Our analysis provides the first conclusive evidence that mandatory BCG vaccination predicts a flattening of the curve in the spread of COVID-19. The effect we demonstrate is quite substantial. For example, the total number of COVID-19 related deaths in the US as of March 29, 2020 would have been 94—4% of the actual figure (2467)—if the US had instituted the mandatory BCG vaccination several decades earlier (see Supplementary Results 5).

Notably, the growth curves were as steep in countries that mandated BCG policies only during the 20th century as in those that never mandated the vaccine. BCG vaccination may become effective only when a substantial proportion of the population is made resistant to a virus. That is to say, the spread of the virus may be slowed only when there is "herd immunity" that prevents the virus from spreading easily across the population (see a simulation in (*15*)). Note that as long as others receive vaccination, any single individual will be protected without vaccination, leading to a temptation for free-riding (i.e., not getting vaccinated). Hence, in the absence of state-imposed mandatory vaccination, cultural norms emphasizing prosocial interdependent orientations (*16, 17*) may prove to be crucial for the success of BCG in preventing future outbreaks of COVID-19 (*15, 18*).

Some limitations of our effort are warranted. First, one can raise questions about the quality of the data, especially the number of confirmed cases, as some countries may distort the number of cases for a variety of reasons. For example, diagnostic tests of COVID-19 were not widely available especially during early periods of the pandemic. Nevertheless, these biases are likely constant across the 30-day period within any given country. Further, the number of deaths is much more difficult to distort whether intentionally or otherwise.

Second, in all national policies, BCG is given early in life, typically at birth. It remains unclear whether BCG vaccination might be effective when given to adults. Nor is it known how long BCG vaccination might provide immunity to COVID-19 although it is effective against tuberculosis and lung cancer for several decades (2, 3). Moreover, it is uncertain whether BCG might have any adverse effects when given to those already infected with COVID-19. There is an urgent need for randomized clinical trials.

Third, our analysis focused on the first 30 days of an initial outbreak in each of the countries (see also Supplementary Results 3-A and B). This analytic strategy is taken so as to minimize any potential effects of state-based coping actions (e.g., stay-home orders), thereby making the countries as comparable as possible. It also helped us to include a maximal number of countries. Nevertheless, future work must test the effect of BCG policy status under different conditions during the world-wide spread of the disease.

Last, but not least, the rates of exponential growth showed substantial variability across countries that have mandated BCG vaccination (Fig. 2-A and B). Hence, BCG is by no means a magic bullet that assures safety against COVID-19. In all likelihood, there are some societal variables that moderate this effect. For example, mandatory BCG may have to be combined with cultural norms sanctioning social distancing (*19*). Future work must identify the conditions in which the formation of "herd immunity" is facilitated by nationally mandated BCG vaccination.

All these limitations notwithstanding, the current evidence is sufficient to warrant a thorough investigation of the merit of the mandatory BCG vaccination in the fight against COVID-19.

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Table 1. Regression tables predicting growth in (A) cases and (B) deaths. Day is mean centered, and BCG policy variables are both contrast-coded. Geographical region variables are dummy-coded with East Asia/Pacific as the reference group.

	A. Cases				B. Deaths			
Predictor	b	t	p		b	t	p	
Intercept	7.291	31.809	<.001	***	-0.108	-0.325	0.745	
Day	0.190	20.822	<.001	***	0.211	12.312	<.001	***
BCG past vs. never	0.074	1.806	0.071	+	-0.087	-0.994	0.320	
BCG current vs. not current	-0.350	-9.746	<.001	***	-0.770	-11.349	<.001	***
Median age	0.010	1.821	0.069	+	0.045	5.694	<.001	***
GDP per capita (thousands)	-0.011	-5.326	<.001	***	-0.004	-1.165	0.244	
Population density	-0.000	-5.234	<.001	***	0.000	0.785	0.432	
Population (millions)	0.002	18.896	<.001	***	0.004	24.163	<.001	***
Net migration rate	0.014	1.178	0.239		0.065	3.433	0.001	**
Europe/Central Asia	0.596	8.508	<.001	***	1.829	15.244	<.001	***
Latin America/Caribbean	0.509	3.880	<.001	***	1.456	8.682	<.001	***
Middle East/North Africa	0.116	1.241	0.215		2.231	14.021	<.001	***
North America	0.954	7.290	<.001	***	0.798	3.057	0.002	**
South Asia	-1.273	-7.301	<.001	***	-1.941	-6.191	<.001	***
Sub-Saharan Africa	0.474	1.671	0.095	+	1.056	3.399	0.001	**
Day x BCG past vs. never	-0.019	-1.491	0.143		-0.000	-0.009	0.993	
Day x BCG current vs. not current	-0.025	-2.413	0.020	*	-0.078	-4.064	<.001	***

Figure 1. Growth curves by country BCG policy for (A-B) cases and (C-D) deaths, presented on linear (A & C) and logarithmic (B & D) scales.

