Comparing COVID-19 Control in the Asia-Pacific and North Atlantic Regions*

Jeffrey D. Sachs
Center for Sustainable Development
Columbia University
475 Riverside Drive, Suite 1040
New York, NY 10115
sachs@columbia.edu

Postscript (21 December 2020)

This paper was completed on 18 June 2020, in the midst of the fast-moving pandemic. At the time, the performance of the Asia-Pacific region in suppressing the epidemic was vastly superior to that of the North Atlantic region (including both North America and Western Europe). A half-year more has now passed. Rather than re-writing the paper, I have allowed the original to stand as was written, but add this postscript for an update. The basic message is clear: The early superior results of the Asia-Pacific region were maintained during the second half of 2020. These superior results were neither early anomalies (such as the particular timing of the arrival of the virus) nor temporary successes that were later overwhelmed by events. The accomplishments have persisted, and reflect a superiority of the public health measures undertaken by the governments, and the public's compliance with them, in the Asia-Pacific region compared with the North Atlantic region.

Table P1 shows the most recent data (21 December 2020) regarding cases and deaths per million population. During the next phase of epidemic control (beyond the scope of this paper), the comprehensive deployment of vaccines will be an additional key component of successful public health implementation. We see clearly that the top-performing countries of the Asia-Pacific region vastly outperformed their North Atlantic counterparts considering the full year up to 21 December. Considering each region as a whole, the (unweighted) average across countries of cumulative cases per million population was 2,236.0 in the Asia-Pacific region, compared with 25,764.8 in the North Atlantic region.

* I thank Ms. Ismini Ethridge for outstanding assistance on all aspects of the paper. I am grateful to Professor Ram Fishman for early discussions and his outstanding work with Professor Nittai Bergman on linking the effective reproduction date with the Google mobility data. I also thank Professor Simas Kuscinskas for discussions about the effective reproduction rate.

https://doi.org/10.1162/asep_a_00795

Table P1. Updated COVID-19 cases and deaths, Asia-Pacific and North Atlantic regions (21 December 2020)

Country	Total cases (per mil)	Total deaths (per mil)	New cases 7-day avg (per mil)	New deaths 7-day avg (per mil)	Growth rate 2020
Asia-Pacific					
Australia	1,105.8	35.6	0.9	–	−4.2
China	66.0	3.3	0.1	0.0	1.9
Indonesia	2,431.0	72.7	24.6	0.6	−1.5
Japan	1,575.6	22.0	21.0	0.3	−5.3
Lao PDR	–	–	–	–	0.2
Malaysia	2,882.9	13.5	43.4	0.1	−6.0
New Zealand	439.8	5.2	0.7	–	−6.1
Philippines	4,195.9	81.6	13.5	0.3	−8.3
Singapore	9,986.1	5.0	2.5	–	−6.0
South Korea	986.8	13.6	19.8	0.3	−1.9
Taiwan	32.2	0.3	0.2	–	0.0
Thailand	70.3	0.9	1.4	–	−7.1
Vietnam	14.5	0.4	0.0	–	1.6
North Atlantic					
Canada	13,559.1	377.4	179.1	3.0	−7.1
Denmark	23,307.0	178.7	609.0	2.3	−4.5
Finland	5,985.1	88.3	60.6	0.9	−4.0
France	38,756.2	929.4	212.7	5.8	−9.8
Germany	18,081.8	315.1	279.9	7.3	−6.0
Italy	32,304.4	1,137.9	258.7	10.1	−10.6
Mexico	10,242.1	916.8	78.1	4.7	−9.0
Norway	8,098.7	74.5	76.5	0.4	−2.8
Spain	38,439.6	1,046.4	203.7	4.0	−12.8
Sweden	36,351.1	791.4	665.1	6.8	−4.7
United Kingdom	30,141.1	994.4	403.3	6.8	−9.8
United States	53,911.0	959.7	651.8	7.9	−4.3
Regional Averages					
Asia-Pacific	2,236.0	23.5	10.8	0.1	−3.3
North Atlantic	25,764.8	650.8	306.6	5.0	−7.1

Note: *This table includes South Korea and New Zealand, and does not include Hong Kong, India, Saudi Arabia, and the United Arab Emirates.*

The Asia-Pacific successes will likely show up as superior economic outcomes as well, though such conclusions for the year 2020 will be available only in 2021. The evidence as of now (December 2020) is that the Asia-Pacific successes in suppressing the virus were achieved with lower economic losses than in the North Atlantic region, disproving the hypothesis of a tradeoff between the economy and suppressing transmission of the disease. It appears that effective deployment of nonpharmaceutical interventions (NPIs) enables *both* the suppression of disease and transmission and an earlier economic recovery compared with two extreme alternatives (either to do little to suppress the epidemic or to shut down the economy on a prolonged basis). The final column of the new table shows the projected 2020 GDP growth rate (in constant dollars, national currency) in the IMF's World Economic Outlook of October 2020. Although these estimates for 2020 are uncertain and preliminary, they do suggest that the Asia-Pacific's superior performance in suppressing the epidemic was achieved alongside superior economic performance as well. We note that China, Vietnam, and Lao PDR are all predicted to have positive growth rates for 2020, and Taiwan is projected as zero growth. The rest of the countries are projected to contract by varying rates, with the projected (unweighted) average decline in the Asia-Pacific far smaller (−3.5 percent) than in the North Atlantic region (−7.5 percent).

There are two notable updates of the conclusions from June. First, despite the clear evidence of a large number of infectious yet asymptomatic cases (in which the infectious individual never shows symptoms) and pre-symptomatic cases (in which the infectious individual shows symptoms after becoming infectious to others), effective control of the pandemic through NPIs is nonetheless feasible. Yet suppression depends on *active surveillance*, meaning that the public health system actively searches for potentially infectious individuals rather than waiting passively for individuals to show up for testing. Active surveillance is mainly carried out by contact tracing, both forward (to potential new cases arising from each newly confirmed case) and backward (to identifying the likely source of infection of each newly confirmed case).

Second, despite the clear evidence from the Asia-Pacific region that NPIs work effectively and at low cost, the North Atlantic region failed to carry them out systematically. This represents a serious lapse of governance, and gives evidence of a deeper and longer-term crisis of governance. There are several apparent reasons why the North Atlantic region fell far short of the potential to control the epidemic, including the following:

Public health populism. Some political leaders, such as Donald Trump, used their prominent positions to downplay the seriousness of the epidemic, to the point of rejecting or undermining the public's compliance with NPIs, such as wearing face masks.

Lack of regional cooperation, including effective border controls. Even though the SARS-Cov-2 virus was clearly crossing national borders at massive rates, the North Atlantic countries failed to implement effective border controls and regional cooperation.

Misplaced claims of "freedom." A recurring ideological claim in North Atlantic public debate has been the assertion that NPIs such as physical distancing, face-mask wearing, and closure of events constitute a denial of freedom, thereby limiting the public's compliance. Such ideological claims seem to be far less frequent in the Asia-Pacific countries, even including Australia and New Zealand, which share the British liberal traditions.

Lack of epidemic preparedness. The Asia-Pacific advantage also seems to reflect epidemic preparedness, probably reflecting the region's recent intensive battles with SARS, H1N1, MERS, and other zoonotic diseases. These experiences gave rise to effective national emergency response systems and to strategies for regional cooperation, including the WHO Western Pacific Regional Office Asian-Pacific Strategy for Emerging Diseases (APSED), now in its third iteration. The North Atlantic countries were far less experienced with epidemic threats.

