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The Impacts of the Coronavirus on the Economy of the United States

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Abstract

We present a formal analysis of the macroeconomic impacts of the COVID-19 pandemic in the U.S., China and the rest of the world. Given the uncertainty regarding the severity and time-path of the infections and related conditions, we examine three scenarios, ranging from a relatively moderate event to a disaster. The study considers a comprehensive list of causal factors affecting the impacts, including: mandatory closures and the gradual re-opening process; decline in workforce due to morbidity, mortality and avoidance behavior; increased demand for health care; decreased demand for public transportation and other leisure activities; potential resilience through telework; increased demand for communication services; and increased pent-up demand. We apply a computable general equilibrium (CGE) model, a state-of-the-art economy-wide modeling technique. It traces the broader economic ramifications of individual responses of producers and consumers through supply chains both within and across countries. We project that the net U.S. GDP losses from COVID-19 would range from $3.2 trillion (14.8%) to $4.8 trillion (23.0%) in a 2-year period for the three scenarios. U.S. impacts are estimated to be higher than those for China and the ROW in percentage terms. The major factor affecting the results in all three scenarios is Mandatory Closures and the Partial Reopenings of businesses. These alone would have resulted in a 22.3% to 60.6% decrease in U.S. GDP across the scenarios. Pent-up Demand, generated from the inability to spend during the Closures/Reopenings, is the second most influential factor, significantly offsetting the negative impacts stemming from other causal factors.

The Impacts of the Coronavirus on the Economy of the United States

I. Introduction

COVID-19 is already having far-ranging economic consequences, and the end is not yet in sight. This paper summarizes a formal analysis of the macroeconomic impacts of the pandemic in the U.S., China and the rest of the world. Given the uncertainty regarding the severity and time-path of the infections and related conditions, we examine three scenarios, ranging from a relatively moderate event to a disaster. Specifically, the study considers a comprehensive list of causal factors affecting the impacts, including: mandatory closures and the gradual re-opening process; decline in workforce due to morbidity, mortality and avoidance behavior; increased demand for health care; decreased demand for public transportation and other leisure activities; potential resilience through telework; increased demand for communication services; and increased pent-up demand. Note, however, that we have not included the impact of countervailing policies, such as the CARES Act, nor the value of lives lost.

The analysis is based on the application of a computable general equilibrium (CGE) model, a state-of-the-art economy-wide modeling technique. CGE is defined as a multi-market model of the behavioral responses of producers and consumers to changing prices, regulations, and other conditions in the workings of interconnected markets, subject to basic resource constraints. CGE models have the advantage of characterizing the economy as a set of interconnected supply chains. These models have been applied successfully to examine economic impacts of health threats, such as influenza pandemics (see, e.g., Dixon et al., 2011; Prager et al., 2017; Walmsley et al., 2020). In particular, we use the ImpactECON Supply-Chain Model (Walmsley and Minor, 2016, 2019). This Model is adapted from one of the most widely-used CGE models, GTAP (Hertel and Tsigas, 1997; Corong et al., 2017), and has the extended capability for examining supply-chain impacts linked to economic activity and policies in the rest of the world.

In performing the analysis, we utilize the assumptions, variables and parameters presented in detail in the various Appendices. The assumptions are invoked primarily to keep the analysis manageable. Sensitivity tests have been performed on some of the major assumptions and parameters to make sure the results presented are robust. Still, we note that the combination of assumptions is such that the results presented should be considered upper-bound estimates. To summarize, the net U.S. Real GDP losses from COVID-19 are estimated to range from $3.2 trillion (14.8%) to $4.8 trillion (23.0%) in a 2-year period for the three scenarios. U.S. impacts are estimated to be higher than those for China and the ROW in percentage terms. The major factor affecting the results in all three scenarios is Mandatory Closures and the Partial Reopenings of businesses. These alone would have resulted in a 22.3% to 60.6% decrease in the U.S. GDP across the scenarios. Pent-up Demand, generated from the inability to spend during the Mandatory Closures and Partial Reopenings, is the second most influential factor and offsets the negative impacts of Closures/Reopenings by about 30% for all three regions in the moderate and declining scenario and up to 60% to 85% in the extensive pandemic scenario.

II. Scenarios

The three scenarios examined are explained below and summarized in Table 1:

Scenario 1: Moderate & Declining. The virus is assumed to have moderate impacts on morbidity and mortality (300 thousand deaths in the U.S. over two years), which can be controlled to a great extent with avoidance and social distancing policies. The initial mandatory closures and minimal avoidance and social distancing measures are effective and sufficient to see a decline in cases by August 2020.

Scenario 2: Moderate & Increasing (No Second Wave and Vaccine). Cases rise as businesses re-open (1.25 million deaths over two years), but the U.S. chooses not to close non-essential businesses again, instead opting for more gradual re-opening and social distancing and other disease spreading mitigation measures, supplemented by the effect of avoidance behavior with regard to public places. The rise in cases does not cease until January 2021, plateauing until a vaccine becomes available to the public in November 2021

Scenario 3: Extensive & Increasing (Second Wave and No Vaccine). Cases ramp up considerably as businesses re-open (1.75 million deaths over two years) and the U.S. is forced to close non-essential businesses again for a further six months. Cases continue to rise despite the second wave of mandatory closures and extensive avoidance and social distancing, eventually plateauing in June 2021. Avoidance and social distancing policies can stave off the rise in cases, but a vaccine would be essential to reduce the number of cases. This scenario assumes that an effective vaccine does not appear, so cases do not decline.

Overall, in all cases we examine the impact of the mandatory business closures in the U.S. and abroad that occurred prior to May 25, 2020. The scenarios differ in their assumptions regarding the trend in cases during the re-opening period: declining; increasing, thereby extending the reopening period; and extensive, resulting in a second wave of business closures. Demand for health care services increases in line with the number of cases under the alternative scenarios. A thorough search of the government and other websites providing data and the literature on analyzing the economic impacts of COVID-19 has been undertaken to establish current and expected levels of avoidance and pent-up demand, with these behaviors assumed to be more extensive the longer and more severe the pandemic.

Table 1. COVID-19 Economic Impact Scenarios

Scenario	Severity & Trend after all Mandatory Closures	Initial Reopening	Second Wave of Closure	Second Wave of Reopening	Travel Ban	Vaccine Timing	Avoidance Behavior	Pent-up Demand
1.	Moderate & Declining	3 months	none	n.a.	limited	none	minimal	weak
2.	Moderate & Increases: No Second Wave but Vaccine	12 months	none	n.a.	complete	18 months	extensive	moderate
3.	Extensive & Increasing: Second Wave and No Vaccine	3 months	6 months	30 months	complete	none	extensive	strong

III. General CGE Methodology

We use the ImpactECON Supply Chain model (IESC) CGE model, developed by Walmsley and Minor (2016),[1] which has been applied to analyze the supply chain impacts of several recent U.S. trade policy initiatives. The model is based on, and includes all the features of, the widely used GTAP model (Hertel and Tsigas, 1997; Corong et al., 2017), considered a benchmark for analysis for global trade and other policy issues. The underlying database contains input-output tables and trading relations for 65 commodities and 141 countries from the GTAP database (Aguiar et al., 2019), as well as additional detail on the source of final and intermediate goods. These data are combined with various demand and substitution elasticities to calibrate the model.

The IESC model adapts the GTAP model to include detailed trade and tariff data on the source of imported intermediate and final goods, thereby improving the analysis of global supply chain effects. In this specific case, we have more detailed information about the extent to which China and other countries supply U.S. firms with intermediate inputs used in the production process. This additional detail improves our ability to examine how the delay or disruption of these imported intermediate inputs from the rest of the world, impacts U.S. firms' ability to produce and export commodities.

The IESC model is a comparative static CGE model that provides a theoretically consistent method for analyzing the impact of global shocks on the U.S. economy. The model consists of demand for domestic and foreign goods by households, government, firms and for investment, and supply of those goods by domestic and foreign firms. It also consists of the demand (by firms) and supply (by households) of eight factors of production (five labor categories, capital, land and natural resources).

To capture the impact of the mandatory closures we reduce the production of the affected sectors, using an expedient device known as a "phantom tax" to raise prices and lower final demand.[2] This is done in several iterations to take account of the indirect effects of closing sectors on other sectors. One of the benefits of these models is that they capture the indirect effects of business closures in one sector on the other sectors. For instance, as restaurants are forced to close, demand for fruit and vegetables used in producing restaurant meals, also declines. In some cases, these indirect effects are larger than the share of that sector subject to the mandatory closure, and hence we allow these indirect effects to dominate and sectoral production to decline by more than the share of the sector subject to the mandatory closure. As a result, we only need to impose a decline in production in those sectors where the direct impacts of the mandatory closure are greater than the indirect effects from the other sectors, primarily construction and recreational services. While mandatory closures reduce production, avoidance and pent-up demand are assumed to lower and raise final demand by private consumers, respectively. In the case of avoidance of education, we also assume a decline in demand by governments.

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[1] See also Walmsley and Minor (2020) for a detailed explanation of model and data used in this analysis.
[2] The taxes are set at a level that achieves a reduction in output reflecting the business closures. It is a "phantom" because the "taxes" are implicitly returned to the businesses as revenue increases associated with the higher price; essentially, the business customers (both other businesses and consumers) cover this revenue by their expenditures at the higher price, and there is no effect on government revenues.

IV. Data sources for Health and Labor Force Impacts

A. Health Outcomes

We estimate the health outcomes of COVID-19 in terms of the number of people seeking outpatient medical treatment, being hospitalized, receiving ICU treatment, or dying from the disease. The primary sources of data include CDC COVID-19 patient characteristics and treatment outcome data (CDC, 2020a, 2020b, 2020c), the New York City Department of Health and Mental Hygiene (2020) data on population rates of COVID-19 cases, hospitalization and death, and the various forecasting models of cumulative number of deaths in the U.S. The calculations below were carried out for three age groups: 0-18, 19-64, and 65+. All the health-related data used in this study were collected in May 2020, and thus reflect the health outcome of the disease between February and mid-May of 2020. As the pandemic is rapidly evolving, recent trends in numbers of infections, hospitalization, and fatality of the virus are not incorporated. However, the modeling framework developed in the study can be updated as more up-to-date data become available.

First, data from several studies were gathered to estimate the percentages of people that were hospitalized, admitted to ICU, and died because of coronavirus infection with respect to the total number of confirmed cases. These estimates are summarized in Appendix Table A1 by age group and by health outcome type. These data were used to calculate the average hospitalization, ICU admission, and death percentages with respect to confirmed cases across studies for the three age cohorts in Table 2.

We also summarize the projections on cumulative COVID-19 deaths in the U.S. provided by 10 models cited in the CDC COVID-19 Forecasts website (CDC, 2020d) in Appendix Table A2. The projected cumulative deaths are further disaggregated based on the information collected from the CDC Provisional Death Counts for Coronavirus Disease by age group (CDC, 2020e). These results are presented in Appendix Table A3.

Next, based on the relationship between the death rate and the hospitalization rate for age groups presented in Table 2, we estimated the projected cumulative number of hospitalizations, ICU admissions, and deaths for May 30, June 6, and August 4 in Appendix Table A4. We also estimated the number of coronavirus patients who received outpatient medical treatment as the difference between the total number of cases and sum of hospitalization (survived) and fatality.

Based on the model projections as of May 15, the projected increase in total number of cases between June 6 and August 5 is projected as 662,000, which translates into an average increase of 11,033 new cases each day. If we use an average of the upper-bound estimates from the forecasting models cited in Appendix Table A2, the average number of increased cases per day is estimated to be 34,226 for this time period.

Table 2 Average Hospitalization, ICU, and Fatality Percentage to Total Confirmed Cases, by Age Group

Age Group (yrs)	Hospitalization	ICU Admission	Fatality
0-18	7.81%	0.65%	0.20%
19-64	19.32%	4.31%	2.16%
65+	39.34%	13.61%	10.75%

Sources: Average estimates calculated by the authors based on the studies presented in Appendix Table A1.

To estimate the projected health outcome of COVID-19 between March 2020 and February 2022 for the three scenarios, the following assumptions are adopted to calculate the daily new cases for each scenario. Again, all the assumptions were based on the information that was available by the end of May:

1. According to CDC data, the total number of cases by May 30 was 1,719,827, and the average number of daily new cases was 23,478.
2. For Scenario 1, it is assumed that, starting from June 2020, the number of daily new cases in each month declines by 40% from the previous month level until September 2020, and remains at 3,000 new cases per day through February 2022.
3. For Scenario 2, it is assumed that the average daily new cases will be 29,212 in June 2020 (same as the level in April). The average daily new cases are assumed to increase by 2% afterwards in each month until they reach the plateau of about 33,000 in December 2020. These cases are assumed to maintain at this level until October 2021 when a vaccine becomes available. Then the number of daily new cases starts to decline sharply to about 11,900 by February 2022.
4. For Scenario 3, it is assumed that the average daily new cases will be 34,226 in June 2020 (the upper-bound estimate based on the forecasting model results in mid-May cited in Appendix Table A2). These cases are assumed to increase by 2% in each subsequent month of the study period.

The total cumulative number of cases are next calculated based on the above assumptions on the changes in average daily new cases over time. The total number of fatalities by the end of the 2-year study period is calculated by applying the fatality to total confirmed cases ratio as of May 2020 (104,000/1,676,401=6.2%) to the total estimated cumulative number of cases by February 2022.