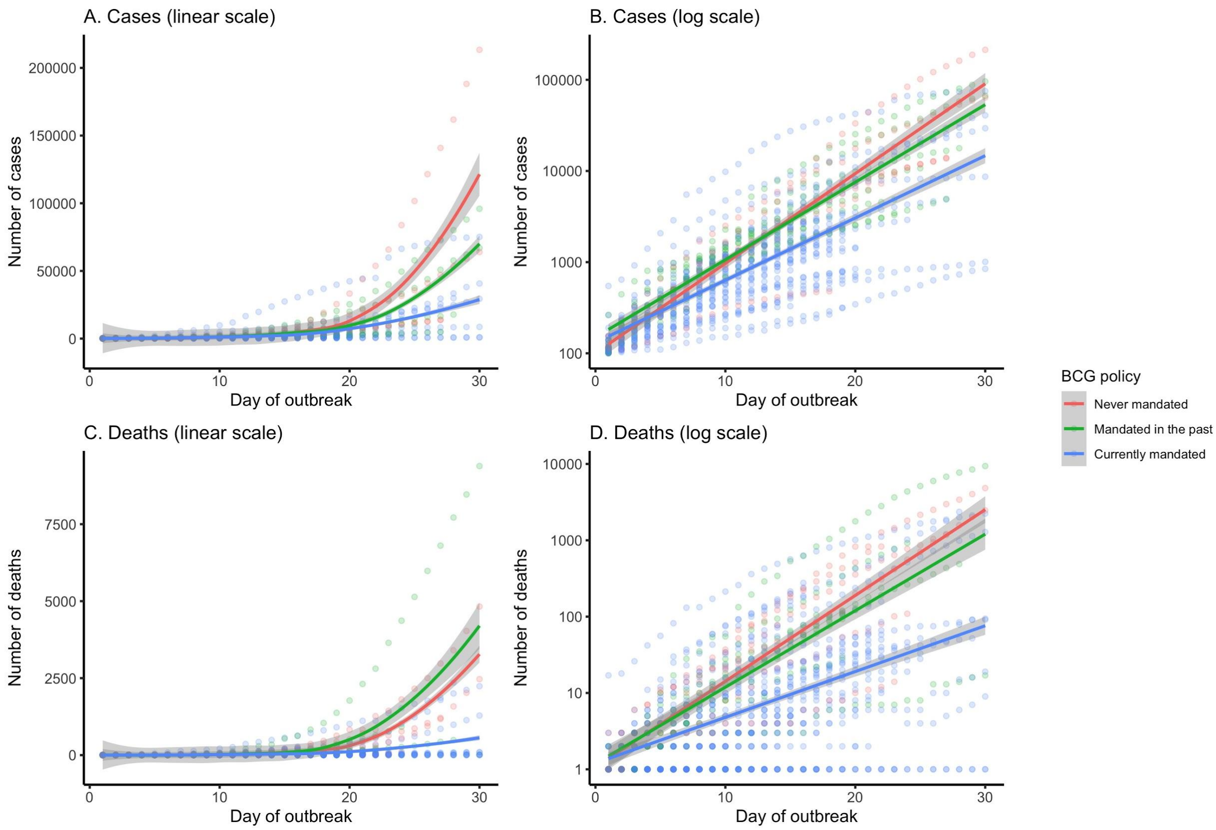