Information technology deployment. Many of the Asia-Pacific countries rapidly deployed digitally enabled responses, including support for public information, contact tracing, and avoidance of high-risk zones. In general, the North Atlantic countries proved to be less adept at deploying digital apps, with less coverage and public uptake, and more concerns about potential infringements on privacy.

Introduction

The COVID-19 pandemic is far more severe than other recent epidemics, including influenza, SARS, MERS, AIDS, and measles, for four main reasons. First, the global population is highly susceptible to the novel virus and there is as yet no vaccine or effective treatment. Second, the transmission of the infection is rapid, with a doubling time of three to four days in the early phase of an uncontrolled outbreak. Third, transmission is difficult to control because pre-symptomatic and asymptomatic individuals transmit the virus.[1] Fourth, the Infection Fatality Rate (IFR) is higher than influenza, though the IFR is not precisely determined and in any event varies according to demography, the health care system, and perhaps the physical environment (e.g., air pollution and humidity). Non-fatal infections cause also serious prolonged impairments. As a result, the COVID-19 epidemic is global, fast-moving, difficult to control, and dangerous.

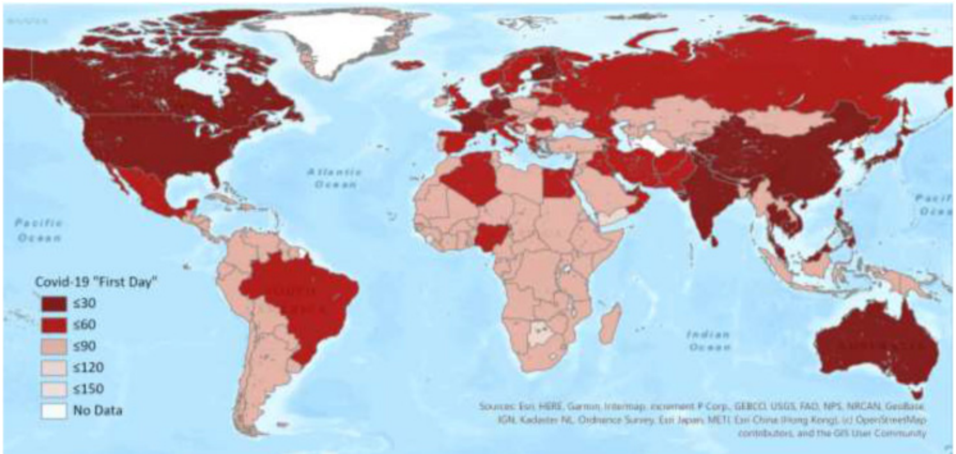
Following the initial outbreak in China in late 2019, COVID-19 spread earliest to countries connected with China through the extensive movement of tourists, business travelers, overseas students and family members, foreign workers, and other expatriates. By the end of January, the virus had already reached many countries in the Asia-Pacific region, South Asia, Western Europe, and North America. During February, the epidemic arrived in countries in Latin America, the Commonwealth of Independent States, and a few in Africa. During March, the virus arrived in more countries of Africa, Eastern Europe, and Central Asia. The progression of the virus is seen in Figure 1, which maps the date of the first confirmed case in each country.

Countries with early first cases tend to have more cumulative infections and deaths per million than countries with later first cases. The obvious reason is that the epidemic has had more time to spread within the population. Another reason, however, is that countries with later first cases learned from the experiences abroad. Most importantly, they saw the need to act quickly to contain the epidemic following the first confirmed cases. As a result, the countries with later arrivals have generally been more effective than the first-wave countries in slowing the spread of the virus.

The pandemic is still in an early phase. The number of people worldwide who have been infected as of the time of writing (17 June 2020) is far below herd immunity. Confirmed

1 *Pre-symptomatic* transmission means that it occurs before the infectious individual develops symptoms. *Asymptomatic* transmission means that the infectious individual transmits the virus but never develops symptoms.

Figure 1. Global map: First day of confirmed case (days since 1 January 2020)



cases total around 8.3 million. Supposing that these confirmed cases represent 5–10 percent of actual cases, the number of people so far infected would be roughly 83–167 million, or 1.1–2.1 percent of the global population of 7.8 billion. Recent testing of the population for antibodies (so-called serological studies) found the rate of infection to be 5.2 percent in Spain and 6.8 percent in England, two hard-hit countries (Cookson 2020).

Moreover, the epidemic is still far from being controlled in much of the world. As I note herein, the basic reproduction rate R(t) measures whether an epidemic is growing or diminishing, depending on whether R(t) >1 or <1 as of day t of the epidemic. Using the most recent estimate of R(t) for June 13, R(t) >1 in 89 countries. These 89 countries have a combined population of 5.9 billion, or 76 percent of the world population. This is an alarming finding, but perhaps not quite as bleak as it seems because many countries have an R(t) close to 1, and because China is likely to come off of the list soon.[2] Still, the evidence is clear that most of the world has not yet suppressed the transmission of the virus though most are trying to do so.

In this paper I compare the performance of 26 countries in controlling the epidemic. These are the countries that were in the first wave of the epidemic (with the first case no later

2 China joined the list of countries with R(t) >1 on 22 May after several weeks of R(t) <1. It is taking rigorous actions to bring new outbreaks under control and is likely to revert to R(t) <1 in the near future.

than March 3) and that have been part of the YouGov Behavior Change Tracker,[3] which collects invaluable survey data on hygienic behaviors (such as wearing face masks and avoiding crowded places). As such, these 26 countries constitute a meaningful group for cross-country comparisons.[4] I note that several high-performing Asia-Pacific countries (including Cambodia, Lao PDR, and New Zealand) are unfortunately not part of the YouGov survey, and so are not included in the regression analysis.

The main finding is that the Asia-Pacific region, which I define as mainland China, Hong Kong, Taiwan, Japan, Korea, Australia, New Zealand, and the ASEAN countries, has effectively controlled the epidemic in comparison with the North Atlantic region, which includes North America (Canada, Mexico, and the United States) and Western Europe. All but three of the 26 countries compared in this paper are in one of these two regions.[5] Comparing the two regions, the Asia-Pacific region has had fewer confirmed cases and deaths per million, and a lower disruption of economic activity as proxied by visits to shops and workplaces. The Asia-Pacific region was more effective than the North Atlantic region in deploying the low-cost strategies of public health, including testing-isolating-and-tracing, widespread use of face masks, and early restrictions on international travel (and hence on barriers to the arrival of infections from abroad).

The basics of epidemic control

In the standard S-E-I-R model of the epidemic, the key parameter of an epidemic is the effective reproduction number R(t), which indicates the average number of infections transmitted by an infectious individual.[6] At the outset of the epidemic, R(t) is called the basic reproduction number R0. For COVID-19, it is estimated to be between 2 and 3, with a frequent point estimate of 2.4. By introducing control measures to limit the transmission of the virus, R(t) is reduced. If R(t) <1, each infectious individual infects less than one other individual on average, and the number of active cases in the population declines over time. If R(t) >1, each infectious individual infects more than one other individual on average, and the epidemic expands.

3 https://today.yougov.com/topics/international/articles-reports/2020/03/17/personal-measures-taken-avoid-covid-19.

4 One country in the YouGov data, Saudi Arabia, is part of the first-wave countries, since the first case is reported on 15 March 2020.

5 The remaining three are India, Saudi Arabia, and the United Arab Emirates.

6 The S-E-I-R model stands for Susceptible-Exposed-Infectious-Recovered model, the basic workhorse model of epidemiologists. In the basic model, 100 percent of the population is susceptible to infection at the start of the epidemic. Individuals who contract the virus are first Exposed (infected but not infectious), then become Infectious to others, and then Recover or die of the infection. This model framework is used throughout the paper.