Again, based on the relationship between the death rate and the hospitalization rate for different age groups presented in Table 2 and the number of deaths in each age group, the projected cumulative number of hospitalizations with and without ICU admissions, number of outpatient treatment, and fatalities are estimated and presented in Table 3 for each scenario.

Table 3. Health Outcome for the Three Scenarios
(cumulative number of people from March 2020 to February 2022)

Scenarios	Total Cases	Outpatients	Hospitalizations (non-ICU)	Hospitalizations (ICU)	Total Deaths
1. Moderate & Declining	4,169,409	2,685,700	859,818	365,231	258,660
2. Moderate & Increases: No Second Closure but Vaccine	20,179,700	12,998,634	4,161,468	1,767,696	1,251,901
3. Extensive & Increasing: Second Closure and No Vaccine	28,193,853	18,160,904	5,814,151	2,469,717	1,749,081

Source: Estimated based on data presented in Appendix A.

B. Health Service Expenditures

In this section, we estimate the increased spending on medical services, focusing primarily on healthcare expenses incurred by inpatient hospital stays or outpatient medical treatment received by the COVID-19 patients. We first collected data on the projected costs for COVID-19 patients that require an inpatient hospital stay. According to Wakely (2020), the allowed cost of non-ICU patients is estimated to be $12,450 for Commercial health insurance, $8,850 for Medicare Advantage Organizations, and $6,800 for Medicaid managed care organizations (MCO). The estimated allowed cost for ICU patients is $38,450, $17,000, and $16,250 for Commercial insurance groups, Medicare Advantage, and Medicaid MCO, respectively (Cohen et al., 2020). Based on the share of people enrolling in these three types of health insurance plans, the weighted average allowed cost is $11,050 for non-ICU patients and $30,950 for ICU patients.

Similarly, in FAIR Health (2020), per patient cost of inpatient stay is provided for the estimated commercial insurance allowed amount, Medicare reimbursement amount, and Medicaid reimbursement amount. The weighted average per patient cost is again calculated using the number of people utilizing each type of health insurance plans as the weights. The weighted average cost is $29,115 for patients with major complication or comorbidity (indicated by diagnosis-related groups (DRG) code 193) and $17,320 for those with no complication or comorbidity (indicated by DRG code 195). We use the former to approximate the cost for ICU patients and the latter for non-ICU patients.

In our analysis, we use the average of the cost estimates provided in the Wakely report and the FAIR Health report, which is $30,033 for ICU patients and $14,185 for non-ICU patients. Average per patient cost for people only received outpatient treatment and other professional service is estimated to be $387.43 (Cohen et al., 2020).[3]

Table 4 presents the total medical expenditures based on the projected health outcome of the three scenarios.

Table 4. Total Medical Expenditures (in millions of 2020 dollars)

Scenario	Outpatient Medical Treatment	Hospitalization Non-ICU	Hospitalization ICU	Hospitalized Not Survived	Total
1	1,041	12,197	10,969	7,768	**31,974**
2	5,036	59,030	53,089	37,598	**154,754**
3	7,036	82,474	74,173	52,530	**216,213**

Source: calculated by the authors based on per patient cost data collected from Wakely (2020) and FAIR Health (2020).

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[3] Note that all the cost estimates presented and calculated above refer to insurance allowed amounts rather than health provider charges. Patients sometimes are asked to pay a good proportion of the difference between the charged and allowed amounts, especially if they use out-of-network services. However, because of the uncertainty with the balance billing and the fact that many patients are treated by preferred providers, we use the allowed cost estimates in our analysis.

C. Workday Losses

Appendix Table B1 summarizes the length of illness onset to hospitalization, as well as length of hospital stay, for both non-severe and severe cases based on several studies we reviewed. Based on these data, we assume that the average hospital stays for non-severe and severe (ICU admitted) COVID-19 patients are 10 days and 15.5 days, respectively. The average length from illness onset to hospitalization is 4.5 days. If we further assume that there will be an additional 3 days for non-severe patients and 5 days for severe patients to fully recover before they can return to work after hospital discharge, the total productivity losses are 17.5 days for non-severe patients and 25 days for severe patients. For patients that only received outpatient treatment, we utilized the data from Prager et al. (2017): 1.5, 1.9, and 5.3 days, respectively, for the three age groups.

Lost productivity due to own illness is presented in Table 5. For each health outcome category, we multiply the projected number of patients in Table 3 by the corresponding number of lost productivity days per person, and adjust for the labor force participation rate of 63.4% in February 2020 (BLS, 2020).

Table 5. Lost Productivity due to Own Illness (days)

Scenario	Outpatient Medical Treatment	Hospitalization – Non-ICU	Hospitalization –ICU	Death	Total
1	5,476,818	10,306,035	6,253,951	32,332,550	54,369,352
2	26,507,481	49,880,613	30,268,761	156,487,676	263,144,533
3	37,034,645	69,690,169	42,289,678	218,635,093	367,649,585

Table 6 presents the lost productivity due to caring for sick family members. These include caring for sick children in the 0–18 age group, sick spouse in the 18–64 age group, and sick elderly family members in the 65+ age group. We made similar assumptions as in Prager et al. (2017) and Dixon et al. (2010) in calculating the productivity day losses due to the care of sick family members. The data and assumptions adopted in the calculations are discussed in Appendix B.

Table 6. Lost Productivity due to Caring of Sick Family Members (days)

	Age Group	Scenario 1	Scenario 2	Scenario 3
Outpatient Medical Treatment	0-17	65,135	315,250	440,448
	18-64	138,902	672,277	939,264
	65+	276,624	1,338,844	1,870,551
Hospitalization – Non-ICU	0-17	30,960	149,844	209,353
	18-64	262,597	1,270,956	1,775,703
	65+	525,891	2,545,281	3,556,112
Hospitalization – ICU	0-17	3,988	19,303	26,969
	18-64	107,584	520,700	727,490
	65+	397,332	1,923,064	2,686,789
Hospitalized – not survived	0-17	1,250	6,050	8,453
	18-64	53,894	260,845	364,437
	65+	313,957	1,519,533	2,122,999
Total		**2,178,114**	**10,541,947**	**14,728,569**

V. Mandatory Shutdown and Reopening

A. Mandatory Shutdown between March and June 2020

The mandatory shutdown and "stay-at-home" orders implemented in individual states between March and June in the U.S. are presented in Appendix Table C1 in terms of the order declared date, order expiration date, and the length (days) of the order.

In order to determine the impacts of mandatory closures on different economic sectors, we first divided the sectors into three categories based on the list of Essential Critical Infrastructure Sectors during COVID-19 defined by DHS Cybersecurity and Infrastructure Security Agency:

> Category 1 refers to sectors that fall entirely under the non-essential category and thus is shut down under the mandatory closures (some examples of such sectors include Non-critical Manufacturing, Recreation & Entertainment, Education). However, we considered telework potentials that help reduce the direct impacts of shutdowns in these sectors.

> Category 2 refers to sectors that only some of their subsectors are non-essential. Some examples in this category include Retail Trade (e.g., Grocery Stores, Special Food Stores, Gas Stations, etc. are excluded from shutdowns), Food Services, Business Services.

> Category 3 refers to sectors that are essential and therefore the sectors in this category are able to maintain operation in its usual manner to the extent possible. Example sectors in this category include Agriculture, Utilities, Critical Manufacturing, etc.

Appendix Table C2 presents the percentage reduction in U.S. annual GDP by sector due to mandatory closures for each of the three scenarios. These estimates also factored in telecommuting for non-essential sectors covered under the mandatory closure order, but only for those that can produce output by telecommuting to some extent. The telework potentials by sector are presented in Appendix Table C3.

B. Reopening Process

For the reopening of the U.S. economy in terms of the duration of the process and the percentage of non-essential sectors that will reopen in each phase-in stages, we referred to the reopening plans of five major states: California, Texas, New York, Illinois, and Florida that were released at the end of May. The detailed reopening stages and timelines are presented in Appendix Table C4. We further made the following assumptions:

- Phase I: Assume the disrupted production under the mandatory closure orders of the following non-essential sectors or sub-sectors will be reduced by half: non-essential manufacturing, construction, wholesale and retail trade, accommodation, food and service activities, other services (government). The other non-essential sectors (such as business services, recreation & other services and education) remain the same closure status.
- Phase II: Assume the disrupted production of the following non-essential sectors or sub-sectors will be further reduced to only 25% of the output reductions during the mandatory closure period: non-essential manufacturing, construction, wholesale and retail trade, accommodation, food and service activities, other services (government). The output disruptions of the remaining non-essential sectors, except for recreation and education, will be reduced by half.

- Phase III: Assume the following non-essential sectors or sub-sectors will be fully re-open: non-essential manufacturing, construction, wholesale and retail trade, accommodation, food and service activities, other services (government). The output disruptions of the remaining non-essential sectors, except for recreation and education, will be further reduced to only 25% of the output reductions during the mandatory closure period. Recreation and Education sectors will be half reopened and operate at 50% baseline level.
- After the reopening period (3-months or 12-months, depending on the scenarios), we assume that all sectors will be open entirely.

Appendix Table C5 presents the percentage reduction in U.S. annual GDP by sector due to the phased-in reopening process for each of the three scenarios. Again, the estimates also factor in the effects of telecommuting.

VI. Other Explanatory Factors

A. Avoidance Behavior

We gathered survey data from public opinion polls or surveys around avoidance behavior in response to COVID-19 pandemic. Data on avoidance behavior trends as a result of the coronavirus before states implemented shutdown orders were gathered from 11 public opinion polls before the announcement of shelter-in-place rules in California and New York. People's willingness to resume activities after their state lifts shutdown orders were collected from 9 public opinion polls conducted in May. Survey data are summarized in Appendix D.

In our scenario analysis, three levels (low, moderate, high) of avoidance behavior are simulated with respect to the magnitude and length of such behaviors. Appendix Table D3 summarize the parameters we estimated based on the various public opinion polls reviewed in Appendix D. The methods and additional assumptions we adopted to translate the survey results in each study to low, moderate, and high estimates are also summarized in Appendix D.

Table 7 summarizes the assumptions on the magnitude of various types avoidance behavior in terms of percentage of people that are likely to practice them. In cases that multiple polls asked similar questions, we take an average of the poll results. The last column of Table 6 presents the method to simulate the impacts of the avoidance behavior in the CGE Model. We assume the duration that people will practice the various types of avoidance behavior after the lift of mandatory closures is 3 weeks, 3 months, and 6 months for Scenarios 1, 2, and 3, respectively.

Table 7. Assumptions on Magnitude of Avoidance Behaviors and CGE Modeling Method

Avoidance Behavior	Percent Avoided			CGE Modeling Linkage
	Low	Moderate	High	
Staying home from work	13%	18%	22%	Reduce workforce participation; adjusted for weighted average telework potential across sectors
Keeping children from school	32%	53%	66%	Reduce demand in education sector

Keeping children from school (caregiver avoidance)	32%	53%	66%	Reduce workforce participation in order to care for children (further factor in % of families with Children but with no stay-at-home parents)
Avoiding medical professionals	20%	35%	50%	Assume people would defer spending; some proportion of the delayed discretionary medical expenditures are part of pent-up-demand
Reducing shopping	34%	48%	61%	Reduce demand in mall/storefront shopping (under Retail Trade)
Avoiding local leisure Activities	38%	46%	53%	Reduce demand in recreation sector
Avoiding dining in	27%	41%	56%	Reduce demand in restaurants and bars sectors[a]
Avoiding public transportation	44%	58%	72%	Reduced demand in public transportation sector
Cancelling travel plans	43%	56%	69%	Allocated by BEA data on the travel expenditures in among consumption categories

[a] These percentages are only applied to the dining-in portion of restaurant services because we assume that the take-out services would be less affected by the avoidance behavior.

B. Savings

Data on U.S. personal savings rate show a rise in the personal savings rate from 7.9 percent to 33 percent during the first few months of the pandemic (Trading Economics, 2020, for US data, and World Bank, 2020, for China and ROW). Savings rates rise due to the increase in demand for precautionary savings and as closures and avoidance behavior make it difficult, or even impossible, to purchase non-essential items, resulting in people putting aside the extra savings for future purchases (pent-up demand). The increased savings rates obtained are used as the basis for Scenario 2, and then are adjusted slightly to reflect differences in the avoidance in Scenarios 1 and 3.

Savings rates are assumed to increase with the mandatory closures and then again with increased avoidance. Savings rates then diminish with increased health care costs and pent-up demand. We assume a similar path for changes in the savings rates of China and the rest of world, although the increase is assumed to be more muted given the relatively higher initial savings rates.

C. Communications

Shutdown orders led to an increase in internet traffic due to remote working and learning. Comscore (2020), estimates that average home data consumption was up 33% in early May 2020 relative to the same period the previous year. The orders also resulted in higher wireless calls and data usage. However, the increase in traffic does not translate into equivalent revenue growth for broadband providers, wireless carriers, and internet companies. While broadband providers and wireless carriers

experienced service revenue increases, those increases are lower than total data usage increase as many consumers pay a flat subscription fee. Furthermore, while internet companies may have seen increased internet traffic, their revenues are based on advertisement demand, which declined along with the consumer demand shock. The estimation of those impacts is presented in Appendix E based on information from the quarterly earnings reports of major public companies.