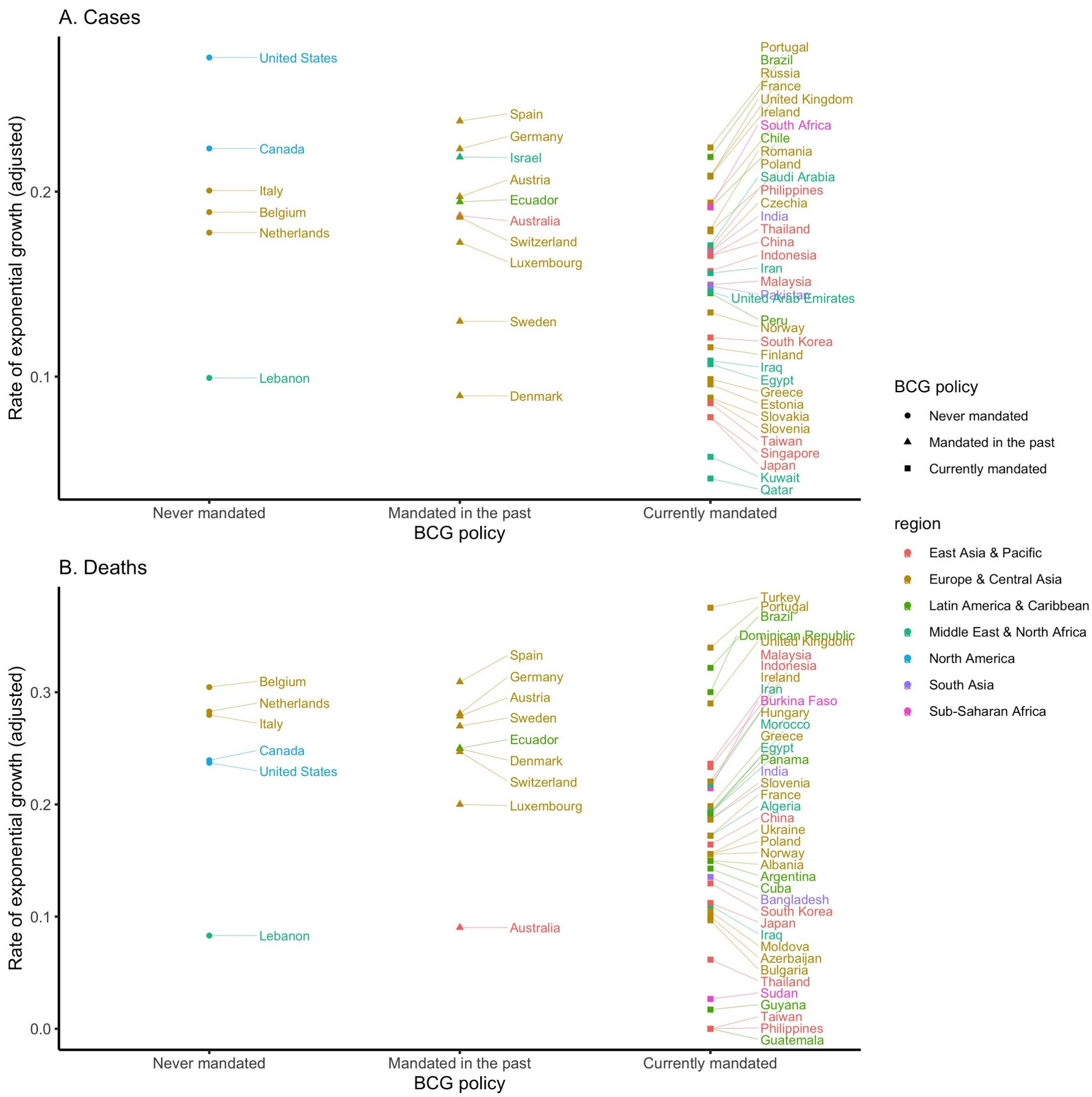