Assuming that a bout of COVID-19 infection leads to acquired immunity that prevents a repeat infection in that individual, R(t) falls over time as the share of the population that has ever been infected rises. Eventually, the share of individuals that have experienced an infection, and therefore that have acquired immunity from a further infection, is large enough to reduce R(t) to a value of 1.0 or below. The threshold occurs when s(t), the share of the susceptible population, falls far enough so that $s(t) \times R0 = 1$, or when $s(t) = 1/R0 = 1/2.4 = 41.7$ percent, or when 58.3 percent ($= 100 - 41.7$ percent) of the population have been infected. After this threshold is reached, the virus spreads at a declining rate until the epidemic comes to an end.

If the COVID-19 epidemic runs its natural course without any control, with $R(t) = R0 = 2.4$, more than 80 percent of the population will eventually be infected. The proportion of the population that is infected in the course of the epidemic is called the *attack rate*. Many epidemiologists assume that the COVID-19 attack rate is at 80 percent. This is the figure that I use in this paper.

With a COVID-19 IFR estimated by epidemiologists to be in the range between 0.5 and 1.5 percent, and with an assumed attack rate of 80 percent, the eventual mortality from an uncontrolled epidemic would be 0.4–1.2 percent of the population. For the United States, with 330 million people, that would mean COVID-19 deaths of 1.3–4.0 million people. As of 1 June, confirmed COVID-19 mortality in the United States was 110,000, or one-tenth of the lower bound estimate. The implication is that unless the epidemic is controlled, the deaths could still multiply by ten times, or more.

Given the high apparent death rates of COVID-19, governments almost everywhere have sought to limit the spread of the disease, despite a few populist leaders (such as Brazil's president Jair Bolsonaro, and Donald Trump from time to time) who downplay the risks of the epidemic. Until there is an effective vaccine or treatment, control strategies mainly focus on public health measures to reduce R(t) and the rate of deaths per infection. Seven approaches can be noted, to be used in combination:

(1) stopping the entry of infected individuals from other countries;
(2) promoting hygienic behavior—such as wearing face masks and physical distancing;
(3) isolating infected individuals to keep them from infecting others;
(4) protecting vulnerable groups, especially the elderly, from infection;
(5) protecting residents of congregate settings such as care centers, prisons, and worker hostels;
(6) shutting down schools and public events (sports, religious, entertainment); and
(7) shutting down workplaces and order non-essential workers to shelter at home.

In principle, the epidemic could be controlled quickly and at low cost using strategies (2) and (3). Suppose that all infected individuals today were enabled to isolate during the period of their infectiousness, which is 7–14 days for most cases. The pandemic would come to a quick end. Around 99 percent of those who are infected today would recover, while perhaps 0.5–1.0 percent would die of the disease. Yet as a result of temporary isolation, those infected today would not infect others, so that the epidemic would end with their recovery or death.

Sadly, the epidemic is not being systematically controlled in most countries. To identify and isolate infected individuals is a skilled task that requires an effective public health system. The challenge is complicated by the fact that asymptomatic and pre-symptomatic individuals transmit the virus. This means that the public health system should help to locate and test even individuals without symptoms, based mainly on their having had close contact with confirmed (tested) COVID-19 cases. Moreover, even when infectious people are tested, they need help to isolate. Many live in crowded conditions in which they are likely to infect others in the household. Others are in such poverty that they need social support to meet their basic needs, including food and safe water, while being in isolation.

The good news is that it is not necessary to isolate 100 percent of infectious individuals to stop the epidemic. It is only necessary to reduce R(*t*) below 1 on a sustained basis. A high enough proportion of infectious individuals should be in isolation so that on average each infectious individual infects less than one additional person. This is accomplished by early self-isolation of symptomatic individuals and by public health measures to identify potentially infected individuals, test them, isolate confirmed cases, and trace close contacts. Moghadas et al. (2020) model the role of early self-isolation in reducing R(*t*).

To drive and keep R(*t*) <1, the testing-tracing-isolating regimen should be complemented by other low-cost measures, most importantly hygienic behaviors that reduce likelihood of transmitting the virus. Wearing face masks in public and keeping an adequate physical distance in public places (such as shops) also reduce viral transmission, thereby further reducing R(*t*) beyond what is accomplished by testing-tracing-and-isolating.[7] Hygienic behavior is inexpensive and reduces R(*t*) without disrupting daily life.

Strategies (1), (6), and (7) are more disruptive. Stopping international travel arrivals from highly impacted zones can be a particularly important way to prevent the initial seeding of the epidemic, and it proved to be extremely useful in the Asia-Pacific region, where

7 A *contact* is generally considered to occur when individuals are proximate for ten minutes or more, for example, in conversation, or at the checkout counter, or in a theater or restaurant or office. Each contact between an infectious and susceptible individual has the potential to transmit the virus, though only a relatively small proportion of such contacts in fact lead to viral transmission. That proportion is reduced by face masks, physical distancing, use of hand sanitizers, and care not to cough or sneeze on others.

countries were quick to introduce travel restrictions. Yet over time such measures create considerable economic disruptions to tourism, trade, and personal needs, and in any event do not stop the community spread of the virus after the virus has arrived.

The biggest disruptions are economic shutdowns—strategies (6) and (7). Rather than isolating the small proportion of infectious individuals, economic shutdowns restrict the movement of the entire society, at a high cost. Economic activity is substantially reduced in the sectors requiring face-to-face contacts, such as retail shops, leisure and accommodations, construction, factory sites, and much of the food service industry. For many activities, such as much of office work and even schooling, the activity can be shifted to online production from home without great loss of productivity, but this is not possible for most goods production (agriculture, mining, construction, and manufacturing), and for many services that require interactions at the workplace.

Why then would a government ever choose to shut down economic activities rather than relying on testing-tracing-and-isolating and on low-cost hygienic measures? There are three main reasons. The first reason is that certain public activities could be superspreaders of the virus. Large public gatherings of people (in religious celebrations, sports and entertainment events, crowded public spaces) can result in large numbers of infections that would be difficult to trace and contain. Such events are called "super-spreader events," and they have evidently played a substantial role in the epidemic.[8] Closing such events has modest economic costs but potentially extremely high benefits.

The second practical reason for a temporary economic shutdown is to buy vital time to build a public health system that can test, trace, and isolate infectious individuals. Most countries entered 2020 ill-equipped to deploy robust testing-tracing-and-isolating regimens. The countries of the Asia-Pacific region, however, were the best prepared, thanks to their experience with previous epidemics. The SARS epidemic in 2003 was a terrifying trial run for these countries, and subsequent waves of epidemics (H1N1 in 2009, MERS and NIPAH infections more recently) honed their epidemic control systems. Western Europe and the United States, by contrast, were not prepared. They chose lockdowns mainly because their testing-and-tracing systems were nonexistent or not up to the task of suppressing the epidemic. Shutdowns were therefore adopted as an emergency expedient to hold the epidemic in check. Yet for the shutdowns to be lifted while keeping $R(t) < 1$, an effective public health system must be put in place during the shutdown.

A third reason given in some countries in the early stages of partial lockdowns was to "flatten the curve" of the epidemic. The idea was to use partial lockdowns to reduce $R(t)$ below

8 The original outbreak in Wuhan, China, was greatly amplified by a massive New Year's public dinner on 18 January; the outbreak in Korea was spread in a mega-church community; Mardi Gras festivities led to a massive outbreak in New Orleans; and so forth.