In sum, we found that the Internet Publishing and Broadcasting and Web Search Portals sector actually experienced a 10% to 30% decrease in revenue because of the sharp decline in advertisement revenue during the mandatory closure period. We assume that this impact is subsumed in the 10% output reduction in the entire Information and Communications sector (see Appendix Table C2). For the other three sectors, we assume Wired Telecommunications Carriers is estimated to have a 0.25% increase in revenue, Wireless Telecommunications Carriers has a 0% increase in revenue, and Data Processing, Hosting, and Related Services a 1% increase in revenue.

D.. Pent-up Demand

Appendix Table F1 presents the estimates of pent-up consumer demand resulting from the COVID-19 related lockdowns across a range of key sectors, goods, and services in the U.S. The estimates provided were calculated using micro-level data from three distinct online sources: Opportunity Insights (2020), Unacast (2020), and SafeGraph (2020). Estimates for pent-up demand for each category are provided using both the "Lowest Point" and "May 1" levels. Lowest point signifies a pent-up demand calculation using the single largest decline in either consumer spending (in the case of Opportunity Insights) or foot traffic at the indicated area of interest (in the case of both Unacast and SafeGraph). May 1 estimates are provided under the rationale that pent-up demand may have begun being released at the beginning of May as opposed to immediately following the departure from the lowest point, because many U.S. states eased lockdowns to some degree around this time period (however, with recent end-of-lockdown reversals this metric may be less meaningful).

Based on the pent-up demand data collected in Appendix Table F1, we determined pent-up demand in percentage terms for three various levels: weak, moderate, and strong in Table 8, where these levels are used as inputs in the simulations of our scenarios. In the second to last column in Table 8, we map the consumption good/service categories to the relevant GTAP sectors, with shares of the pent-up demand goods or services presented in the last column. The GTAP sectoral shares of the pent-up demand goods and services were calculated based on the output data for more disaggregated 536 sectors obtained from IMPLAN U.S. I-O table (IMPLAN, 2018), and then aggregated to match the sectoring scheme of our CGE model.

Table 8. Pent-up Demand Assumptions and Mapping to CGE Sectors

Good/Service	Weak (Scenario 1)	Moderate (Scenario 2)	Strong (Scenario 3)	GTAP Sector	Share of GTAP Sector
Automobiles	50%	70%	90%	50 Wholesale and retail trade; repair of motor vehicles	5.5%
Real Estate	30%	50%	70%	59 Real estate activities	100%

Air Travel	5%	15%	35%	54 Air transport	94.10%
Restaurant Dining	40%	60%	80%	51 Accommodation, Food and service activities	71.7%
Live Experiences (sporting events, concerts, etc.)	13%	33%	53%	61 Recreation & Other Services	16.5%
Apparel	50%	70%	90%	50 Wholesale and Retail Trade; Repair of Motor Vehicles	4.1%
General Merchandise	70%	90%	90%	50 Wholesale and Retail Trade; Repair of Motor Vehicles	6.8%
Hotels and other Hospitality	30%	50%	70%	51 Accommodation, Food and Service Activities	16.8%
Movie Theatres	5%	10%	30%	56 Information and Communication	8.7%
Wellness and Fitness	30%	50%	70%	61 Recreation and Other Services	3.0%

VI. Simulation Specification

The CGE model is comparative static and set up to examine the short-run implications of the pandemic. The comparative static nature of the model limits our ability to trace all of the dynamic impacts of the pandemic over its time-path and in particular during the recovery period.   Our strategy is to simulate the short-run negative impacts of the mandatory closures, partial reopening, avoidance behavior, morbidity and mortality and health care. We then add back the impact of pent-up demand – that is the portion of production lost during the pandemic due to the other factors, which could eventually be recovered as consumers buy goods they were unable to obtain during the pandemic. Previously laid-off workers will be rehired to meet this pent-up demand, and GDP will rise towards baseline growth.

Our approach and its relationship to a fully dynamic analysis is illustrated in Figure 1 in Appendix G. While the pent-up demand is an important part of the recovery process, it is worth noting that the increase in GDP it stimulates does not reflect the full extent of the recovery process because we do not consider the inevitable rise in GDP as consumers resume their normal activities, and unemployed workers accept lower wages in order to get back into the labor market. This is analogous to looking at the economic impact of the COVID-19 and the mandatory closures in the troughs of these time-path curves, approximately a year after the beginning of the pandemic (see again Figure 1, as well as the scenario descriptions in Appendix G). We use a very short-run closure rule in which we assume factors of production (including capital and labor) are not mobile across sectors and any fall in demand of a factor will result in its unemployment. We also assume real private consumption of essential goods and services is fixed, and that households will first use their income to purchase food and utilities. Government expenditure is also fixed, and hence the government deficit is assumed to adjust to any changes in tax revenues, as production and demand fall. Trade balances, on the other hand, are determined endogenously. This reflects the decision to allow any increase in savings in the U.S. to move

abroad rather than increase domestic investment.[4] Increased private savings is also assumed to fund any changes in the government deficit.

In each scenario we decompose the results into the following parts:

- Mandatory closures and re-openings – impact of the mandatory closure of businesses and associated reopening process across the U.S. and the world in response to the outbreak of COVID-19. These mandatory closures also take into account the extent to which a sector can continue to produce remotely through telework. With the lack of availability of non-essential goods and services, their consumption declines, and thus savings rise considerably.

- Avoidance –impact of consumers avoiding activities that would put a person at increased risk of contracting the virus. Consumers are assumed to avoid work, in-class learning[5], restaurants and other social activities even after the mandatory closures have been lifted and businesses reopen. Purchases avoided are assumed to further raise the savings rate. It is worth noting that any avoidance behavior that occurs during the mandatory closure of business is subsumed into the mandatory closures effect.

- Communications – increase in working from home increases the demand for internet and communications considerably. Production in part of this sector rises to reflect this increase in demand.

- Morbidity and Mortality – impact on the labor force of an increase in sickness and deaths, including days taken off to care for sick family members. The increase in deaths also lowers the population and demand for private consumption, including essential goods.

- Health – increase in demand for health care services by the private sector and government. Government expenditure is assumed to rise and the deficit to increase in line with the increase in demand for health care. We also assume that the health care sector has considerable excess capacity (assuming a 60 percent utilization rate of capital in the health care sector), due to normal excess capacity levels and the ability to delay non-emergency procedures (Cox et al., 2020).

- Pent up demand – extent to which demand lost during the mandatory closures is recovered when businesses re-open as consumers use their savings to buy items they could not during the shutdown. We assume savings falls and demand rises.

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[4] Although incomes and hence savings are falling as a result of the pandemic, savings rates are rising dramatically with increased precautionary savings and as mandatory closures and avoidance behavior make it difficult or even impossible to purchase non-essential items. Savings rates rise most in the U.S. where savings rates are historically very low. Moreover, in the model, all savings must be invested – savings cannot be placed 'under the mattress'. Under the assumption of a fixed trade balance, the relative increase in U.S. savings must be invested in the U.S., making investment in the U.S. increase relative to other countries. In reality this is unlikely: first, a lot of this increase in savings is temporary – related to pent-up demand (delayed purchases); second, the closure of a significant proportion of the construction and related sectors means that this savings cannot be invested in the construction of capital goods; and finally, the level of uncertainty regarding the ability of different countries to control the pandemic has been significant and is likely to cause savers to be very cautious about where they invest. To mitigate the impact of this issue on the U.S economy results, we assume that the trade balance is endogenous, thereby sharing the increase in savings, and its impact on an economy, across all countries.
[5] Note that we also assume government demand for education falls.

X. Results

The GDP impacts of Scenario 1 are presented in percentage terms in Table 9 for the U.S., China and Rest of the World. The results are decomposed according to the causal factors described in the previous section, though with some combining where appropriate. Overall, the total impact on the U.S. economy is a $3.2 trillion, or 14.8%, decline in GDP. The percentage results are almost 3 times higher in the U.S. than in China and nearly 50% higher than in the Rest of the World (ROW).

The major factors affecting the results are Mandatory Closures and the partial reopenings of businesses. These alone would have resulted in a 22.3% decrease in the U.S. GDP, but only about 40% of that amount in China because of the much shorter lock-down period in the latter. The results for ROW fall about half-way in-between the other two regions.

The impacts of the other causal factors are simulated in a semi-dynamic way, where each type of shock is added to the previous ones, rather than being simulated in isolation. First, avoidance behavior impacts are simulated with mandatory closures/partial reopenings and reflect continued avoidance behaviors after reopening, rather than avoidance behavior during the mandatory closure period, which is dominated by the mandatory closures themselves. In Scenario 1 we also assume weak additional avoidance behavior as we assume the mandatory closures have been effective at reducing the number of COVD-19 cases and deaths and further avoidance after reopening is low. As a result, they have an almost imperceptible impact in all three regions.

Increased communication expenditures have a very slightly positive effect in all three regions, especially in China. Note also that the communication expenditures reflect, to a great extent, one of the major resilience responses of telecommuting. The much smaller positive effects in China are due to the relatively much shorter shutdown duration.

Death and illness impacts are relatively negligible on the economy in percentage terms due to the high levels of unemployment caused by the mandatory closures, which again dominate the economic impact of this. Healthcare expenditure impacts are also relatively small in Scenario 1. Note that these expenditures have a positive impact on GDP, since the economy is not in full employment and consumer expenditures on other items are suppressed by the closures, thereby freeing up disposable income without an otherwise dampening effect on the economy.[6]

Pent-up Demand is the second most influential factor by far and offsets the mandatory closures/partial reopenings by about 30% of mandatory closure impacts for all three regions. Of course, these expenditures take place with a lag, such that a time decomposition would yield a dip in GDP in the mandatory closure, followed by an upswing during reopening, and then even a level of GDP above baseline at the final sub-period of the time-horizon (see Figure 1 in Appendix G).

Note also some of the limitations of our analysis, especially due to potential structural changes in the economy, including many business failures and slow replacements. These would likely exacerbate the net losses and stretch out the recovery.

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[6] Note that workday losses stemming from death and illness, as well as caring for sick family members, do not result in noticeable GDP impacts in any of the three scenarios because they do not represent an effective constraint on the labor force. This is primarily because demand for goods and services declined significantly, thereby reducing the drive of demand for labor.

The employment impacts for this Scenario and the other two are presented in Table 10. The employment decline of 23.3% in the U.S. represents a decline in demand of 36.5 million workers, as reduced production from the mandatory closures and their indirect effects leads to a reduction in demand for labor. The employment impacts are slightly greater in percentage terms than the GDP impacts because service sectors, which are an important part of U.S. non-essential production, are much more negatively impacted than agriculture, processed food, and other essential manufacturing, and a large share of U.S. workers are employed in the former. In China and the ROW, non-essential businesses are less important to the economy and employ a much smaller portion of the workforce. Note also that employment increases due to Pent-up Demand are of a higher percentage than their counterpart GDP increases, thereby offsetting the Mandatory Closure employment declines slightly more strongly than is the case for GDP.

The GDP impacts of Scenario 2 are presented in the second partition of Table 9. Overall, the total impact on the U.S. economy is a $3.9 trillion, or 18%, decline in GDP. The percentage results are more than 2.5 times higher in the U.S. than in China and about 33% higher than in ROW. As in the U.S., the larger negative impacts on the ROW reflect the more gradual Reopenings of their economies, while in China the greater loses are due to indirect effects of COVID-19 on the world and hence trade.

The major factor affecting the results is again Mandatory Closures and the phased Reopenings of businesses. These alone would have resulted in a 37.5% decrease in U.S. GDP, but again only about 40% of that amount in China because of the much shorter lock-down period in the latter. The results for ROW again fall about half-way in-between the other two regions.

Avoidance behavior impacts are significant in this case, amounting to an additional $853 million of negative impacts on U.S. GDP, and adding a negative few percentage points to the impacts in all three regions. This reflects the assumption that the continuing increase in cases and deaths causes avoidance to continue even after businesses start to reopen. Communication demand in the U.S. is similar to Scenario 1, but about twice the size in the other two regions. GDP losses due to Death and Illness go up very slightly in all three regions, but their relatively small size compared to the labor force, coupled with decreased labor demand, make for relatively insignificant impacts on GDP. Healthcare costs go up and now have a sizable positive stimulating effect in all three regions. The reason for the larger impact of health care is that health care services now require the use of previously under-utilized resources, which allows production of Health Care Services to increase without a decline in the provision of other services. China also gains considerably as it increases exports of Health Care Services to the ROW, with the decline in exports from the U.S. Most importantly, Pent-up Demand triples in all three regions.

In Scenario 2, demand for workers declines by 39.2 percent under the Mandatory Closures, reflecting the significant slow-down in the reopening of businesses in response to continued increases in COVID-19 cases and deaths. Since the same industries are closed or indirectly impacted in this and the previous scenario, this further decline in employment reflects the longer closure period and hence the longer these workers are not required, rather than an almost doubling of the unemployment rate. That said, the longer the mandatory closures remain in place the more likely the decline in demand for workers would increase unemployment, as firms can no longer keep under-employed workers on their payroll.

The GDP impacts of Scenario 3 are presented in the third partition in Table 9. Overall, the total impact on the U.S. economy is a $4.9 trillion, or 23%, decline in GDP. The percentage results are more than 3.5 times higher in the U.S. than in China and about 33% higher than in ROW.

The major factor affecting the results is again Mandatory Closures and the slow reopenings of businesses, which have both been extended in this scenario relative to Scenario 1. These alone would have resulted in a whopping 60.6% decrease in U.S. GDP, but again only about 40% of that amount in China because of the much shorter lock-down period in the latter. In this scenario, consumption of essentials in the U.S. and ROW cannot be maintained due to the significant decline in incomes. As a result, the percentage decline in GDP for the ROW is relatively larger since essentials are a more important part of this economy.