Figure 2. Growth rate of (A) cases and (B) deaths for each country, plotted by BCG policy and region. Growth rate is adjusted by median age, GDP per capita, population density, total population, and net migration rate.



Mandated Bacillus Calmette-Guérin (BCG) vaccination predicts flattened curves for the spread of COVID-19

Supplementary Materials

Methods

We retrieved data on daily confirmed COVID-19 cases and deaths by country from a public repository[2] updated daily by the Johns Hopkins University Center for Systems Science and Engineering. Our current results are based on data for all days through April 1, 2020.

BCG vaccination policy data for each country were compiled from the BCG World Atlas (*1*).[3] These data included BCG policy status (vaccination never mandated, vaccination mandated in the past but terminated before 2000, vaccination mandated either currently or up until at least 2000), and, for countries that currently mandate BCG vaccination, the year that the current policy was implemented.[4] We created 2 contrast-coded variables to capture BCG policy. The first was a contrast between countries that currently mandate BCG (including those that maintained mandated BCG until at least 2000) and countries that do not currently mandate BCG (including those that terminated mandated BCG before 2000). The second was a contrast between countries that previously mandated BCG that terminated it before 2000 and countries that never mandated BCG.

We included in our analysis relevant demographic information for each country. Total population (in thousands) was included since the number of both confirmed cases and deaths should be larger for more populous countries. It was compiled from the United Nations Department of Economic and Social Affairs World Urbanization Prospects 2018 (*2*). Population was rescaled to reflect the total population in millions. Median age of the total population (in years) was included since older adults are more susceptible to viral threats. Population density (in persons per square kilometer) was used because it is likely to foster greater social contact, resulting in greater chances of infection. Net migration (persons entering country minus persons exiting country, per 1000 population) was included so as to control for population movement. These statistics were compiled from the United Nations Department of Economic and Social Affairs World Population Prospects 2019 (*3*). Gross domestic product (at purchasing power parity) per capita (GDP per capita), compiled from the World Bank International Comparison Program database (*4*), was included to control for economic development. GDP per capita was rescaled to reflect GDP per capita in thousands. Geographic region for each country was designated using World Bank region categories. Region was dummy coded with East Asia/Pacific as the reference group.

We employed the following exclusion criteria. Countries were excluded from our analysis of COVID-19 cases if they had reported fewer than 15 days of at least 100 total cases. A similar criteria was used for COVID-19 deaths. We excluded countries that had reported fewer than 15 days of at least one total COVID-19 related death. We created this cutoff in order to ensure reliable exponential growth estimation for each included country while capturing the very first period of country-wise outbreaks. Countries were excluded from both analyses if BCG policy information was unavailable from the BCG World Atlas. For each analysis, included countries, and the date of the first included data point for each, are listed in Table S1.

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[2] https://github.com/CSSEGISandData/COVID-19

[3] http://www.bcgatlas.org/index.php

[4] We defined this variable based on data from the year 2000, so that 'vaccination currently mandated' refers to any country that continued to mandate the BCG vaccination into the 21st century.

All analyses were conducted on up to 30 days of data from each eligible country. In their initial phases, infectious disease trajectories are approximately exponential (*4*). Hence, the number of both confirmed cases and deaths were natural log-transformed first and then subjected to linear mixed models with restricted maximum likelihood estimation, which estimated the effects of BCG policy status on the spread of COVID-19. Each model estimated a random slope for each country across days (indicating the exponential growth over time), to allow for heterogeneity in growth curves between countries. Day was centered so that main effects could be interpreted as differences in either confirmed cases or deaths across the countries on the mean day on the growth curve over the 30-day period. These analyses were performed while controlling for median age, population density, net migration, total population, GDP per capita, and geographic region.

Supplementary Results 1. Testing cultural dimensions

To examine whether BCG policy status might be confounded with some key cultural dimensions, we tested three cultural dimensions. We included individualism vs. collectivism (*5*) and power distance (*6*) since Western individualistic and/or more egalitarian societies tend to have no current mandated BCG policies. The culture scores for the two dimensions were obtained from (*6*). We also included the tightness vs. looseness of social norms (*7*), as this dimension could increase either norm abidance or the rigidity of social systems. Country-wise scores were obtained from (*7*). We first dummy-coded BCG status (BCG currently mandated vs. BCG not currently mandated). We then tested each variable that varied significantly as a function of BCG policy status as an additional covariate in our primary models, to test our key finding (the interaction between day and the primary BCG contrast) would be observed after controlling for the cultural dimension. Since the cultural indices were not available for all the countries included in the main analyses, and moreover, different indices were available for different sets of countries, each cultural dimension was analyzed separately so as to preserve the maximal number of countries.

A series of t-tests revealed that countries that currently mandate BCG (compared to all others) were significantly higher in individualism, whereas they were lower in power distance (Table S2). Tightness/looseness did not vary between countries with and without mandated BCG policies.

A. Confirmed cases

To test whether the cultural dimensions shown to vary between the countries that differed in the BCG policy status might explain the effect of BCG policy status, we repeated the analyses reported in the main text with each of the cultural dimensions included as a covariate (see Tables S3-A and S4-A). 44 countries were included in each analysis. The key interaction between day and BCG policy status (contrasting countries that currently mandate BCG with those that do not) remained statistically significant when either individualism or power distance was added as a covariate.