R0 but not necessarily below 1. With R(*t*) between 1 and R0, the epidemic was expected to continue, but more gradually and with a less pronounced peak of cases. The main idea was to reduce the surge of patients in hospitals, so as not to overwhelm the health care facilities (e.g., the number of intensive care unit beds required). By flattening the curve, the hope was to prevent an overload of hospital cases without necessarily diminishing the number of long-term infections.

The flatten-the-curve rationale is a halfway house between doing little to stop the infection and taking more significant steps to suppress the epidemic by driving R(*t*) <1. It is essentially a pessimistic strategy: that policy measures can blunt the epidemic but not by enough to stop the spread of the virus or to prevent a high long-term attack rate (short of a vaccine). The success of several countries in keeping R(*t*) <1 has tended to undermine the rationale for merely flattening the curve. The expression "flattening the curve" is used much less as of mid-2020 than in the early weeks of the epidemic.

In the rest of the paper I consider the comparative performance of countries in containing the epidemic. First, I illustrate the costs of an uncontrolled versus controlled epidemic, and show the enormous advantages of a public-health approach to suppressing the epidemic. Then I examine the performance of the 26 countries in the YouGov survey. The countries of the Asia-Pacific region deployed public health mechanisms early and relied on low-cost hygiene and isolating rather than deep shutdowns. As a result, these countries brought the epidemic under control more decisively and at lower cost than did countries of the North Atlantic region.

The costs of the epidemic and its control

Consider the cost of an uncontrolled epidemic, one that runs its full course until herd immunity is achieved. Such an epidemic infects around 80 percent or more of the population, based on an R0 of around 2.4. Of those infections, a certain fraction pass through the infection asymptomatically and with no apparent detriment to the individual. The rest of the infections pass through a cascade of possible outcomes. A certain proportion, around 80 percent, experience mild cases that can be treated at home or as an outpatient. Severe cases progress to hospitalization. Some of those progress to the intensive care unit (ICU). And some fraction of those die from the disease. The probabilities in this cascade are age-specific: Young people tend to have milder cases, fewer hospitalizations, and many fewer deaths per infection. The probabilities of severe illness, hospitalizations, transfers to the ICU, and ultimately death rise with age.

The progression of illness and the probabilities of hospitalization, need for the ICU, and eventual death, are being intensively studied by epidemiologists, together with the costs associated with each stage of illness. According to one recent study of the U.S. context by

Bartsch et al. (2020), the median direct health care cost per symptomatic infection is estimated to be $3,994, which includes the costs of outpatient and inpatient coverage and one-year post-hospital discharge. Assuming an 80 percent attack rate, and assuming that symptomatic infections are 82.1 percent of all infections, the total added health care cost of the epidemic would come to $866 billion, or 4 percent of 2019 GDP.

To these health care costs, we should add two other costs: the monetary losses associated with the excess mortality, and the lost income due to lost work. The most direct way to measure the mortality loss is to assign to each death a loss equal to the Value of a Statistical Life (VSL), with the VSL suitably adjusted by age at death. Using age-specific VSLs, Greenstone and Nigam (2020) find an age-weighted VSL of around US$ 4.5 million given the age-specific mortality rates of COVID-19 mortality. An alternative approach, that leads to a lower monetary valuation, places a dollar value on each Quality-Adjusted Life Year (QALY) lost to the epidemic. The value of a QALY in the United States is conventionally measured at around US$ 100,000–150,000. A QALY value of US$ 125,000 is reasonable, equal to roughly two times the GDP per capita. A QALY-based valuation of COVID-19 mortality would therefore be on the order of US$ 1.25 million.

The overall cost of mortality from the epidemic depends on the IFR. The IFR is currently estimated to lie between 0.5 and 1.5 percent, with a central estimate converging to around 0.6 percent. This would imply 2 million U.S. deaths in total. Using a VSL of US$ 4.5 million, the monetary valuation of those deaths would come to US$ 9 trillion, or 42 percent of the 2019 GDP (US$ 21.43 trillion). Using a QALY-based valuation, the monetary loss would come to around US$ 2.5 trillion, or around 12 percent of the 2019 GDP. The QALY estimates should in principle also include the costs of longer-term disabilities that follow some COVID-19 infections. At this stage there is evidence that many individuals suffer persisting illnesses even after clearing the infection, but there is as yet no comprehensive epidemiological assessment of these longer-term consequences of infection, and therefore no possibility to assign a monetary valuation to such losses. They could well be significant.

To complete the cost calculations, we should also add the monetary losses due to lost work. According to the infection cascade as projected by Bartsch et al. (2020), with an 80 percent attack rate, there would be 215 million symptomatic infections, requiring 89 million ambulatory care visits and 250 million hospital-bed days. Of these, 43 million ambulatory care visits and roughly 140 million hospital days would be for individuals aged 20–64 years, whom I will presume to be in the workforce. Assuming at least one day of lost work for each ambulatory visit and one day of lost work for each hospital-bed day, an 80 percent attack rate would therefore result in at least 283 million lost workdays, and perhaps many more. With 150 million workers, 200 workdays per year, and a US$ 21.4 trillion economy in 2019, the average GDP per workday is US$ 713. If for simplicity we assume that GDP declines by US$ 713 for each workday lost, the overall loss from sick days would be at least US$ 202 billion, or almost 1 percent of GDP. Again, this is likely to be a very conservative estimate of the output lost to sick days.

Taking these three categories of losses together, the overall cost of an uncontrolled epidemic in the United States would be on the order of 4 percent of GDP in direct health care costs, 1 percent of GDP in lost earnings, and somewhere between 12 and 42 percent of GDP in the monetary valuation of the catastrophic loss of life, or between 17 and 47 percent of GDP, not including various longer-term costs of the epidemic. Fortunately, the epidemic can be contained at a far smaller cost than even the lower bound.

The costs of a public health system to contain the epidemic are not easy to determine with any precision, especially since the total costs of controlling the epidemic depend heavily on how early and effectively the public health response is deployed. Suppose that the United States deploys as many as one public health worker per 250 in the U.S. population, in activities to contain the epidemic, including contact tracing, case testing, social service support, implementation of quarantining, home delivery services, workplace safety, implementation of online software, protections of the elderly population, and other means. That is almost surely a vast overestimate of the actual personnel need. The result would be a workforce of 1.3 million individuals (= 330 million/250). Assuming a plausible unit cost of US$ 250,000 per health worker including both salary and operations, this would require US$ 325 billion per year, or roughly 1.5 percent of GDP, for the public health workforce. Clearly this is a pittance compared with the massive costs of an uncontrolled epidemic, assuming that the public health measures successfully suppress the epidemic.

How about the costs of an economic shutdown? To estimate roughly the costs, I assume that a 120-day shutdown would be enough to contain the epidemic permanently. The shutdown entails closing almost all retail shops other than food stores and pharmacies, almost all restaurants, entertainment and leisure sites, accommodations, and most personal services (hairdressers, gyms, etc.). Essential services including grocery stores, pharmacies, public utilities, agriculture, essential manufacturing (e.g., food processing), associated transport and warehousing, public safety services such as police and fire, and most health care would remain open. Rough calculations shown in the Data Appendix (Table A.1) suggest that essential production at the workplace constitutes around 40 percent of the economy, so a complete shutdown reduces workplace output by 60 percent.

Of the 60 percent of workplace output that is temporarily closed, rough calculations shown in the Data Appendix suggest that around half could be carried out from home, mostly online, including most education services, financial services, professional services other than health care, and many government services. Thus, we might expect that a shutdown would mean that 40 percent of production would continue at the workplace and another

30 percent of production would continue from home. In short, during the shutdown, the decline in aggregate output would be around 30 percent.