Avoidance Behavior impacts are only very slightly higher in this case than in Scenario 2, reflecting the fact that we assume extensive avoidance in both Scenarios 2 and 3. Communication Demand, on the other hand, is about twice the size in percentage terms as Scenario 2. GDP losses due to Death and Illness are actually lower than in Scenario 2 in all three regions as unemployment rose more between Scenario 2 and 3 than the number of deaths, while between Scenarios 1 and 2, deaths rose more than unemployment.[7] Gains from the increase in demand for Healthcare are also much lower than in Scenario 2, especially for China and ROW due to the decline in health care resulting from the mandatory closures and reopenings. As mentioned previously, in Scenario 3 people can no longer afford all of their baseline essential goods and services, including health care, due to the collapse in incomes and employment. This means that medical services for COVID-19 patients can now be met without resorting to excess capacity.[8] Most importantly, the impact of Pent-up Demand more than doubles in all three regions vis-à-vis Scenario 2, consistent with our assumption that pent-up demand is extensive under this scenario.

VII. Interpretation and Policy Implications

Our results should be considered upper-bound estimates due to the exclusion of countervailing policies. In addition, we have assumed that reductions in business output are accompanied by reductions in wages and salaries paid as people become unemployed, though some businesses will continue paying their employees. We have also omitted the spending of the small percentage of teleworkers who will continue to be employed in non-essential sectors, primarily as office staff.[9] Finally, we have omitted some sources of business resilience, such as the use of inventories and relocation.

We also acknowledge the limitations of our model and its application, as well as of our assessment on how they bear on the results. As is the case in most GTAP-based analysis, we assume that, with the

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[7] The number of deaths in Scenarios 2 and 3 are 1.25 and 1.75 million respectively. Between Scenarios 1 and 2 deaths increased considerably and at a greater rate than unemployment, while in Scenario 3, unemployment grew at a faster rate. In Scenario 2, the deaths had an impact on the labor force, while in scenario 3, the unemployment exceed the deaths again.

[8] Using excess capacity in Scenario 2 is like reducing unemployment, which gives a big boost to employment and incomes.

[9] For sectors that an output cannot be produced by telecommuting (e.g., most manufacturing), we assume that they produce no products for the supply chain, and hence such sectors are modeled as a complete shutdown. It is possible that a proportion of the "output" of these sectors can continue in the form of administrative/clerical work. However, we did not model this as injections to the spending streams in the simulations.

Table 9. Real GDP Impacts (billions of U.S. dollars and percent changes relative to baseline)

Country/ Region	Mandatory Closure & Reopening	Avoidance	Communi- cation Demand	Deaths and Illness	Health Care Expenditure	Pent-up Demand	Total Impacts
Scenario 1							
USA	-4,780.8	-6.7	208.7	-0.7	21.4	1,394.3	-3,163.7
	(-22.3)	(0.0)	(1.0)	(0.0)	(0.1)	(6.5)	(-14.8)
China	-1,210.9	-7.9	83.3	0.0	0.2	394.2	-741.2
	(-8.6)	(-0.1)	(0.6)	(0.0)	(0.0)	(2.8)	(-5.2)
ROW	-8,301.9	-66.7	710.8	-0.3	4.5	2,503.7	-5,123.1
	(-15.8)	(-0.1)	(1.4)	(0.0)	(0.0)	(4.8)	(-9.8)
Scenario 2							
USA	-8,040.1	-853.2	263.2	-23.7	966.3	3,821.1	-3,866.5
	(-37.5)	(-4.0)	(1.2)	(-0.1)	(4.5)	(17.8)	(-18.0)
China	-2,392.3	-758.8	174.1	0.2	531.4	1,434.4	-1,010.9
	(-16.9)	(-5.4)	(1.2)	(0.0)	(3.8)	(10.1)	(-7.1)
ROW	-13,943.1	-3,282.2	1,395.4	3.5	1,613.2	7,852.4	-6,360.8
	(-26.6)	(-6.3)	(2.7)	(0.0)	(3.1)	(15.0)	(-12.1)
Scenario 3							
USA	-12,996.8	-885.1	5277.8	-5.1	189.8	8,186.6	-4,932.8
	(-60.6)	(-4.1)	(2.7)	(0.0)	(0.9)	(38.2)	(-23.0)
China	-3,513.0	-539.8	119.3	-0.2	1.2	2,993.5	-939.0
	(-24.8)	(-3.8)	(0.8)	(0.0)	(0.0)	(21.2)	(-6.6)
ROW	-26,251.3	-2,596.3	1,768.1	1.1	22.1	17,697.1	-9,359.3
	(-50.0)	(-4.9)	(3.4)	(0.0)	(0.0)	(33.7)	(-17.8)

Table 10. Employment Impacts (% changes from baseline)

Country/ Region	Mandatory Closure & Reopening	Avoidance	Communi- cation Demand	Deaths and Illness	Health Care Expenditure	Pent-up Demand	Total Impacts
Scenario 1							
USA	-23.3	0.3	1.2	0.0	0.2	6.9	-14.7
China	-19.3	0.1	1.1	0.0	0.0	5.7	-12.3
ROW	-23.9	0.0	1.3	0.0	0.0	6.8	-15.7
Scenario 2							
USA	-39.2	-4.6	2.5	0.0	5.7	22.1	-13.7
China	-38.7	-5.2	2.6	0.0	6.0	22.4	-13.0
ROW	-38.3	-6.0	2.7	-0.1	5.5	21.5	-14.7
Scenario 3							
USA	-58.4	-3.6	2.8	0.1	1.4	33.8	-23.8
China	-20.3	-1.2	0.8	0.0	0.0	18.0	-2.7
ROW	-47.2	-3.0	3.9	0.0	0.2	32.6	-13.6

exception of factor markets, all other markets clear and firms are perfectly competitive. In addition to unemployment, factors of production are also assumed to be immobile across sectors, consistent with this paper focusing on very short-run impacts of the pandemic. Our results also rely on the estimated elasticities taken from the literature and used in the GTAP database. We conduct sensitivity analyses on some of our assumptions regarding investment and the trade balance, as well as our assumption that real consumption of essential goods and services will be maintained in the aggregate. Fixing the trade balance causes the losses in China, and to a lesser extent the ROW, to be much larger than when capital flows were endogenous. This reflects the fact that with the trade balance fixed, U.S. savings must remain in the U.S. With less investment moving to the to China, China's GDP declines by about the same amount as the U.S. decline, despite mandatory closures only being in place for 6 weeks. In the U.S., increased demand for investment goods raises the potential for increased production, but with businesses closed that increase in demand cannot translate into an increase in GDP and hence prices rise. Our assumptions regarding real consumption of essentials ensures that consumers continue to purchase and firms continue to produce essential items, despite declining incomes and the closure of non-essential businesses, although our sensitivity tests indicate that it has only a small impact on the macroeconomic impacts in the U.S. We do find that the loses for the ROW rise when consumption of essentials is not fixed. This is consistent with our other results and data that show that the ROW is more heavily reliant on the production of essentials.

Finally, we summarize our results in comparison to other studies that have examined the impact of COVID-19 under various conditions. Several studies, including one by the authors of this paper, have focused on the impacts of mandatory closures and generally found the impacts on GDP to be in the range of 20 to 25% for scenarios similar to those that actually took place (see Del Rio-Chanona et al., 2020; Mandel and Veetil, 2020; OECD, 2020; Walmsley et al., 2020). Dixon et al. (2020), using a quarterly CGE model, have explored the macroeconomic impacts of COVID-19 in relation to several drivers over a two-year time horizon. They estimated a 19% reduction in GDP at the trough of the economic downturn at the end of the first quarter of 2020 and 12% decline by the end of the second quarter. They have incorporated our estimates of telework, and also include government expenditures on health care and some countervailing fiscal policies, such as unemployment compensation and tax relief, all of which dampen the negative impacts. CBO (2020) estimates that Real GDP will contract by 11 percent in the second quarter of this year, resulting in the number of people employed being almost 26 million lower than the number in the fourth quarter of 2019. If this rate were to continue the decline in U.S. Real GDP for the year would be up to 38 percent on an annual basis; however, given the reopenings the overall annual decline is projected to drop to 5.4 percent. Our results fall in-between these extreme bounds.

-   Our analysis leads to several important insights and policy implications: Mandatory closures do have a severe impact on the world economy and employment, and in particular the production of non-essential goods and services. Scenario 3, however, shows that, if the pandemic requires a prolonged shutdown or continued partial closure of non-essential services, then the outcome for economic well-being in terms of essential and non-essential consumption and production could be devastating.

-   While China may have been able to avoid the severe repercussions of the virus itself, it cannot avoid the negative impacts of the decline in production and trade in the rest of the world on global supply chains. As indicated in the sensitivity analysis discussion, these losses could be even larger if excess savings does not flow into China.

-   The impact of additional avoidance behaviors following the reopening of the economy were also found to be considerable. The impact of any avoidance behavior that occurred during the mandatory closure period is included as part of the mandatory closure effect. Hence, the impact of all avoidance behavior due to the pandemic is likely to be a multiple of these effects. Further analysis of the full extent of these avoidance behaviors, especially during the lockdown period, is necessary to examine the true cost of the mandatory closures.

-   The analysis of the increase in demand for health care clearly demonstrates the tradeoffs that will need to be made in this sector. The inclusion of excess capacity in the health care sector was essential to ensuring that this sector could respond to the increase in demand, as well as the ability of the sector to delay other procedures. In Scenario 3, the excess capacity was insufficient. It was only the substantial decline in incomes and demand for essential goods that allowed the health care sector to meet the increase in demand, but the cost in terms of other health care services was significant.

-   Finally, pent-up demand is an important factor to consider in our ability to recover from this severe downturn. We can only hope that those who are accumulating savings will spend those and help boost the economy once the pandemic is over.

VIII. Conclusion

In this study, we have used a state-of-the-art, static computable general equilibrium model to simulate three COVID-19 scenarios that range from a relatively moderate event to an extensive pandemic. The net U.S. GDP losses from COVID-19 are estimated to range from $3.2 trillion (14.8%) to $4.8 trillion (23.0%) in a 2-year period for the three scenarios. The employment decline is estimated to range from 14.7% to 23.8%. Note that the effect of Mandatory Closures is still so sizable even after we have made a resilience adjustment for telework.

The major factor affecting the results in all three scenarios is Mandatory Closures and the Partial Reopenings of businesses. These alone would have resulted in a 22.3% to 60.6% decrease in the U.S. GDP and a 23.3% to 58.4% decline of employment across the scenarios. U.S. impacts are estimated to be higher than those for China and the ROW in percentage terms because: 1) a higher proportion of the U.S. economy is impacted by the mandatory closures, 2) the U.S. has a relatively longer duration of mandatory closures, and 3) the U.S. produces and exports a higher share of non-essential goods and services.

The impacts of people's avoidance behavior are almost imperceptible in the moderate and declining scenario (Scenario 1). However, they become significant, causing about $850 to $900 billion U.S. GDP losses in the more severe scenarios.

Pent-up Demand is the second most influential factor and offsets the negative impacts of Closures/Reopenings by about 30% for all three regions in the moderate and declining scenario and up to 60% to 85% in the extensive pandemic scenario.

Both increased Communication Demand because of telecommuting and increased expenditure on Health Care result in positive offset effects in all three regions. The positive effects of the former increase as the Mandatory Closures and Partial Reopenings last longer. The Health Care expenditures only have a sizable positive stimulating effect in the second severe pandemic scenario because it is accompanied by a large increase in the utilization of excess capacity. In Scenario 3, the most severe pandemic scenario, on the other hand, it is accompanied by a significant fall in the provision of other health care services due to the collapse in incomes and ensuing reduced demand for essential goods and services, including health services fro more standard needs.

Text References:

Congressional Budget Office (CBO). 2020. *Interim Economic Projections for 2020 and 2021.*, Washington, DC. https://www.cbo.gov/publication/56351

Cornwall, W. 2020. "Can you put a price on COVID-19 options? Experts weigh lives versus economics," *Science*, March 31.

Corong, E., T. W. Hertel, R. McDougall, M. E. Tsigas, and D. van der Mensbrugghe. 2017. "The Standard GTAP Model, Version 7," *Journal for Global Economic Analysis* 2(1): 1-119.

del Rio-Chanona, R. M., Mealy, P., Pichler, A., Lafond, F., and Farmer, D. 2020. "Supply and Demand Shocks in the COVID-19 Pandemic: An Industry and Occupation Perspective." *arXiv preprint.* https://arxiv.org/abs/2004.06759

Dixon, P., M. Rimmer, B. Lee, A. Rose et al. 2010. "Effects on the U.S. of an H1N1 Epidemic: Analysis with a Quarterly CGE Model," *Journal of Homeland Security and Emergency Management* 7(1): Article 7.

Dixon, P., M. Rimmer, J. Giesecke, C. King and R. Waschik. 2020. "The effects of COVID-19 on the U.S. macro economy, industries, regions and National Critical Functions. Report to the U. S. Department of Homeland Security Centre of Policy Studies, Victoria University, Melbourne, Australia.

Dormady, N., A. Rose, A. Roa-Henriquez, and H. Rosoff. 2019. *Measuring Business and Economic Resilience in Disasters*, Final Report to the Critical Infrastructure Resilience Institute (CIRI), University of Illinois, Urbana, IL.