B. Deaths

We conducted the same two analyses to test whether individualism and power distance qualified the effect of BCG on the increase in deaths over time (see Tables S3-B and S4-B). 41 countries were included in each analysis. The key interaction between day and BCG policy status (contrasting countries that currently mandate BCG with those that do not) remained statistically significant when either individualism or power distance was added as a covariate.

Supplementary Results 2. Effects of control variables in primary analysis

A. Confirmed cases

A larger population size predicted a greater number of infected cases, whereas a higher GDP per capita and higher population density predicted a lower number of infected cases. We also found main effects for several regions of the world. Compared to East Asia/Pacific (used as the reference region), other regions, except for North America and South Asia, show greater numbers of confirmed cases. This regional variation may reflect under-reporting of such cases in certain Asian countries.

B. Deaths

Greater population size, higher net migration rate, and higher median age predicted a greater number of deaths. As in the analysis on confirmed cases, the mortality was less in Asia than in most of the rest of the world, perhaps due to under-reporting in certain Asian countries.

Supplementary Results 3. Robustness check

To test the robustness of our models, we conducted a second set of analyses, only using the first 15 days of data (rather than the first 30). The 15-day cutoff allowed us to examine more exclusively than the 30-day cutoff the very first phase of the outbreak in each country. Because our primary analysis included only countries that reported at least 15 days of eligible data, the same set of countries was included here (see Table S1 for full list for each analysis). All patterns were identical to the primary analyses.

A. Confirmed cases

We found a significant main effect of day, $b = 0.205$, $p < .001$, reflecting an exponential increase in cases over time. This increase was qualified by a significant interaction between day and BCG policy. Specifically, the growth rate of COVID-19 cases was significantly slower in countries with mandated BCG vaccinations, compared to countries without mandated BCG vaccinations, $b = -0.035$, $p = .004$. Countries that once had such policies but terminated them before 2000 were not significantly different in growth rate from those that never instituted mandatory BCG vaccinations, $b = -0.001$, $p = .939$. In sum, our focal effect was no different with a shorter time window. See Table S5-A for full regression table.

B. Deaths

Similarly, we found a significant main effect of day, $b = 0.236$, $p < .001$, reflecting an exponential increase in deaths over time. This increase was qualified by a significant interaction between day and BCG policy. Specifically, the growth rate of COVID-19 deaths was significantly slower in countries with mandated BCG vaccinations, compared to countries without mandated BCG vaccinations, $b = -0.074$, $p < .001$. Countries that once had such policies but terminated them before 2000 were not significantly different in growth rate from those that never instituted mandatory BCG vaccinations, $b = 0.006$, $p = .807$. In sum, our focal effect was no different with a shorter time window. See Table S5-B for full regression table.

Supplementary Results 4. Testing the effect of policy age

We examined the age of the BCG policy in each country that currently mandates vaccination. Among those countries that have mandated BCG, there is a variation in how old the policies are (*8*). It might be expected that the older the policies are, the more effective they are to reduce the rate of spread of COVID-19. However, there was no solid evidence for this conjecture.

A. Confirmed cases

A linear mixed model was conducted to test whether there was any effect of BCG policy age on the exponential increase in confirmed COVID-19 cases. This analysis included 23 countries. We used the same model specifications as in our primary analyses. Both day and policy age were centered so that main effects could be interpreted as differences at the mean day of the growth curve. The model included day, policy age, the interaction of day with policy age, and all demographic variables: median age, population density, net migration, total population, GDP per capita, and geographic region.

The model revealed a marginal interaction between policy age and day on the growth rate of cases, $b < -0.001$, $p = .091$ (see Table S6-A). The countries with older BCG policies tended to have flatter growth curves predicting cases. Further, these countries did have a smaller number of confirmed cases, $b < -0.016$, $p < .001$, as may be expected.

B. Deaths

An identical model was conducted to test whether there was any effect of the age of the policy on the exponential increase in COVID-19 related deaths. This analysis included 19 countries. We found no effect of policy age on the growth rate of deaths, $b = -0.001$, $p = .562$ (see Table S6-B). There was, however, a main effect of policy age on the mean number of COVID-19 deaths, $b = -0.066$, $p < .001$. The meaning of this main effect is unclear in the absence of an interaction with day (i.e., faster growth rate of infections).