Now suppose that the shutdown lasts for 120 days, or one-third of the year. The result for the year would be a 10 percent decline in GDP, an enormous decline unmatched in depth since the Great Depression. Yet even a 10 percent decline in GDP would be preferable to an uncontrolled epidemic—*assuming that the temporary shutdown is used to adopt policies that achieve a permanent suppression of the epidemic following the shutdown*.

To illustrate this claim, suppose that the temporary shutdown results in a long-term attack rate of 10 percent rather than 80 percent, as in the uncontrolled epidemic. In that case, the costs of illnesses, deaths, and lost work time would be reduced to one-eighth of the losses of the uncontrolled epidemic. Instead of 2 million lost lives, the mortality would be 250,000 lives lost. The economic losses in health care costs, mortality, and lost workdays would be cut by seven-eighths, thereby averting losses of roughly 15–41 percent of GDP. At a cost of around 10 percent of GDP, the temporary shutdown would be cost effective.

For a temporary shutdown to stop the epidemic *permanently*, the shutdown would have to be followed by public health measures that keep the virus suppressed, notably hygienic measures and testing, isolating, and tracing. The shutdown period thereby serves two purposes: It reduces the number of active infections in the population, making it easier for the public health system to engage in testing, tracing, and isolating; and it gives the government time to build the capacities of the public health system.

There is one more obvious set of measures that can dramatically reduce the costs of the epidemic: protecting high-risk groups, notably the elderly, and vulnerable groups living in congregate settings including long-term care centers, prisons, homeless shelters, and worker hostels. To get a sense of how many lives could be saved by keeping the elderly out of harm's way, note that the IFR for the population aged 65+ is 8.8 times the IFR of the under-65 population according to the estimates in Bartsch et al. (2020). In the uncontrolled epidemic, 80 percent of the total deaths are expected to be of individuals aged 65+. Therefore, a high proportion of deaths could be averted through special measures to protect the elderly.

Shockingly, this special protection has not generally been implemented. The United States has suffered catastrophic outbreaks in its long-term care centers, prisons, and shelters. Roughly one-third of the total deaths have been in nursing care centers and other long-term care centers (Yourish et al. 2020). In New York State, the government made a catastrophic mistake in sending convalescing COVID-19 patients back to nursing homes, thereby seeding infections, the opposite of enhanced protection. Major outbreaks have similarly occurred in the U.S. prison system. In Singapore, widespread outbreaks have been reported in the crowded hostels of foreign workers. Throughout Western Europe

Table 1. R(*t*), deaths per million, day of first case, for selected first-wave countries (June 13 2020)

Country	R(*t*)	Deaths per million	First day
Taiwan	0.33	0.29	21
Vietnam	0.44	0.00	24
Hong Kong	0.50	0.54	23
Thailand	0.81	0.84	13
Italy	0.82	560.16	31
Norway	0.85	44.80	58
Australia	0.86	4.08	25
Germany	0.90	104.55	28
Spain	0.92	579.87	32
Denmark	0.95	101.32	58
Finland	0.96	58.38	30
China	0.97	3.33	1
France	0.99	435.10	25
Malaysia	1.00	3.71	25
Japan	1.04	7.24	15
Canada	1.13	209.75	26
United Kingdom	1.14	608.86	31
US	1.16	336.11	21
Sweden	1.18	457.58	32
Singapore	1.22	4.43	24
Philippines	1.23	9.32	30
Indonesia	1.23	6.73	62
United Arab Emirates	1.26	28.55	27
Saudi Arabia	1.35	20.06	63
Mexico	1.37	107.07	60
India	1.43	5.12	30
Asia-Pacific	0.88	3.68	23.91
North Atlantic	1.02	293.63	34.10

and the United Kingdom, major outbreaks have occurred in elder-care centers. As the data of the first half of 2020 are analyzed with more care, it seems likely that a high proportion of total deaths will have occurred in the context of care centers and other congregate settings, a rather shocking outcome given the plausible controllability of infections in those environments.

Comparing the efficiency of epidemic control in the first-wave countries

I now turn to a comparison of epidemic control in 26 countries in the first wave of the epidemic. I consider two key measures of the epidemic and study their determinants. The first measure is the average effective reproduction number R(*t*) during the period 23 March to 13 June. I use the estimates of R(t) prepared daily by Marioli et al. (2020). The second measure is deaths per million population, as reported by the John Hopkins University COVID-19 reporting system, for 13 June. These measures are reported for the 26 countries in Table 1, ranked from the lowest to highest average R. Table 1 also reports the day of the first confirmed case in each country. The final two rows of the table show the simple (unweighted) averages for the Asia-Pacific countries and North Atlantic countries. The Asia-Pacific region has a lower average R(*t*) and far lower death rate than the North Atlantic region.

Table 2. Determinants of R(*t*), selected first-wave countries (March 23–June 12 2020)

Country	Hygiene	Tracing	School closure	Visits	Travel ban	Low-cost control
Taiwan	0.78	1.00	0.00	0.07	1.00	2.04
Vietnam	0.75	1.00	0.51	0.20	1.00	1.99
Hong Kong	0.81	1.00	0.93	0.18	0.96	2.09
Thailand	0.81	0.87	1.00	0.31	0.86	2.03
Italy	0.75	1.00	0.96	0.55	0.62	1.86
Norway	0.56	0.50	0.52	0.25	1.00	1.53
Australia	0.61	0.50	0.74	0.31	1.00	1.63
Germany	0.55	0.50	0.84	0.31	0.91	1.49
Spain	0.74	0.50	1.00	0.60	1.00	1.90
Denmark	0.51	0.81	0.76	0.26	0.95	1.46
Finland	0.52	0.50	0.56	0.33	0.92	1.43
China	0.80	1.00	0.97	0.74	1.99	
France	0.64	0.70	0.87	0.54	0.97	1.70
Malaysia	0.81	1.00	1.00	0.54	0.82	2.04
Japan	0.67	0.50	0.95	0.22	0.72	1.66
Canada	0.66	0.50	1.00	0.42	1.00	1.73
United Kingdom	0.52	0.10	1.00	0.55	0.02	1.06
United States	0.61	0.50	1.00	0.32	0.75	1.54
Sweden	0.49	0.50	0.33	0.19	0.75	1.30
Singapore	0.75	1.00	0.76	0.45	0.56	1.84
Philippines	0.79	1.00	1.00	0.66	1.00	2.06
Indonesia	0.74	0.50	1.00	0.35	1.00	1.88
United Arab Emirates	0.74	1.00	1.00	0.48	0.96	1.95
Saudi Arabia	0.70	1.00	1.00	0.54	0.98	1.87
Mexico	0.66	0.50	1.00	0.42	0.75	1.65
India	0.77	1.00	1.00	0.57	0.93	1.99
Asia-Pacific	0.76	0.85	0.80	0.33	0.88	1.93
North Atlantic	0.58	0.51	0.79	0.38	0.83	1.51

The effective reproduction rate R depends on a range of actions including partial shutdowns, wearing face masks, engaging in physical distancing, and limiting international travel. I consider the following five indicators, with details on data sources and definitions provided in the data appendix. The values of these indicators for the 26 countries are shown in Table 2, as well as the averages for the two regions at the bottom of the table.

Hygienic behavior. YouGov surveys measure the use of facemasks and other hygienic behaviors (such as avoiding large crowds and improving personal hygiene).

Testing and tracing. The Oxford Coronavirus Government Response Tracker (OxCGRT) evaluates daily the performance of countries' testing-and-tracing systems on a 0–3 scale.