Hertel, T. W. and M. E. Tsigas. 1997. "Structure of GTAP," in T.W. Hertel (ed.), *Global Trade Analysis: Modeling and Applications*, New York: Cambridge, pp. 13-73.

Mandel, A., and V. P. Veetil, V. P. 2020. "The Economic Cost of COVID Lockdowns: An Out-of-Equilibrium Analysis." *Available at SSRN 3588421*. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3588421

OECD. (2020). Evaluating the Initial Impact of COVID-19 Containment Measures on Economic Activity." http://www.oecd.org/coronavirus/policy-responses/evaluating-the-initial-impact-of-covid-19-containment-measures-on-economic-activity-b1f6b68b/

Prager, F., D. Wei, and A. Rose. 2017. "Total Economic Consequences of an Influenza Outbreak in the United States," *Risk Analysis* 37(1): 4-19.

Rose, A. 2017. "Benefit-Cost Analysis of Economic Resilience Actions," in S. Cutter (ed.) *Oxford Research Encyclopedia of Natural Hazard Science*, New York: Oxford.

Thunström, L., S. Newbold, D. Finnoff, M. Ashworth, and J. Shogren. 2020. "The Benefits and Costs of Flattening the Curve for COVID-19," *Journal of Benefit-Cost Analysis* 11(2): 179-95.

U.S. Bureau of Labor Statistics. 2019. "Table 1. Workers who could work at home, did work at home, and were paid for work at home, by selected characteristics, averages for the period 2017-2018." https://www.bls.gov/news.release/flex2.t01.htm

Walmsley, T. L., and P. Minor. 2020. "US Trade Actions against China: A Supply Chain Perspective", *Foreign Trade Review* 55(3): 337-371.

Walmsley, T. L., and P. Minor. 2020. "Demand Shifts and Willingness to Pay in Applied Models," *World Economy, 43(6), 1499-1520*.

Walmsley T. L., and P. Minor. 2016. "ImpactECON Global Supply Chain Model: Documentation of Model Changes," Working Paper No. 06, ImpactECON, Boulder, CO. https://impactecon.com/resources/supply-chain-model/

Walmsley, T.L., A. Rose, D. Wei. 2020. "Impacts on the U.S. Macroeconomy of Mandatory Business Closures in Response to the COVID-19 Pandemic," *Applied Economic Letters*, forthcoming.

Data References:

ABC News/Ipsos Poll. (2020, May 1). *Topline & Methodology* [PDF File]. Retrieved from https://www.ipsos.com/sites/default/files/ct/news/documents/2020-05/topline-abc-coronavirus-wave-7.pdf

ABC News/Ipsos Poll. (2020, March 20). *Coronavirus Outbreak Triggering Significant Changes to American Society* [Press release]. Retrieved from https://www.ipsos.com/en-us/news-polls/abc-news-coronavirus-poll

ABC News/Ipsos Poll. (2020, May 8). *Two in three Americans: Opening country is not worth it* [Press release]. Retrieved from https://www.ipsos.com/en-us/news-polls/abc-news-coronavirus-poll

The Associated Press-NORC Center for Public Affairs Research. (2020, March 19). *Worries about the Coronavirus Increase* [Blog post]. Retrieved from http://www.apnorc.org/projects/Pages/Worries-about-the-Coronavirus-Increase.aspx

Axios/Ipsos Poll. (2020, March 17). *Axios/Ipsos Coronavirus Index March 18, 2020* [Press release]. Retrieved from https://www.ipsos.com/en-us/news-polls/axios-ipsos-coronavirus-index-03-18-2020

Axios/Ipsos Poll. (2020, May 5). *Social Distancing Coming to an End?* [Press Release] https://www.ipsos.com/en-us/news-polls/axios-ipsos-coronavirus-index

BEA. 2019. *Tourism Satellite Account*. https://www.bea.gov/tourism-satellite-accounts-data-sheets

BLS. 2020. Civilian Labor Force Participation Rate. https://www.bls.gov/charts/employment-situation/civilian-labor-force-participation-rate.htm.

Center for Disease Control. 2020a. "Severe Outcomes Among Patients with Coronavirus Disease 2019 (COVID-19) — United States, February 12–March 16, 2020." MMWR Morbidity and Mortality Weekly Report 69: 343 - 346. Retrieved from https://www.cdc.gov/mmwr/volumes/69/wr/mm6912e2.htm

Center for Disease Control. 2020b. "Coronavirus Disease 2019 in Children — United States, February 12–April 2, 2020." MMWR Morbidity and Mortality Weekly Report 69: 422-426. Retrieved from https://www.cdc.gov/mmwr/volumes/69/wr/mm6914e4.htm

Center for Disease Control. 2020c. "Coronavirus Disease – Older Adults." Centers for Disease Control and Prevention Coronavirus Disease 2019. Retrieved from https://www.cdc.gov/coronavirus/2019-ncov/need-extra-precautions/older-

adults.html?CDC_AA_refVal=https%3A%2F%2Fwww.cdc.gov%2Fcoronavirus%2F2019-ncov%2Fspecific-groups%2Fhigh-risk-complications%2Folder-adults.html

CDC. 2020d. "COVID-19 Forecasts." Centers for Disease Control and Prevention Coronavirus Disease 2019. Retrieved from https://www.cdc.gov/coronavirus/2019-ncov/covid-data/forecasting-us.html

CDC. 2020e. *Provisional Death Counts for Coronavirus Disease (COVID-19)*. https://data.cdc.gov/NCHS/Provisional-COVID-19-Death-Counts-by-Sex-Age-and-S/9bhg-hcku/data. Accessed on 5/15/2020.

CDC. 2020f. COVID19Surge v1.0 Manual. https://www.cdc.gov/coronavirus/2019-ncov/hcp/COVIDSurge.html

Chow, N. et al. 2020. "Preliminary Estimates of the Prevalence of Selected Underlying Health Conditions Among Patients with Coronavirus Disease 2019 — United States, February 12–March 28, 2020" MMWR Morbidity and Mortality Weekly Report 69(13): 382 – 386. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7119513/

Cohen, M., K. Whittal, and T. Murray. 2020. "COVID-19 Cost Scenario Modeling." *Wakely Consulting Group LLC.* Retrieved from https://www.ahip.org/wp-content/uploads/AHIP-COVID-19-Modeling.pdf

Cox, C., Kamal, R., and McDermott, D. 2020. "Health System Tracker: How Have Healthcare Utilization and Spending Changed So Far during the Coronavirus Pandemic?" Retrieved from https://www.healthsystemtracker.org/chart-collection/how-have-healthcare-utilization-and-spending-changed-so-far-during-the-coronavirus-pandemic/#item-start.

The Economist/YouGov (2020, May). Poll of 1500 US Adult citizens. [PDF File]. Retrieved from https://docs.cdn.yougov.com/5yope37lqh/econTabReport.pdf

FAIR Health. 2020. "The Projected Economic Impact of the COVID-19 Pandemic on the US Healthcare System." *FAIR Health*. Retrieved from https://s3.amazonaws.com/media2.fairhealth.org/brief/asset/COVID-19%20-%20The%20Projected%20Economic%20Impact%20of%20the%20COVID-19%20Pandemic%20on%20the%20US%20Healthcare%20System.pdf

Gallup. (2020, March 20). *Americans Rapidly Answering the Call to Isolate, Prepare* [Blog post]. Retrieved from https://news.gallup.com/poll/297035/americans-rapidly-answering-call-isolate-prepare.aspx

Gold JA, Wong KK, Szablewski CM, et al. 2020. Characteristics and Clinical Outcomes of Adult Patients Hospitalized with COVID-19 — Georgia, March 2020. MMWR Morb Mortal Wkly Rep 2020; 69:545–550. DOI: https://www.cdc.gov/mmwr/volumes/69/wr/mm6918e1.htm?s_cid=mm6918e1_w

Ipsos. (2020, March). Tracking the Coronavirus: Results from a Multi-Country Poll. Retrieved from https://www.ipsos.com/sites/default/files/ct/news/documents/2020-03/tracking-the-coronavirus-wave-4-ipsos.pdf

Kaiser Family Foundation. (2020, March 17). *KFF Coronavirus Poll: March 2020* [Blog post]. Retrieved from https://www.kff.org/global-health-policy/poll-finding/kff-coronavirus-poll-march-2020/

Kaiser Family Foundation (2020, April). *KFF Health Tracking Poll – Late April 2020* [PDF File]. Retrieved from http://files.kff.org/attachment/Topline-KFF-Health-Tracking-Poll-Late-April-2020.pdf

Marketplace-Edison (2020, May 5). *Marketplace Survey Wave Nine* [PDF File]. Retrieved from https://www.marketplace.org/wp-content/uploads/2020/05/Edison-poll-data-pt.-2.pdf

Morin, R. (2020, May 8). Americans more worried about reopening too quickly than not opening quickly enough, survey says." *USA Today.* Retrieved from https://www.usatoday.com/story/news/politics/2020/05/08/survey-most-americans-worried-country-reopen-too-quickly/5180069002/

National Alliance for Caregiving. 2020. *Caregiving in the U.S. 2020*. https://www.caregiving.org/caregiving-in-the-us-2020/

NBC News/Wall Street Journal. (2020, March). NBC News/Wall Street Journal Survey. Retrieved from https://www.documentcloud.org/documents/6810602-200149-NBCWSJ-March-Poll-Final-3-14-20-Release.html?utm_source=link_newsv9&utm_campaign=item_296681&utm_medium=copy

New York City Department of Health and Mental Hygiene. 2020. COVID-19 Data. https://github.com/nychealth/coronavirus-data/blob/master/by-age.csv. April 29, 2020

NPR/PBS NewsHour/Marist Poll. (2020, March 17). *NPR/PBS NewsHour/Marist Poll Results & Analysis* [Blog post]. Retrieved from http://maristpoll.marist.edu/npr-pbs-newshour-marist-poll-results-analysis-13/

Reuters/Ipsos. (2020, March 17). *Reuters/Ipsos Poll: Core Political – Coronavirus* [Press Release]. Retrieved from https://fingfx.thomsonreuters.com/gfx/mkt/13/3563/3524/Topline%20Reuters%20Coronavirus%2003%2017%202020.pdf

Reuters/Ipsos Poll. (2020, April 29). *Reuters/Ipsos Coronavirus Impact on Recreation* [PDF File]. Retrieved from https://www.ipsos.com/sites/default/files/ct/news/documents/2020-05/topline_reuters_coronavirus_tracker_recreation_questions_04_29_2020_.pdf

SurveyUSA. (2020, March 19). Results of SurveyUSA News Poll #25248. Retrieved from http://www.surveyusa.com/client/PollReport.aspx?g=23b10fd3-4f50-43a0-b722-64b5a9fc143d

Trading Economics. 2020. United States Personal Savings Rate. Retrieved from: https://tradingeconomics.com/united-states/personal-savings

World Bank. 2020. Gross Savings as Percentage of GDP by Country. Retrieved from: https://data.worldbank.org/indicator/NY.GNS.ICTR.ZS

U.S. Census Bureau. 2019. America's Families and Living Arrangements 2019: Table A1. Marital Status of People 15 Years and Over, by Age, Sex, and Personal Earnings. https://www.census.gov/data/tables/2019/demo/families/cps-2019.html

U.S. Census Bureau. 2020a. Table 4. Families with Own Children: Employment Status of Parents by Age of Youngest Child and Family Type, 2018–2019 Annual Averages. https://www.bls.gov/news.release/famee.t04.htm

U.S. Census Bureau. 2020b. National Population by Characteristics: 2010-2019.
https://www.census.gov/data/tables/time-series/demo/popest/2010s-national-detail.html

University of Southern California. (2020, March 13) *Bracing for coronavirus, U.S. residents are changing their behavior* [Press release]. Retrieved from https://news.usc.edu/166834/coronavirus-survey-usc-behavior-changes-health-economic-fallout/

Voter Study Group. (2020, May 13). COVID-19: Tracking American Perspectives.
https://www.voterstudygroup.org/covid-19-updates

Appendix A. Additional Data Used in COVID-19 Health Outcome Calculation

Appendix Table A1 presents a summary of estimated percentages of people that were hospitalized, admitted to ICU, and died because of coronavirus infection with respect to the total number of confirmed cases based on the data gather from serval studies.

Appendix Table A1. Synthesis of Data on Hospitalization, ICU Admission, and Death Rates of COVID-19

Data Source	Age Group (yrs)	No. Cases	Hospitalization			ICU Admission			Case-Fatality		
			Lower-Bound	Upper-Bound	Average	Lower-Bound	Upper-Bound	Average	Lower-Bound	Upper-Bound	Average
CDC (2020a)	0-19	123	1.60%	2.50%	2.05%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	20-64	1563	17.90%	25.41%	21.65%	3.67%	7.82%	5.75%	0.57%	1.02%	0.80%
	65+	763	29.63%	52.74%	41.19%	8.42%	24.08%	16.25%	4.59%	10.67%	7.63%
	Total	2449	20.73%	32.78%	26.75%	4.97%	12.50%	8.73%	1.79%	3.98%	2.88%
CDC (2020b) CDC (2020c)	0-18	745	5.70%	20.00%	12.85%	0.58%	2.00%	1.29%			
	19-64	35,061	10.00%	33.00%	21.50%	1.40%	4.50%	2.95%			
	65-84		31.00%	59.00%	45.00%	11.00%	31.00%	21.00%	4.00%	11.00%	7.50%
	85+		31.00%	70.00%	50.50%	6.00%	29.00%	17.50%	10.00%	27.00%	18.50%
Chow et al. (2020)	19-64	4,562	14.14%	15.46%	14.80%	4.00%	4.44%	4.22%			
	65+	1,318	52.41%	56.20%	54.31%	17.01%	18.23%	17.62%			

NYDHMH (2020)[a]	Age Group (yrs)	Case Rate	Hospitalization Rate						Death Rate	
			Rate	% to Case Rate					Rate	% to Case Rate
	0-17	286.9	24.4	8.5%					0.6	0.2%
	18-64	5,441.3	1,051.8	19.3%					191.5	3.5%
	65+	7,470.2	4,147.7	55.5%					1,980.3	26.5%

[a] The case, hospitalization, and death rates are with respect to 100,000 people in New York City.