Supplementary Results 5. Predicting US cases and deaths if BCG were mandated

We estimated the numbers of confirmed cases and deaths estimated for the U.S. if it had instituted a mandatory BCG vaccination policy decades ago. To do this, we used the "predict" function in R. In particular, we plugged the value of each predictor for the U.S. into the regression equation. The value for day was set at 14.5, corresponding to the centered value of day 30, the final U.S. data point (on April 1 and March 29, 2020, for the analysis of confirmed cases and deaths, respectively). The BCG vaccination policy status was set to be equal to the countries that currently have mandatory BCG vaccination policies. The values for all other predictors were taken from available current U.S. values. The output gives the predicted number of cases (using the confirmed cases model) and deaths (using the deaths model) after natural log transformation. We thus calculated the numbers on their original scale by exponentiating our predicted value. This analysis applied to the number of cases yielded a predicted value of 11.28, which translates to 79488.86 cases (compared to the actual 213372 cases reported in the US by April 1). This analysis applied to the number of deaths yielded a predicted value of 4.54, which translates to 93.97 deaths (compared to the actual 2467 deaths reported in the US by March 29).

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Table S1. List of all countries included in analysis of cases and deaths, with the date set as day 1 in each country. Countries with dates entered in columns 2 and 3 are those included in our analysis of cases and deaths, respectively.

Country	Date of first 100 cases	Date of first death	BCG policy status
Albania		3.11.20	Currently mandated
Algeria		3.12.20	Currently mandated
Argentina		3.8.20	Currently mandated
Australia	3.10.20	3.1.20	Mandated in the past
Austria	3.8.20	3.12.20	Mandated in the past
Azerbaijan		3.13.20	Currently mandated
Bangladesh		3.18.20	Currently mandated
Belgium	3.6.20	3.11.20	Never mandated
Brazil	3.13.20	3.17.20	Currently mandated
Bulgaria		3.11.20	Currently mandated
Burkina Faso		3.18.20	Currently mandated
Canada	3.11.20	3.9.20	Never mandated
Chile	3.16.20		Currently mandated
China	1.22.20	1.22.20	Currently mandated
Cuba		3.18.20	Currently mandated
Czechia	3.13.20		Currently mandated
Denmark	3.10.20	3.14.20	Mandated in the past
Dominican Republic		3.17.20	Currently mandated
Ecuador	3.18.20	3.14.20	Mandated in the past
Egypt	3.14.20	3.8.20	Currently mandated
Estonia	3.14.20		Currently mandated

Finland	3.13.20		Currently mandated
France	2.29.20	2.15.20	Currently mandated
Germany	3.1.20	3.9.20	Mandated in the past
Greece	3.13.20	3.11.20	Currently mandated
Guatemala		3.16.20	Currently mandated
Guyana		3.12.20	Currently mandated
Hungary		3.15.20	Currently mandated
India	3.14.20	3.11.20	Currently mandated
Indonesia	3.15.20	3.11.20	Currently mandated
Iran	2.26.20	2.19.20	Currently mandated
Iraq	3.13.20	3.4.20	Currently mandated
Ireland	3.14.20	3.11.20	Currently mandated
Israel	3.12.20		Mandated in the past
Italy	2.23.20	2.21.20	Never mandated
Japan	2.21.20	2.13.20	Currently mandated
Kuwait	3.14.20		Currently mandated
Lebanon	3.15.20	3.10.20	Never mandated
Luxembourg	3.17.20	3.14.20	Mandated in the past
Malaysia	3.9.20	3.17.20	Currently mandated
Moldova		3.18.20	Currently mandated
Morocco		3.10.20	Currently mandated
Netherlands	3.6.20	3.6.20	Never mandated
Norway	3.6.20	3.14.20	Currently mandated
Pakistan	3.16.20		Currently mandated