Closing schools. The Oxford Coronavirus Government Response Tracker (OxCGRT) measures daily the extent of school closures across the world.

Partial economic shutdown. Google provides data on the decline in daily visits to economic locations including retail and entertainment sites, grocery stores and pharmacies, transit stations, and offices, measured relative to 3 January–6 February. The larger the decline in visits, the deeper is the economic shutdown.

Restricting international travel. The Oxford Coronavirus Government Response Tracker (OxCGRT) measures daily the control by countries of international arrivals on a scale from 0 (no controls) to 4 (no arrivals permitted).

I estimate a time-series, cross-section regression of the daily R(t) for the 23 countries in the first wave of the epidemic that are included in the YouGov survey data on hygienic behavior.

The panel regression is of the form:

$$R_i(t) = \alpha + \Sigma \beta^j I_{ji}(t) + \gamma_{\mathrm{i}} + \delta t + \varepsilon_{it}. \qquad (1)$$

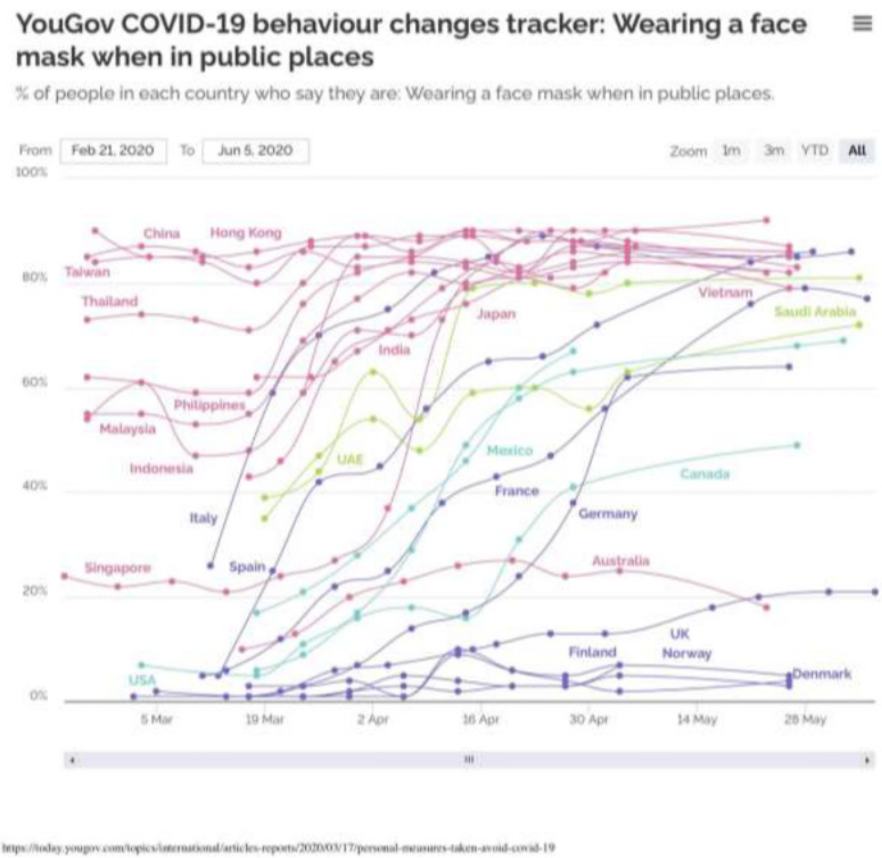
Subscript i is country i and subscript j is indicator j. The panel is run with individual country controls and a daily time trend. The results are reported in Table 3 Panel A. The panel data are for the interval 23 March–13 June.

All of the indicator variables are highly significant and of the expected sign. The variable with the largest magnitude by far is Hygienic Behavior, which averages over four distinct hygienic behaviors: wearing face masks, avoiding crowded places, improving personal hygiene, and avoiding touching objects in public. According to the estimate, varying hygienic behavior from 0 to 1 leads to a reduction of R(t) equal to 2.0. If R0 is 2.4, then universal hygienic practices reduce R to 0.4, enough to suppress the epidemic. Note that the hygiene variable measures behaviors on four hygienic dimensions: wearing face masks, avoiding crowded places, improving personal hygiene, and refraining from touching objects in public. Each of these is measured as a percentage of the survey respondents, then averaged and put on a 0–1 scale.

In the early weeks of the epidemic, there was an enormous gap in hygienic behavior between the Asia-Pacific and the North Atlantic countries (Western Europe and the United States). For example, as of Monday, 9 March, face mask use was greater than 50 percent in China, Taiwan, Hong Kong, Thailand, the Philippines, and Malaysia, but under 10 percent in the United States, Germany, and the United Kingdom. Figure 2 shows the YouGov data on wearing face masks in public places across countries, making vivid the sharp distinction between the Asian and Western countries in the first months of the epidemic.

Returning to the regression results, the indicator with the next largest impact is the economic shutdown indicator, proxied by the Google measure of the percent decline in visits to economic sites. A full shutdown, meaning a 100 percent drop in visits, would reduce R(t) by 0.25 according to the regression coefficient. This is a modest reduction, far from bringing R down to less than 1. This underscores again that an economic shutdown is at best a

Figure 2. Wearing a face mask when in public places by country, YouGov Tracker



stop-gap policy until more efficient and powerful public health measures—hygiene and isolating—can be scaled up.

Testing, tracing, and isolating has a coefficient of 0.15. This also looks like a small contribution to reducing R(t) but the variable is measured with considerable error and the coefficient is almost surely biased downward as a result. The Oxford data rate countries on a scale from 0–100 (which I rebase to 0–1) that looks very generous to many countries. The United States, for example, is given a midway score of 0.5 since 21 January, but in fact there was little testing and almost no contact tracing in most of the United States until May at the earliest. Indeed, the U.S. Centers for Disease Control and Prevention (CDC) was still claiming as late as 11 March that the COVID-19 epidemic was under control when in fact it was spreading dramatically, because the CDC as well as state and local authorities had lost track almost completely of the spread of the virus.

School closures have a coefficient of 0.11, indicating that they contribute modestly to epidemic control beyond economic shutdowns. This makes sense for the reason mentioned earlier: Children are susceptible to infection but are often asymptomatic or have mild symptoms, and are therefore likely to transmit the virus to friends, family, and teachers.

Closures of international travel receive a score of 0.35, indicating that the complete closure of international travel reduces R(t) by a significant amount. Timing here makes a huge difference: The early control of infectious arrivals can prevent a mass outbreak, while later control of infectious arrivals makes little difference once community transmission has begun at large scale. According to the Oxford COVID-19 Policy Tracker data, the first countries to implement strong travel bans (scoring at least 3 on the Oxford 0–4 scale) were the following, with the day of the year the ban was introduced: Taiwan, 23; Singapore, 23; Hong Kong, 27; Malaysia, 30; Italy, 30; the Philippines, 31; Japan, 32; Australia, 32; and Vietnam, 32. Clearly, the Asia-Pacific got the message first, thereby stopping or massively reducing the influx of potentially infectious individuals from China.

The final explanatory variable is the daily time trend, which shows a daily reduction of R by 0.0057, or $\Delta R(t) = -0.57$ over 100 days. This marks a sizable reduction in the rate of transmission per day. If the point estimate is taken seriously, it suggests that in 246 days R(t) would fall from 2.4 to 1.0. In principle, the time trend reflects two kinds of phenomena. The first is the declining proportion of susceptible individuals in the population, as a rising proportion of the population has already been infected. This is likely to be a modest part of the observed downtrend, at least if we believe that only a small proportion of the population has been infected by this stage. The second phenomenon is the adoption of improved transmission-avoiding behaviors that are not suitably captured by the other explanatory variables. For example, individuals are presumably learning better ways to physically distance themselves from potentially infectious individuals.