Appendix Table A2 summarized the projections on cumulative COVID-19 deaths in the U.S. provided by 10 models that are cited in the CDC COVID-19 Forecasts website. The data collected in the Appendix Table 1 were model projections as of May 15, 2020.

Appendix Table A2. Projections of Cumulative COVID-19 Deaths in the U.S.

Forecast Model	through May 30			through June 6			through August 4		
	Lower-Bound	Mean	Upper-Bound	Lower-Bound	Mean	Upper-Bound	Lower-Bound	Mean	Upper-Bound
Columbia U. (20% contact reduction)	99,092	106,425	118,577	104,687	116,748	137,401			
IHME	102,712	111,473	127,868	106,827	119,799	145,148	113,182	147,040	226,971
MOBS	79,920	100,454	125,306	84,361	106,665	141,957			
LANL	87,367	99,444	120,942	176,263	208,211	286,762			
UT Austin	101,581	105,682	111,358	104,192	109,728	117,743			

YYG	97,704	107,636	119,648	101,262	116,086	134,486	116,350	190,016	321,484
MIT	109,508	111,885	114,262	117,638	120,192	122,746			
UCLA	97,128	104,724	113,246	101,204	110,695	121,476			
GA_Tech	98,567	105,479	112,665	149,098	158,364	173,858			
Average	**97,064**	**105,911**	**118,208**	**116,170**	**129,610**	**153,509**	**114,766**	**168,528**	**274,228**

Source: CDC (2020d).

We further estimated the projected cumulative numbers of hospitalization, ICU admissions, and deaths by age group in Appendix Table A3. An additional piece of information we used in this calculation is the distribution of COVID-19 deaths among different age groups. The data presented in the first numerical column in Appendix Table A3 are collected from the CDC Provisional Death Counts for Coronavirus Disease by age group (CDC, 2020e). In the last three columns, we estimated the number of deaths in the three age groups for the May 30, June 6, and August 4 projections, respectively.

Appendix Table A3. Projections of Cumulative COVID-19 Deaths by Age Group

Age Group (yrs)	COVID-19 Deaths (2/1 to 5/9)[a]		through May 30	through June 6	through Aug 4
	Number	**%**			
0-18	41	0.1%	79	97	126
19-64	10,888	19.8%	21,020	25,723	33,447
65+	43,932	80.1%	84,812	103,790	134,955
Total	54,861	100.0%	105,911	129,610	168,528

[a] Data during this period are incomplete because of the lag in time between when the death occurred and when the death certificate is completed, submitted to NCHS and processed for reporting purposes. This delay can range from 1 week to 8 weeks or more, depending on the jurisdiction, age, and cause of death.

Next, based on the relationship between the death rate and the hospitalization rate for different age groups presented in Table 1 and the number of deaths in each age group (presented in Appendix Table A3), we estimated the projected cumulative number of hospitalizations, ICU admissions, and deaths for May 30, June 6, and August 4 in Appendix Table A4. The number coronavirus patients received outpatient medical treatment is calculated as the difference between the total number of cases and sum of hospitalization (survived) and fatality.

Appendix Table A4. Health Outcome Estimates (number of people)

May 30 Forecast

Age Group (yrs)	Total Confirmed Cases	Outpatient Medical Treatment	Total Hospitalization	Hospitalization - Non ICU	Hospitalization - ICU	Fatality
0-18	39,500	36,619	3,054	2,802	252	79
19-64	973,148	805,817	188,271	146,311	41,960	21,020
65-84	788,949	501,188	310,284	202,949	107,335	84,812
Total	1,801,597	1,343,624	501,608	352,061	149,547	105,911

June 6 Forecast

Age Group (yrs)	Total Confirmed Cases	Outpatient Medical Treatment	Total Hospitalization	Hospitalization - Non ICU	Hospitalization - ICU	Fatality
0-18	48,500	44,975	3,737	3,428	309	97
19-64	1,190,880	986,108	230,398	179,049	51,348	25,723
65-84	965,488	613,338	379,712	248,360	131,352	103,790
Total	2,204,868	1,644,421	613,847	430,838	183,009	129,610

August 5 Forecast

Age Group (yrs)	Total Confirmed Cases	Outpatient Medical Treatment	Total Hospitalization	Hospitalization - Non ICU	Hospitalization - ICU	Fatality
0-18	63,000	58,416	4,859	4,458	402	126
19-64	1,548,472	1,282,212	299,580	232,813	66,767	33,447
65-84	1,255,395	797,504	493,729	322,936	170,794	134,955
Total	2,866,868	2,138,133	798,168	560,206	237,962	168,528

Appendix B. Additional Data Used in Workday Losses Calculation

Based on a small sample of COVID-19 patients with critical conditions in the Seattle region, a study found that the median length of ICU stay of survivors was 14 days (IQR 4-17). The median length of total hospital stay of the survivors that were admitted in ICU was 17 days (IQR 16-23) (Nhatraju, et al., 2020).

Among the 305 adults hospitalized with COVID-19 in Georgia, for patients admitted in ICU, the median ICU duration was 8 days (IQR 5-12). Patients older than 65 have a slightly longer median ICU stay. For all the hospitalized patients, the median duration of hospital stay was 8.5 days (IQR 5-14) (Gold et al., 2020).

In response to the increased demand for hospital services, CDC released an Excel spreadsheet-based tool, COVID19Surge, to help hospital administrators to evaluate the impact of COVID-19 on hospital capacity and resource utilization. The default assumptions of average length of hospital stays adopted in the tool are 8 days for Non-ICU patients, 10 days for ICU patients without the use of ventilator, and 16 days for ICU patients that required ventilator (CDC, 2020f).

Among the 5,139 patients confirmed with COVID-19 and received critical care treatment in UK, the median length of stay in critical care is 6 and 7 days for survivors and non-survivors, with IQR of 3 to 13 and 4 to 13, respectively. Patients that received advanced respiratory support or renal support have longer median length of stay (13 [7-19] vs. 16 [9-23] days for survivors and 8 [5-13] vs. 10 [6-15] days for non-survivors) (ICNARC, 2020). Note that all the durations of stays reported in this study are the lengths of stay in ICU, not the total duration of hospitalization.

Another study, which focused on 249 COVID-19 patients in Shanghai, China, estimated a median duration of onset of symptoms to hospitalization of 4 days (IQR 2-7). The median hospitalization duration was 16 (IQR 12-20) days. Patients who were admitted in ICU had a significantly longer median

length of fever compared to those who were not treated in ICU (31 days vs. 9 days after the onset of symptoms). The median length to have viral clearance in the upper respiratory route after onset of symptoms was 10 days for non-ICU patients and 22 days for ICU patients (Chen et al., 2020).

For a cohort of 77 COVID-19 patients in Beijing, a study found that the median hospitalization duration for all patients was 13 days (IQR 10-18). The hospitalization duration was 12 days (IQR 10-16) and 18.5 days (IQR 15-21) for non-severe and severe patients, respectively. The median time of illness onset to hospital discharge for all patients was 18.5 days (IQR 12-22), and was 18 days (IQR 15-21) and 24.5 days (IQR 22-27) for non-severe and severe patients, respectively (Zhao et al., 2020).

Appendix Table B1 summarizes the length of illness onset to hospitalization as well as length of hospital stay for both non-severe and severe cases from the above reviewed studies.

Based on the data presented in Table B1, we assume that the average hospital stays for non-severe and severe (ICU admitted) COVID-19 patients are 10 days and 15.5 days, respectively. The average length from illness onset to hospitalization is 4.5 days. If we further assume that there will be an additional 3 days for non-severe patients and 5 days for severe patients to fully recover before they can return to work after hospital discharge, the total productivity losses are 17.5 days for non-severe patients and 25 days for severe patients. Appendix Table B2 presents the per-person lost productivity in days for different categories of health outcome.

Appendix Table B1. Length from Illness Onset to Hospitalization and Duration of Hospital Stay

Data Source	Study Country/Region	From Illness Onset to Hospitalization (days)	Non-Severe Cases	Severe Cases	
			Entire Hospital Stay (days)	ICU Stay (days)	Entire Hospital Stay (days)
Nhatraju et al. (2020)	Seattle			14	17
Gold et al. (2020)	Georgia			8	11[a]
CDC (2020)	US		8	10 to 16	13 to 19[a]
ICNARC (2020)	UK			7 to 16	10-19[a]
Chen et al. (2020)	Shanghai, China	4			
Zhao et al. (2020)	Beijing, China	5.5	12		18.5

[a] Assume the entire hospital stay is 3 days longer than the length of ICU stay based on Nhatraju et al. (2020).

Appendix Table B2. Per Patient Lost Productivity (days)

	Outpatient Medical Treatment	Hospitalized – Non-ICU	Hospitalized - ICU	Deaths
0-17	1.5			
18-64	1.9	17.5	25	125
65+	5.3			

To calculate the lost productivity due to caring for sick family members, the following assumptions are adopted:

For sick children: 1) for any day that the children are sick at home, one full workday is lost for the caring parent; and 2) for any day that the children are hospitalized, half workday of the caring parent is lost. We also adjust the workday losses down according to the percentage of families with children that has no parent that is not employed. Based on the U.S. Census Bureau data, this percentage is 75.5% in 2019 (U.S. Census, 2020a).[10]

When we calculate the workday losses due to the care of sick spouses, we first apply the percentage of total population married with spouse present. This percentage is 48.9% in 2019 (U.S. Census, 2019). We next assume that 50% of working people with spouses will decide to take sick days to care for their sick spouses during their illness. We further assume that: 1) for any sick day due to outpatient medical treatment, half workday of the caring spouse is lost; 2) for any day that is lost because of hospitalization, half workday of the caring spouse is lost.

When we calculate the workday losses due to the care of sick elderly family members, we first assume that 35.3% of the sick old people will receive cares from their family members. This is based on the data presented in the Caregiving in the U.S. 2020 report, which indicated that about 53 million adult Americans provide unpaid family cares for someone 50+ years of age over the last 5 years (NAC, 2020). This represents 35.3% of the 50+ population (U.S. Census, 2020b). We also use the labor force participation rate to get the percentage of unpaid family caregivers that are in the labor forth. We then further assume that: 1) for any sick day due to outpatient medical treatment of people in the 65+ age group, half workday of the caring family member is lost; 2) for any day that is lost because of hospitalization, half workday of the caring family member is lost.

Appendix C. Estimation of Direct Output Impacts by Sector for Mandatory Closures and Reopening

Appendix Table C1 summaries the mandatory shutdown and "stay-at-home" orders implemented in individual states between March and June in the U.S. Information is presented for the order declared date, order expiration date, and the length (days) of the order.

Appendix Table C2 presents the percentage reduction in U.S. annual GDP by sector due to mandatory closures for the three scenarios analyzed in this study. The telework potentials by sector (presented in Appendix Table C3) are factored in when we estimate the percentage direct production declines for non-essential sectors that are affected by the mandatory closure order.

Appendix Table C1. Stay-at-Home Orders and Mandatory Closures by U.S. State (March to June 2020)

State	Order declared	Order expired or reopening started	Length (days) of Closure	Note
Alabama	3-Apr	30-Apr	27	

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[10] There were 33,399 thousand families with own children, of which there were 14,661 thousand married-couple families with both parents employed, 7,914 thousand families maintained by mother with employment, and 2,631 thousand families maintained by father with employment (U.S. Census, 2020a).