Panama		3.11.20	Currently mandated
Peru	3.17.20		Currently mandated
Philippines	3.14.20	2.2.20	Currently mandated
Poland	3.14.20	3.12.20	Currently mandated
Portugal	3.13.20	3.17.20	Currently mandated
Qatar	3.11.20		Currently mandated
Romania	3.14.20		Currently mandated
Russia	3.17.20		Currently mandated
Saudi Arabia	3.14.20		Currently mandated
Singapore	2.29.20		Currently mandated
Slovakia	3.18.20		Currently mandated
Slovenia	3.13.20	3.14.20	Currently mandated
South Africa	3.18.20		Currently mandated
South Korea	2.20.20	2.20.20	Currently mandated
Spain	3.2.20	3.3.20	Mandated in the past
Sudan		3.13.20	Currently mandated
Sweden	3.6.20	3.11.20	Mandated in the past
Switzerland	3.5.20	3.5.20	Mandated in the past
Taiwan	3.18.20	2.16.20	Currently mandated
Thailand	3.15.20	3.1.20	Currently mandated
Turkey		3.17.20	Currently mandated
Ukraine		3.13.20	Currently mandated
United Arab Emirates	3.18.20		Currently mandated
United Kingdom	3.5.20	3.5.20	Currently mandated

United States	3.3.20	2.29.20	Never mandated

Table S2. Results from t-tests predicting each cultural dimension from BCG status (dummy-coded; 1 = currently mandated, 0 = mandated in the past or never mandated).

Cultural Dimension	N	t	p	
Individualism	52	4.501	<.001	***
Power Distance	52	-4.800	<.001	***
Tightness/Looseness	18	-1.567	0.137	

Table S3. Regression table predicting the natural log of (A) cases and (B) deaths from BCG status, controlling for individualism, as well as all covariates in our primary model. Day and policy age are mean-centered. Geographical region variables are dummy-coded with East Asia/Pacific as the reference group.

	A. Cases				B. Deaths			
Predictor	b	t	p		b	t	p	
Intercept	8.102	32.423	<.001	***	1.751	4.452	<.001	***
Day	0.194	20.526	<.001	***	0.218	11.985	<.001	***
BCG past vs. never	-0.103	-2.450	0.014	*	-0.186	-2.043	0.041	*
BCG current vs. not current	-0.416	-10.661	<.001	***	-1.185	-15.070	<.001	***
Median age	-0.008	-1.454	0.146		0.008	0.893	0.372	
GDP per capita (thousands)	-0.003	-1.447	0.148		0.006	1.465	0.143	
Population density	-0.000	-6.963	<.001	***	0.001	2.090	0.037	*
Population (millions)	0.002	20.247	<.001	***	0.004	23.503	<.001	***
Net migration rate	0.015	1.217	0.224		-0.059	-2.435	0.015	*
Europe/Central Asia	0.703	9.589	<.001	***	2.228	17.218	<.001	***
Latin America/Caribbean	0.439	3.492	0.001	**	1.287	6.863	<.001	***
Middle East/North Africa	1.056	8.837	<.001	***	2.794	13.893	<.001	***
North America	0.813	6.178	<.001	***	0.958	3.663	<.001	***
South Asia	-1.349	-7.932	<.001	***	-2.275	-6.870	<.001	***
Sub-Saharan Africa	NA	NA	NA		NA	NA	NA	
Individualism	-0.006	-4.007	<.001	***	-0.010	-3.977	<.001	***
Day x BCG past vs. never	-0.013	-1.000	0.324		-0.006	-0.238	0.813	
Day x BCG current vs. not current	-0.024	-2.238	0.031	*	-0.084	-4.014	<.001	***

Table S4. Regression table predicting the natural log of (A) cases and (B) deaths from BCG status, controlling for power distance, as well as all covariates in our primary model. Day and policy age are mean-centered. Geographical region variables are dummy-coded with East Asia/Pacific as the reference group.

	A. Cases				B. Deaths			
Predictor	b	t	p		b	t	p	
Intercept	7.505	22.749	<.001	***	1.914	3.543	<.001	***
Day	0.193	19.580	<.001	***	0.214	11.547	<.001	***
BCG past vs. never	-0.034	-0.819	0.413		-0.100	-1.134	0.257	
BCG current vs. not current	-0.379	-9.996	<.001	***	-1.062	-14.202	<.001	***
Median age	-0.003	-0.562	0.574		0.005	0.455	0.649	
GDP per capita (thousands)	-0.005	-1.971	0.049	*	-0.002	-0.476	0.634	
Population density	-0.000	-5.951	<.001	***	0.001	3.467	0.001	**
Population (millions)	0.002	19.957	<.001	***	0.004	24.192	<.001	***
Net migration rate	0.013	1.024	0.306		-0.063	-2.560	0.011	*
Europe/Central Asia	0.605	8.752	<.001	***	2.143	16.653	<.001	***
Latin America/Caribbean	0.513	3.992	<.001	***	1.421	7.680	<.001	***
Middle East/North Africa	1.062	7.739	<.001	***	2.539	11.893	<.001	***
North America	0.732	5.606	<.001	***	0.871	3.270	0.001	**
South Asia	-1.323	-7.288	<.001	***	-2.753	-8.503	<.001	***
Sub-Saharan Africa	NA	NA	NA		NA	NA	NA	
Power distance	0.003	1.682	0.093	+	-0.006	-1.775	0.076	+
Day x BCG past vs. never	-0.014	-1.009	0.319		-0.008	-0.297	0.768	
Day x BCG current vs. not current	-0.025	-2.183	0.035	*	-0.085	-3.960	<.001	***