It is useful to create a measure of each country's overall use of the *low-cost* epidemic control measures. I do this by multiplying the three main low-cost policies (hygiene, testing-tracing-isolating, and restrictions on international travel) by their respective coefficients and then summing the products to determine their overall contribution to the reduction of R(t) each day. The resulting daily sum is averaged for the period 4 March–26 May. This index is reported in the final column of Table 2. We see that the Asia-Pacific countries show the highest scores on the contribution of low-cost control measures.

Another way to note the Asia-Pacific success is to examine all the countries that kept R(t) <1 and the economic shutdown less than 20 percent during the period from

23 March–13 June. Only four countries accomplished this dual feat, all in East Asia: Vietnam, Hong Kong, South Korea, and Taiwan.

I next turn to the cross-country comparisons of the COVID-19 mortality rate. Cross-country differences in the mortality rate depend on the overall success in repressing the epidemic, measured by R(*t*), the proportion of elderly in the population, and the per capita availability of hospital beds. The COVID-19 mortality rate also depends on the policies, if any, that are undertaken to protect vulnerable groups, especially the elderly. Unfortunately, we currently lack cross-country data on such policies. Note also that countries differ in their reporting standards on COVID-19 deaths, adding noise to the regression estimates. It is believed, for example, that high-mortality Belgium is including more deaths in its COVID-19 accounting than other countries, notably including deaths suspected of COVID-19 even if not confirmed by testing. For purposes of this regression, I consider all countries in the first wave (confirmed cases by 3 March) with the available data, rather than only the 23 first-wave countries in the YouGov survey. There are, as a result, 54 countries in the sample.

The regression equation for COVID-19 deaths per million is as follows:

$$\mathrm{D_i\,(May\ 25)} = \alpha + \beta * \mathrm{R\,(average)} + \gamma\,(\mathrm{Age} - 70+) + \delta \mathrm{Hospital\ Beds} + \kappa \mathrm{First\ Day} + \lambda \mathrm{Belgium}. \quad (2)$$

The deaths per million are measured as of 13 June, in line with the available date on R(*t*). The variable ranges from a low of 0 confirmed COVID-19 deaths in Cambodia and Vietnam to a high of 844 deaths per million in Belgium. In general, the Asia-Pacific countries report far lower death rates than North Atlantic countries, below 10 per million in the Asia-Pacific and above 200 per million in the North Atlantic region. R(average) is the average R(*t*) during the days 23 March–13 June. The variable Age-70+ is the percent of the population of age 70 years or greater. Hospital beds are measured per 100,000 population. First day is day of the first confirmed case. Belgium is a dummy variable. (Data are in Data Appendix.) We expect deaths per million to be higher in countries with a higher average R(*t*), higher Age-70+, fewer hospital beds per 100,000, and earlier arrival (and so more time for the virus to spread). Belgium is expected to be an outlier for the reason just mentioned.

As we see in Table 3, all five explanatory variables are statistically significant (first day at the 10 percent level). The coefficient value 126.8 on R(average) suggests that the difference between a country with an average R of 0.52 (New Zealand) and 1.15 (United States) accounts for a difference of 80 deaths per million. This is a little less than a fourth of the gap between the two countries, with New Zealand reporting 5 deaths per million and the United States reporting 351 deaths per million as of 13 June. The coefficient value of 25.9 on Age-70+ suggests that the difference in age structure between Italy, with 16.2 percent population of age 70+, versus Vietnam, with 4.7 percent of the population Age-70+,

Table 3. Regression results

Panel A: R(*t*)

Random-effects GLS regression	Number of obs =	**2,062**				
Group variable: **iso3n**	Number of groups =	**25**				
R-sq:	Obs per group:					
within = **0.5881**	min =	**77**				
between = **1.0000**	avg =	**82.5**				
overall = **0.7804**	max =	**83**				
	Wald chi2(30) =	**7216.69**				
corr(u_i, X) = **0** (assumed)	Prob > chi2 =	**0**				

r	Coef.	Std. err.	z	P<z	[95% conf.	interval]
Daily time	−0.0056757	0.0002624	−21.63	0	−0.0061901	−0.0051614
Visits to econimic sites	−0.2484495	0.0464216	−5.35	0	−0.3394342	−0.1574649
Hygenic behavior	−1.979354	0.1013687	−19.53	0	−2.178033	−1.780675
Testing, tracing, isolating	−0.1510938	0.0411616	−3.67	0	−0.2317689	−0.0704186
School closures	−0.1177335	0.0260731	−4.52	0	−0.1688358	−0.0666312
International travel closure	−0.3500513	0.0474668	−7.37	0	−0.4430844	−0.2570181

Panel B: Deaths per million

Source	SS	df	MS	
Model	**1160175.37**	**5**	**232035.074**	Number of obs = 74
Residual	**960189.049**	**68**	**14120.4272**	F(5, 68) = 16.43
Total	**2120364.42**	**73**	**29046.0879**	Prob > F = 0
				R-squared = 0.5472
				Adj R-squared = 0.5139
				Root MSE = 118.83

d1M	Coef.	Std. err.	t	P>t	[95% conf.	interval]
raverage	126.842	58.90647	2.15	0.035	9.295996	244.3881
firstday	−1.542007	0.8349569	−1.85	0.069	−3.208137	0.124124
age_70	25.93515	4.137526	6.27	0.000	17.67885	34.19146
hb_p100k	−30.33684	6.766519	−4.48	0.000	−43.83922	−16.83447
belgium	676.2318	120.9485	5.59	0.000	434.8828	917.5808
_cons	−66.05882	83.53741	−0.79	0.432	−232.7551	100.6375

Note: *(Panel A) The regression is run with country fixed effects and constant term. All right-hand-side variables are lagged by 6 days. Day = 1, 2, 3, . . . beginning on 1 January 2020.*

accounts for a difference of 298 deaths per million, more than half of the reported difference of Vietnam, with 0 reported deaths and Italy with 566 deaths per million. The coefficient value of −30.3 on hospital beds suggests that the difference of having 2.8 hospital beds per 100,000 in the United States and 8 hospital beds per 100,000 in Germany would account for 158 deaths per million higher in the United States than in Germany out of an actual difference of 245 deaths per million. Japan and Korea have the highest hospital beds per 100,000 (13 and 12.2, respectively) and among the lowest death rates. A delay in arrival of 20 days is associated with a reduction of 34 deaths per million. Finally, Belgium is found to have 676 deaths per million higher than explained by the other variables. How much of this is due to reporting differences versus other factors is an important question.

Conclusions

It is notable that the Asia-Pacific region has achieved superior results compared with the North Atlantic region in lowering R(*t*) and in maintaining a low mortality rate despite a lower reliance on economic shutdowns. The key lesson of the Asia-Pacific experience is the ability to control the epidemic through improved hygiene and isolating of infectious individuals rather than reliance on deep economic shutdowns. Several Asian-Pacific countries have shown superlative results in suppressing the virus and keeping deaths rates per million incredibly low. These include Australia, Cambodia, China, Hong Kong, Japan, Korea, Lao PDR, New Zealand, Taiwan, and Vietnam.