State				
Alaska	28-Mar	24-Apr	27	
Arizona	30-Mar	15-May	46	
Arkansas				Did not have a statewide stay-at-home order, but some business restrictions lifted starting May 6
California	19-Mar	12-May	54	Starting May 12, restaurants and shopping centers can open in counties that meet certain criteria
Colorado	26-Mar	26-Apr	31	
Connecticut	23-Mar	20-May	58	
DC	1-Apr	8-Jun	68	
Delaware	24-Mar	31-May	68	
Florida	3-Apr	4-May	31	
Georgia	3-Apr	30-Apr	27	
Hawaii	25-Mar	7-May	43	Order set to expire May 31 but reopening started May 7
Idaho	25-Mar	30-Apr	36	
Illinois	21-Mar	31-May	71	
Indiana	25-Mar	4-May	40	
Iowa				Did not have a statewide stay-at-home order, but loosened restrictions in most counties starting May 1
Kansas	30-Mar	3-May	34	
Kentucky	26-Mar	20-May	55	
Louisiana	22-Mar	15-May	54	
Maine	2-Apr	11-May	39	Stores (May 11) and restaurants (May 18) will be allowed to reopen in certain rural counties
Maryland	30-Mar	15-May	46	
Massachusetts	24-Mar	18-May	55	
Michigan	24-Mar	28-May	65	
Minnesota	27-Mar	17-May	51	
Mississippi	3-Apr	27-Apr	24	
Missouri	6-Apr	3-May	27	
Montana	26-Mar	26-Apr	31	
Nebraska				Did not have a statewide stay-at-home order, but some business restrictions lifted starting May 4
Nevada	1-Apr	9-May	38	
New Hampshire	27-Mar	11-May	45	Order set to expire May 31 but reopening started May 11
New Jersey	21-Mar	5-Jun	76	
New Mexico	24-Mar	16-May	53	Retailers, offices and houses of worship can open at limited capacities beginning May 16
New York	22-Mar	15-May	54	Limited reopening in five regions starting May 15
North Carolina	30-Mar	8-May	39	Order set to expire May 31 but reopening started May 8
North Dakota				Did not have a statewide stay-at-home order, but some business restrictions lifted starting May 1
Ohio	23-Mar	15-May	53	Order set to expire May 29 but reopening started May 15

Oklahoma					Did not have a statewide stay-at-home order, but some business restrictions lifted starting April 24
Oregon	23-Mar	15-May		53	Retail stores statewide to reopen on May 15
Pennsylvania	1-Apr	8-May		37	Counties to open in phases
Rhode Island	28-Mar	8-May		41	
South Carolina	7-Apr	4-May		27	The reopening began with retail stores around April 20
South Dakota					Did not have a statewide stay-at-home order, but state announced a "Back to Normal" plan on April 28
Tennessee	1-Apr	30-Apr		29	
Texas	2-Apr	30-Apr		28	
Utah					Did not have a statewide stay-at-home order, but some business restrictions lifted starting May 1
Vermont	24-Mar	15-May		52	
Virginia	30-Mar	15-May		46	First phase of reopening starting May 15
Washington	25-Mar	11-May		47	Small counties were approved for partial reopenings
West Virginia	23-Mar	3-May		41	
Wisconsin	24-Mar	13-May		50	
Wyoming					Did not have a statewide stay-at-home order, but some business restrictions lifted starting May 1

Appendix Table C2. Percentage Reduction of Output by Sector under Mandatory Closure (with Telecommuting)

#	Sector	Mandatory Closure Category[a]	% Reduction in U.S. annual GDP by sector due to mandatory closures after factoring in telework		Notes
			Scenarios 1a and 1c	Scenario 2c	
1	Rice	3	0.0%	0.0%	
2	Wheat	3	0.0%	0.0%	
3	Other Grains	3	0.0%	0.0%	
4	Veg & Fruit	3	0.0%	0.0%	
5	Oil Seeds	3	0.0%	0.0%	
6	Cane & Beet	3	0.0%	0.0%	
7	Fibers crops	3	0.0%	0.0%	
8	Other Crops	3	0.0%	0.0%	
9	Cattle	3	0.0%	0.0%	
10	Other Animal Products	3	0.0%	0.0%	
11	Raw milk	3	0.0%	0.0%	
12	Wool	3	0.0%	0.0%	
13	Forestry	3	0.0%	0.0%	
14	Fishing, hunting, trapping, etc.	3	0.0%	0.0%	
15	Coal: mining	3	0.0%	0.0%	
16	Oil: extraction of crude petroleum	3	0.0%	0.0%	

17	Gas: extraction of natural gas	3	0.0%	0.0%	
18	Other Mining Extraction	3	0.0%	0.0%	
19	Cattle Meat	3	0.0%	0.0%	
20	Other Meat	3	0.0%	0.0%	
21	Vegetable Oils	3	0.0%	0.0%	
22	Milk: dairy products	3	0.0%	0.0%	
23	Processed Rice: semi- or wholly milled	3	0.0%	0.0%	
24	Sugar and molasses	3	0.0%	0.0%	
25	Other Food	3	0.0%	0.0%	
26	Beverages and Tobacco products	2	2.9%	11.4%	Closure: Tobacco products
27	Manufacture of textiles	1	10.4%	48.5%	
28	Manufacture of wearing apparel	1	13.2%	48.1%	
29	Manufacture of leather and related prdcts	1	13.2%	46.3%	
30	Lumber	3	0.0%	0.0%	
31	Paper and Paper Products	3	0.0%	0.0%	
32	Petroleum and Coke Products	3	0.0%	0.0%	
33	Manufacture of chemicals and products	3	0.0%	0.0%	
34	Manufacture of pharmaceuticals, medicinal chemical and botanical products	3	0.0%	0.0%	
35	Manufacture of rubber and plastic prdcts	1	11.3%	47.3%	
36	Manufacture of other non-metallic mineral products	1	11.9%	46.5%	
37	Iron & Steel: basic production and casting	3	0.0%	0.0%	
38	Non-Ferrous Metals: production and casting of copper, aluminum, zinc, lead, gold, and silver	3	0.0%	0.0%	
39	Manufacture of fabricated metal products, except machinery and equipment	3	0.0%	0.0%	
40	Manufacture of computer, electronic and optical products	1	12.8%	45.3%	
41	Manufacture of electrical equipment	3	0.0%	0.0%	
42	Manufacture of machinery and equipment n.e.c.	3	0.0%	0.0%	
43	Manufacture of motor vehicles, trailers and semi-trailers	3	0.0%	0.0%	
44	Manufacture of other transport equipment	3	0.0%	0.0%	
45	Other Manufacturing: includes furniture	1	12.4%	48.3%	
46	Electricity; steam and air conditioning	3	0.0%	0.0%	
47	Gas manufacture, distribution	3	0.0%	0.0%	
48	Water supply; sewerage, waste management and remediation activities	3	0.0%	0.0%	
49	Construction	2	8.9%	36.3%	Closure: all construction except for emergency repair or maintenance
50	Wholesale and retail trade; repair of motor vehicles and motorcycles	2	5.1%	20.2%	Closure: Retail except for Grocery Stores, Special Food Stores, Gas Stations, etc.
51	Accommodation, Food and service activities	2	9.0%	35.4%	Open: Accommodation; Closure: Food services except for take out

52	Land transport and transport via pipelines	2	1.9%	1.9%	Transportation sectors are essential sectors. However, there have been service reductions / route eliminations that were caused by a combination of reduced economic activities because of the shutdowns, drop in demand, a reduced number of transit workers available to work, and the need to implement safety precautions. Based on data from various sources, we estimated that the Air Transportation, Rail Transportation, Water Transportation, and Transit Transportation experienced reduction in service by 66%, 47.5%, 50%, and 50%, respectively during the mandatory closure period.
53	Water transport	2	4.5%	4.5%	
54	Air transport	2	8.0%	8.0%	
55	Warehousing and support activities	3	0.0%	0.0%	
56	Information and communication	2	0.6%	2.4%	Closure: Motion Picture and Video Industries, Sound Recording Industries, etc.
57	Other Financial Intermediation: auxiliary activities but not insurance and pensions	2	1.5%	5.7%	Closure: Securities, Commodity Contracts, and Other Financial Investments and Related
58	Insurance	3	0.0%	0.0%	
59	Real estate activities	1	6.0%	23.1%	
60	Other Business Services nec	2	4.7%	18.0%	Closure: All except for Scientific Research & Development Services, Waste Management, and some Administration & Support Services
61	Recreation & Other Services	1	11.6%	44.6%	
62	Other Services (Government)	2	4.3%	17.9%	Closure: All except for emergency services
63	Education	1	9.7%	36.3%	
64	Human health and social work	3	0.0%	0.0%	Mostly open; exception: Civic and Social Organizations
65	Dwellings: imputed rents of owner-occupied dwellings	3	0.0%	0.0%	

Mandatory Closure Categories:

1. Sector is entirely non-essential and thus is completely shut down

2. Sector for which only some subsectors are non-essential (see notes in the last column)

3. Sector that is essential and thus still able to operate in its usual manner to the extent possible Telecommuting adjustment is based on data presented in Table A2).

Appendix Table C3. Percent of Workers Who Could Work at Home and Who Did Work at Home in 2017-2018

Industry	% of workers who could work at home	% of workers who did work at home at least occasionally	average
Agriculture, forestry, fishing, and hunting	11.1	10.4	10.75
Mining, quarrying, and oil and gas extraction	*estimate is suppressed*	*estimate is suppressed*	
Construction	17.2	14.4	15.8
Manufacturing	30.3	25.7	28
Wholesale and retail trade	16.5	13.9	15.2
Transportation and utilities	14	12.5	13.25

Information	53.3	45.1	49.2
Financial activities	57.4	46.7	52.05
Professional and business services	53.4	47.4	50.4
Education and health services	25.9	23.7	24.8
Leisure and hospitality	8.8	6.8	7.8
Other services	27.7	22.6	25.15
Public administration	29.8	21.8	25.8
Federal government	31.4	24.5	27.95

Source: Adapted from BLS (2019).

The detailed reopening stages and timelines of five major states (California, Texas, New York, Illinois, and Florida) according to the reopening plans released by these states by the end of May are summarized in Appendix Table C4.

Appendix Table C5 presents the percentage reduction in U.S. annual GDP by sector due to the phased-in reopening process for each of the three scenarios.

Appendix Table C4. Reopening Plans in Five Major States

State	Reopening Stages	Timeline	Regional scope
California	Stage 1: Government and private organizations are working to make it more consistently safe for essential workers, like grocery store employees or nurses. Stage 2 (May 8): Some lower-risk businesses and public spaces can reopen, also with modifications to allow for distancing. Includes retail (curbside and delivery only), related logistics and manufacturing, office workplaces, limited personal services, outdoor museums, child care, and essential businesses can open with modifications. Stage 3: Higher-risk businesses will be able to reopen with modifications. Includes nail and hair salons, gyms, movie theaters and sports without live audiences, as well as in-person religious services. Stage 4: The end of the state's stay-at-home order. That will be when concerts, conventions and sports with a live crowd will be allowed to reopen.	California entered Stage 2 on Friday, May 8. Schools and dine-in restaurants with modifications, will be part of a later Stage 2 statewide opening. The third phase may come in June over the next few weeks, but these businesses will not reopen all at the same time. Rather, the state plans to **slowly roll out openings and ease restriction**s in the coming weeks. Stage 4 will be allowed only once treatments or a vaccine have been developed.	Counties that want to reopen their economies faster can apply for a variance from state orders, provided that they meet public health guidelines. The governor estimates that all but five of California's 58 counties would qualify for a variance, but the list is unlikely to include populous counties such as LA.
Texas	Phase I (May 1): All retail stores, restaurants, movie theaters, and malls are permitted to reopen. These services must limit their capacity to 25% of their listed occupancy. Phase II (May 18 - 31): Restaurants may increase occupancy to 50%, businesses located in office buildings may also open but must limit their occupancy, and childcare centers may open. Other phases not announced	Reopening will be staggered from May 18 -31 depending on business activity. Unclear what the other phase are and when they may be announced, but Texas has been on aggressive reopening timeline.	Certain counties experiencing surges in COVID-19 cases will have their beginning date of Phase II delayed until May 29.
New York	Phase I (Entire state except for Long Island, New York City, and mid-Hudson region): Agriculture, Forestry, Fishing and Hunting, Retail (curbside or in-store pickup), Manufacturing, Wholesale Trade Phase II: Professional Services, Retail, Administrative Support, Real Estate / Rental & Leasing Phase III: Restaurants / Food Services	Eligibility for reopening will be determined by health metrics for each region. It is unclear when regions may move to Phase Two.	Eligibility is determined by region.

State	Reopening Stages	Timeline	Regional scope
	Phase IV: Arts / Entertainment / Recreation, Education		
Illinois	Phase 1: Rapid Spread, only essential businesses remain open Phase 2 (May 6): Flattening, Non-essential retail stores reopen for curb-side pickup and delivery Phase 3: Manufacturing, offices, retail, barbershops, and salons can reopen to the public with capacity and other limits and safety precautions Phase 4: Revitalization, Gatherings of 50 people or fewer are allowed, restaurants and bars reopen, travel resumes, child care and schools reopen Phase 5: Restored, the economy fully reopens with safety precautions continuing.	Phase 3 may come on May 29. Moving to phase 3 requires the rate of infection among those surveillance tested, the number of patients admitted to the hospital, and the number of patients needing ICU beds to stabilize or decline. Moving to phase 4 requires the rate of infection among those surveillance tested and the number of patients admitted to the hospital to continue to decline	A region can move both forward and backward, where more parts of society can open and shut depending on the seriousness of the outbreak.
Florida	Phase 1 (May 4): Restaurants and retail establishments can operate at 50 percent capacity, employers should plans for employees to return to work in phases Phase 2: Bars, pubs, and nightclubs can operate at 50 percent of building capacity, restaurants and retail establishments at 75 percent capacity, and large spectator sporting events should limit occupancy of venues to 50 percent of building capacity. Phase 3: Employees can resume unrestricted staffing of worksites, bars, restaurants, and retailers can operate at full capacity but are encouraged to practice social distancing.	Phase 2 may come as early as Friday, May 22. The official criteria are that the state should begin downward trajectory of the syndromic and epidemiology criteria while maintaining adequate health care capacity. This will occur when there is no evidence of a rebound or resurgence of COVID-19 cases.	