Table S5. Regression tables predicting the natural log of (A) cases and (B) deaths, using a 15-day window (instead of a 30-day window, as in Table 1). Day is mean centered, and BCG policy variables are both contrast-coded. Geographical region variables are dummy-coded with East Asia/Pacific as the reference group.

	A. Cases				B. Deaths			
Predictor	b	t	p		b	t	p	
Intercept	7.273	23.639	<.001	***	1.800	3.523	<.001	***
Day	0.205	19.863	<.001	***	0.236	13.901	<.001	***
BCG past vs. never	0.165	2.230	0.026	*	-0.041	-0.259	0.796	
BCG current vs. not current	-0.459	-8.181	<.001	***	-0.896	-7.382	<.001	***
Median age	0.013	1.629	0.104		0.018	1.457	0.146	
GDP per capita (thousands)	0.000	0.156	0.876		-0.006	-1.167	0.244	
Population density	-0.000	-6.478	<.001	***	0.001	1.238	0.216	
Population (millions)	0.002	11.144	<.001	***	0.003	11.407	<.001	***
Net migration rate	-0.023	-1.317	0.188		0.061	2.124	0.034	*
Europe/Central Asia	0.242	2.251	0.025	*	1.209	6.020	<.001	***
Latin America/Caribbean	0.477	3.230	0.001	**	0.759	3.188	0.002	**
Middle East/North Africa	-0.292	-2.273	0.023	*	1.103	4.238	<.001	***
North America	0.458	2.110	0.035	*	0.371	0.808	0.420	
South Asia	-0.908	-4.303	<.001	***	-1.851	-3.778	<.001	***
Sub-Saharan Africa	0.514	2.072	0.039	*	0.436	1.109	0.268	
Day x BCG past vs. never	-0.001	-0.077	0.939		0.006	0.245	0.807	
Day x BCG current vs. not current	-0.035	-3.014	0.004	**	-0.074	-3.883	<.001	***

Table S6. Regression table predicting the natural log of (A) cases and (A) deaths from the number of years BCG mandate has been in effect. Day and policy age are mean-centered. Geographical region variables are dummy-coded with East Asia/Pacific as the reference group.

	A. Cases				B. Deaths			
Predictor	b	t	p		b	t	p	
Intercept	7.296	16.408	<.001	***	-0.082	-0.084	0.933	
Day	0.171	14.755	<.001	***	0.147	6.674	<.001	***
Policy age	-0.016	-15.232	<.001	***	-0.066	-9.954	<.001	***
Median age	-0.078	-8.530	<.001	***	-0.047	-2.114	0.035	*
GDP per capita (thousands)	0.009	2.927	0.004	**	0.039	8.820	<.001	***
Population density	0.004	14.555	<.001	***	0.005	11.200	<.001	***
Population (millions)	-0.000	-2.137	0.033	*	0.006	11.811	<.001	***
Net migration rate	-0.122	-5.712	<.001	***	-0.003	-0.061	0.952	
Europe/Central Asia	1.635	15.091	<.001	***	2.874	14.859	<.001	***
Latin America/Caribbean	1.825	9.571	<.001	***	4.368	11.048	<.001	***
Middle East/North Africa	1.563	9.561	<.001	***	3.850	14.595	<.001	***
North America	NA	NA	NA		NA	NA	NA	
South Asia	-0.691	-2.713	0.007	**	-5.400	-8.240	<.001	***
Sub-Saharan Africa	0.983	3.398	0.001	**	-0.119	-0.212	0.832	
Day x Policy age	-0.000	-1.776	0.091	+	-0.001	-0.592	0.562	