Given the substantial transmission of the virus by asymptomatic and pre-symptomatic individuals, there has been an open question and ongoing debate as to whether suppression of the epidemic is feasible through public health measures, or whether economic shutdowns would have to remain more or less permanent until a vaccine is developed or herd immunity is acquired. The experience of the Asia-Pacific region offers strong evidence that it is indeed possible to sustain $R(t) < 1$ and thereby to suppress the epidemic through public health means, accompanied by only limited economic shutdowns. This is powerful and encouraging news.

The world learns too slowly from best practices. In the United States, little notice has been taken of the enormous success of the Asia-Pacific region in suppressing the epidemic. Of course, we need to understand in greater depth than this note permits just how the Asian countries have succeeded, and whether and how their public health strategies can be suitably adopted and adapted by the rest of the world. The next steps of analysis will be to probe more deeply into the mechanics of control measures as well as the reasons for the extraordinary range of COVID-19 death rates per million observed across the world.

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Data appendix

YouGov data

"YouGov is a global public opinion and data company. YouGov's COVID-19 Public Monitor gather[s] information about COVID-19,[9] asking people to share their experiences[10] of the global pandemic, and using that unique insight to provide health organizations with data[11] that helps them understand and fight the spread of the virus."

The survey indicators used in the data analysis for this paper are listed below. For more information or to access the data, visit https://today.yougov.com/COVID-19.

1. **YouGov COVID-19 tracker: Government handling**
   Percent of people in each country who think the government is handling the issue of coronavirus "very" or "somewhat" well.
2. **YouGov COVID-19 tracker: Avoiding crowded public places**
   Percent of people in each country who say they are: Avoiding crowded public places.
3. **YouGov COVID-19 tracker: Wearing a face mask when in public places**
   Percent of people in each country who say they are: Wearing a face mask when in public places.
4. **YouGov COVID-19 tracker: Avoiding going to work**
   Percent of people in each country who say they are: Avoiding going to work (e.g., by working from home).
5. **YouGov COVID-19 tracker: Improving personal hygiene**
   Percent of people in each country who say they are: Improving personal hygiene (e.g., washing hands frequently, using hand sanitizer).
6. **YouGov COVID-19 tracker: Refraining from touching objects in public**
   Percent of people in each country who say they are: Refraining from touching objects in public (e.g., using objects to press elevator buttons).

COVID-19 Community Mobility Reports, from Google

"Community Mobility Reports aim to provide insights into what has changed in response to policies aimed at combating COVID-19. The reports chart movement trends over time by

9 https://yougov.co.uk/covid-19.

10 https://www.yougov.chat/channels/yougov-health.

11 https://business.yougov.com/.

geography, across different categories of places such as retail and recreation, groceries and pharmacies, parks, transit stations, workplaces, and residential areas.

These data sets show how visits and length of stay at different places change compared to a baseline. [Changes are calculated] using the same kind of aggregated and anonymized data used to show popular times for places in Google Maps.

Changes for each day are compared to a baseline value for that day of the week:

The baseline is the median value, for the corresponding day of the week, during the five-week period 3 January–6 February 2020. The data sets show trends over several months with the most recent data representing approximately 2–3 days ago—this is how long it takes to produce the data sets.

What data are included in the calculation depends on user settings, connectivity, and whether it meets [Google's] privacy threshold. If the privacy threshold is not met (when somewhere is not busy enough to ensure anonymity) [Google doesn't] show a change for the day. As a result, [one] may encounter empty fields for certain places and dates.

[Google] include[s] categories that are useful to social distancing efforts as well as access to essential services.

[Google] calculate[s] these insights based on data from users who have opted-in to Location History for their Google Account, so the data represents a sample of [their] users. As with all samples, this may or may not represent the exact behavior of a wider population."

The categories of places used in the community mobility reports are:

1. Retail and recreation percent change from baseline
2. Grocery and pharmacy percent change from baseline
3. Parks percent change from baseline
4. Transit stations percent change from baseline
5. Workplaces percent change from baseline
6. Residential percent change from baseline

Oxford Coronavirus Government Response Tracker (OxCGRT)

(Used for testing and tracing, school closures, and restriction of international travel data)

"The Oxford COVID-19 Government Response Tracker (OxCGRT) systematically collects information on several different common policy responses that governments have taken to respond to the pandemic on 17 indicators such as school closures and travel restrictions. It now has data from more than 160 countries. The data are also used to inform a Lockdown Rollback Checklist[12] that looks at how closely countries meet four of the six World Health Organization recommendations for relaxing 'lockdown."'

Further details on how these metrics are measured and collected is available in the project's working paper.[13]

The data can be accessed here: https://www.bsg.ox.ac.uk/research/research-projects/coronavirus-government-response-tracker.

Tracking R: Real-Time Estimates of the Effective Reproduction Rate (R) of COVID-19
Data used for R(*t*) are accessed here: http://trackingr-env.eba-9muars8y.us-east-2.elasticbeanstalk.com/.

For further information on these data, see Marioli et al. (2020).

Data on COVID-19 by Our World in Data
(Used for COVID-19 Deaths per Million, "First Day," Hospital beds per 100k, and Age 70+ calculations)

"[The] complete COVID-19 dataset is a collection of the COVID-19 data maintained by Our World in Data. It is updated daily and includes data on confirmed cases, deaths, and testing, as well as other variables of potential interest."

Confirmed cases and deaths: "[The] data comes from the European Centre for Disease Prevention and Control (ECDC). The cases & deaths dataset is updated daily. Note: the number of cases or deaths reported by any institution—including the ECDC, the WHO, Johns Hopkins and others—on a given day does not represent the actual number on that date. This is because of the long reporting chain that exists between a new case/death and its inclusion in statistics. This also means that negative values in cases and deaths can sometimes appear when a country sends a correction to the ECDC, because it had previously overestimated the number of cases/deaths."

The data are accessed here: https://github.com/owid/COVID-19-data/tree/master/public/data.

12 https://www.bsg.ox.ac.uk/research/publications/lockdown-rollback-checklist.
13 https://www.bsg.ox.ac.uk/research/publications/variation-government-responses-covid-19.

Table A.1 Calculation of GDP during shutdown

Sector	GDP 2019	Essential GDP %	WFH (φ)	Essential GDP $	WFH GDP $	GDP $ with shutdown	GDP shutdown % baseline
GDP	21428	43%	0.51	9198	6290	15488	72%
Agriculture	169	90%	0.00	152	0	152	90%
Mining	320	90%	0.00	288	0	288	90%
Utilities	335	100%	0.00	335	0	335	100%
Construction	887	40%	0.00	355	0	355	40%
Manufacturing	2360	50%	0.00	1180	0	1180	50%
Wholesale trade	1278	50%	0.50	639	320	959	75%
Retail trade	1173	30%	0.30	352	246	598	51%
Transport	685	60%	0.00	411	0	411	60%
Information	1120	30%	0.50	336	392	728	65%
Finance	4492	20%	0.80	898	2875	3773	84%
Professional & business	2742	20%	0.80	548	1755	2303	84%
Educational services	264	20%	0.80	53	169	221	84%
Health and social	1618	90%	0.20	1456	32	1488	92%
Leisure and accommodations	899	10%	0.10	90	81	171	19%
Federal government	813	80%	0.80	651	130	781	96%
State and local government	1818	80%	0.80	1454	291	1745	96%

Calculation of GDP during shutdown

For each sector, output during the shutdown equal Essential GDP + WFH GDP, where WFH GDP is the share of non-essential GDP that can be produced at home, given by parameter φ. The data in Table A.1 are the author's judgments rather than empirical estimates. Based on the assumptions for Essential GDP and φ, we find that GDP during the shutdown is 72 percent of the baseline GDP.