Appendix Table C5. Percentage Reduction of Output by Sector Due to Phased-in Reopening (with Telecommuting)

#	Sector	Mandatory Closure Category[a]	% Reduction in U.S. annual GDP by sector due to phased-in reopening after factoring in telework		
			Scenarios 1a	Scenario 1c	Scenario 2c
1	Rice	3	0.0%	0.0%	0.0%
2	Wheat	3	0.0%	0.0%	0.0%
3	Other Grains	3	0.0%	0.0%	0.0%
4	Veg & Fruit	3	0.0%	0.0%	0.0%
5	Oil Seeds	3	0.0%	0.0%	0.0%
6	Cane & Beet	3	0.0%	0.0%	0.0%
7	Fibers crops	3	0.0%	0.0%	0.0%
8	Other Crops	3	0.0%	0.0%	0.0%
9	Cattle	3	0.0%	0.0%	0.0%
10	Other Animal Products	3	0.0%	0.0%	0.0%
11	Raw milk	3	0.0%	0.0%	0.0%
12	Wool	3	0.0%	0.0%	0.0%

13	Forestry	3	0.0%	0.0%	0.0%
14	Fishing: hunting, trapping and game propagation	3	0.0%	0.0%	0.0%
15	Coal: mining	3	0.0%	0.0%	0.0%
16	Oil: extraction of crude petroleum	3	0.0%	0.0%	0.0%
17	Gas: extraction of natural gas	3	0.0%	0.0%	0.0%
18	Other Mining Extraction	3	0.0%	0.0%	0.0%
19	Cattle Meat	3	0.0%	0.0%	0.0%
20	Other Meat	3	0.0%	0.0%	0.0%
21	Vegetable Oils	3	0.0%	0.0%	0.0%
22	Milk: dairy products	3	0.0%	0.0%	0.0%
23	Processed Rice: semi- or wholly milled, or husked	3	0.0%	0.0%	0.0%
24	Sugar and molasses	3	0.0%	0.0%	0.0%
25	Other Food	3	0.0%	0.0%	0.0%
26	Beverages and Tobacco products	2	1.4%	5.8%	3.1%
27	Manufacture of textiles	1	6.1%	24.3%	12.5%
28	Manufacture of wearing apparel	1	6.0%	24.2%	12.5%
29	Manufacture of leather and related products	1	5.8%	23.4%	12.5%
30	Lumber	3	0.0%	0.0%	0.0%
31	Paper and Paper Products	3	0.0%	0.0%	0.0%
32	Petroleum and Coke Products	3	0.0%	0.0%	0.0%
33	Manufacture of chemicals and chemical products	3	0.0%	0.0%	0.0%
34	Manufacture of pharmaceuticals, medicinal chemical and botanical products	3	0.0%	0.0%	0.0%
35	Manufacture of rubber and plastics products	1	6.0%	23.9%	12.5%
36	Manufacture of other non-metallic mineral products	1	5.9%	23.7%	12.5%
37	Iron & Steel: basic production and casting	3	0.0%	0.0%	0.0%
38	Non-Ferrous Metals: production and casting of copper, aluminum, zinc, lead, gold, and silver	3	0.0%	0.0%	0.0%
39	Manufacture of fabricated metal products, except machinery and equipment	3	0.0%	0.0%	0.0%
40	Manufacture of computer, electronic and optical products	1	5.8%	23.0%	12.5%
41	Manufacture of electrical equipment	3	0.0%	0.0%	0.0%
42	Manufacture of machinery and equipment n.e.c.	3	0.0%	0.0%	0.0%
43	Manufacture of motor vehicles, trailers and semi-trailers	3	0.0%	0.0%	0.0%
44	Manufacture of other transport equipment	3	0.0%	0.0%	0.0%
45	Other Manufacturing: includes furniture	1	6.1%	24.3%	12.5%
46	Electricity; steam and air conditioning supply	3	0.0%	0.0%	0.0%
47	Gas manufacture, distribution	3	0.0%	0.0%	0.0%
48	Water supply; sewerage, waste management and remediation activities	3	0.0%	0.0%	0.0%
49	Construction	2	4.6%	18.3%	9.4%

50	Wholesale and retail trade; repair of motor vehicles and motorcycles	2	2.5%	10.2%	5.3%
51	Accommodation, Food and service activities	2	5.9%	23.8%	12.5%
52	Land transport and transport via pipelines	2	1.2%	5.0%	2.6%
53	Water transport	2	3.1%	12.3%	6.3%
54	Air transport	2	5.1%	20.5%	11.0%
55	Warehousing and support activities	3	0.0%	0.0%	0.0%
56	Information and communication	2	0.6%	2.5%	1.3%
57	Other Financial Intermediation: includes auxiliary activities but not insurance and pension funding	2	1.4%	5.8%	3.0%
58	Insurance	3	0.0%	0.0%	0.0%
59	Real estate activities	1	6.8%	27.1%	14.0%
60	Other Business Services nec	2	5.3%	21.1%	10.9%
61	Recreation & Other Services	1	18.7%	74.8%	38.4%
62	Other Services (Government)	2	2.6%	10.5%	5.4%
63	Education	1	15.3%	61.0%	31.3%
64	Human health and social work	3	0.0%	0.0%	0.0%
65	Dwellings: imputed rents of owner-occupied dwellings	3	0.0%	0.0%	0.0%

Appendix D. Summary of Survey Data on Avoidance Behavior

This Appendix summarizes findings from public opinion surveys around avoidance behavior in response to COVID-19 pandemic. The first section summarizes avoidance behavior trends before states implemented shutdown orders. The second section focuses on people's willingness to resume activities after their state lifts shutdown orders, or when they believe it would be safe to resume certain activities. In the third section, we present the assumptions we will use in the economic impact analysis regarding each type of avoidance behaviors. These assumptions are based on a synthesis of the literature that is summarized in detail in the first two sections.

1. Avoidance Behavior at the Beginning of the Shutdown Orders

We reviewed 11 most recent public opinion polls that asked U.S. adults questions related to avoidance behavior resulting from the coronavirus. All polls surveyed respondents before the announcement of shelter-in-place rules in California and New York and the results therefore mostly represent voluntary avoidance efforts. Below, we synthesize the adoption of avoidance behavior by either using the most up-to-date estimate or by taking an average of up to three of the most recent surveys conducted before shutdown orders when multiple polls asked questions in comparable ways (see Appendix Table D1 for a full summary of the studies reviewed).

29% of respondents were working from home because of the virus (ABC News/Ipsos Poll, March 20)
11% have kept children home from school (The Associated Press, March 19; Reuters/Ipsos, March 17)
6% have canceled or postponed a medical appointment (USC, March 13)
23% said they had more frequently used e-commerce to purchase products (Ipsos, March 2020)
53% have canceled plans to attend events with large crowds (ABC News/Ipsos Poll, March 20; Gallup, March 20; NPR/PBS NewsHour/Marist Poll, March 17)
55.5% have canceled or avoided going to restaurants (ABC News/Ipsos Poll, March 20; Gallup, March 20)
37.5% have canceled or postponed travel plans (Gallup, March 20; NPR/PBS NewsHour/Marist Poll, March 17; Reuters/Ipsos, March 17)
47.5% are avoiding large gatherings of people (Axios/Ipsos Poll, March 17; Kaiser, March 17; Reuters/Ipsos, March 17)

The proportion of respondents indicating they are practicing a type of avoidance behavior has generally increased over time, as the number of cases in the United States has grown.

2. Avoidance Behavior After Restriction Orders Are Lifted

We reviewed the results of 9 most recent public opinion polls that asked people's willingness to resume activities after their state lifts shutdown orders. People's indications on when they believe it would be safe to resume certain activities are also reviewed. The results are summarized in Appendix Table D2.

Appendix Table D1. Summary of U.S. Public Opinion Polls on Avoidance Behaviors Before COVID-19 Shutdowns

Avoidance Responses	Percent Who Avoid	Data Source
Staying Home from Work	Working from home: • 29% of those employed were working from home because of the virus (3/18-3/19) • 16% of those employed said they are working from home every day and an additional 10% said they are working some days from home because of the virus (3/18-3/19) • 16% said they have worked from home at least once because of the virus (3/16-3/17) • 21% of those employed had been told to work remotely or from home (3/13-3/16) • 26% stayed home instead of going to work or other regular activities (3/11-3/15)	ABC News/Ipsos Poll (Mar 20) SurveyUSA (Mar 19) Reuters/Ipsos (Mar 17) Axios/Ipsos Poll (Mar 17) Kaiser (Mar 17)
Keeping Children from School	Kept children home from school: • 11% (3/16-3/17) • 11% (3/12-3/16) 38% said their child's daycare, K-12 school, or college has closed or stopped in-person classes (3/11-3/13)	Reuters/Ipsos (Mar 17) The Associated Press (Mar 19) NBC News/Wall Street Journal (March)
Avoiding Medical Professionals	6% have canceled or postponed a medical appointment (3/10-3/12)	USC (Mar 13)
Reducing Shopping	11% attempted to visit a store or business that is closed due to the virus (3/13-3/16) 23% said they had more frequently used e-commerce to purchase products they would normally buy in-store (3/12-3/14)	Axios/Ipsos Poll (Mar 17) Ipsos (March)
Avoiding Local Leisure Activities	Events with large crowds: • 32% have canceled or postponed plans to attend a sporting event or concert (3/18-3/19) • 79% avoided going to events with large crowds (3/16-3/19) • 48% cancelled plans to avoid crowds (3/13-3/14) • 68% said there were staying away from large groups (3/12-3/16) Dining out: • 57% cancelled or postponed plans to go to dinner (3/18-3/19) • 54% avoided going to public places, such as stores or restaurants (3/16-3/19) • 46% decided to eat at home more often? (3/13-3/14) • 13% stopped eating out at restaurants (3/11-3/13) • 25% avoided restaurants (3/10-3/12)	ABC News/Ipsos Poll (Mar 20) Gallup (Mar 20) NPR/PBS NewsHour/Marist Poll (Mar 17) The Associated Press (Mar 19) ABC News/Ipsos Poll (Mar 20) Gallup (Mar 20) NPR/PBS NewsHour/Marist Poll (Mar 17) NBC News/Wall Street Journal (March) USC (Mar 13)
Avoiding Public Transportation	24% are avoiding public transportation (3/16-3/17)	Reuters/Ipsos (Mar 17)

Avoidance Responses	Percent Who Avoid	Data Source
Canceling Travel Plans	Canceled/changed/postponed travel plans:	
	• 57% (3/16-3/19)	Gallup (Mar 20)
	• 25% (3/16-3/17)	Reuters/Ipsos (Mar 17)
	• 30% (3/13-3/14)	NPR/PBS NewsHour/Marist Poll (Mar 17)
	• 42% (3/11-3/15)	Kaiser (Mar 17)
	• 19% (3/11-3/13)	NBC News/Wall Street Journal (March)
	Canceled/changed/postponed business trips:	
	• 13% (3/18-3/19)	ABC News/Ipsos Poll (Mar 20)
	• 20% of those employed (3/18-3/19)	SurveyUSA (Mar 19)
	International/Domestic:	
	• 5% have canceled international trips over the next three months (3/12-3/16)	The Associated Press (Mar 19)
	• 9% have canceled domestic trips over the next three months (3/12-3/16)	The Associated Press (Mar 19)
	75% avoided traveling by airplane, bus, subway or train (3/16-3/19)	Gallup (Mar 20)
General Avoidance Behavior	Large gatherings:	
	• 56% avoiding large gatherings of people whenever possible (3/16-3/17)	Reuters/Ipsos (Mar 17)
	• 46% canceled or skipped attending large gatherings over the last week (3/13-3/16)	Axios/Ipsos Poll (Mar 17)
	• 40% canceled plans to attend large gatherings (3/11-3/15)	Kaiser (Mar 17)
	• 25% stopped attending large public gatherings (3/11-3/13)	NBC News/Wall Street Journal (March)

Appendix Table D2. Summary of U.S. Public Opinion Polls on Avoidance Behaviors after COVID-19 Restrictions Are Lifted

Avoidance Responses	Percent Who Avoid	Data Source
Staying Home from Work	Working from home: • 35% of those in the workforce are still working from home (5/6-7) • 46% of those still employed are working from home (5/1-4) Returning to work: • 13% said they are "not likely at all" to return to work if restrictions were lifted, and an additional 9% said they are "not so likely" to do so (4/29-30)	ABC News/Ipsos Poll (May 8) Axios/Ipsos Poll (May 5) ABC News/Ipsos Poll (May 1)
Keeping Children from School	Kept children home from school: • 37% of parents said they definitely would not send their children to school if restrictions were lifted, another 26% said they probably wouldn't do it (4/30-5/6) • 36% said they are "not likely at all" to send their children to school if restrictions were lifted, and an additional 19% said they are "not so likely" to do so (4/29-30) • 16% believe it will be safe to reopen schools in several weeks, 42% believe it will be safe in several months, 22% believe it will be safe in six months or more (4/23-29)	Voter Study Group (May 13) ABC News/Ipsos Poll (May 1) Morin (May 8)
Reducing Shopping	34% of respondents said they definitely would not go to a shopping mall if restrictions were lifted, another 27% said they probably wouldn't go (4/30-5/6)	Voter Study Group (May 13)
Avoiding Local Leisure Activities	Events with large crowds: • 57% said they are "not likely at all" to attend a large sports event if restrictions were lifted, and an additional 21% said they are "not so likely" to do so (4/29-30) • 21% believe it will be safe to attend large events in several weeks, 36% believe it will take several months and 23% believe it will be safe in six or more months (4/23-29) • 26% said they would only attend a professional sports event when there is a proven coronavirus vaccine, even if that's a year or more from now (4/15-21) Dining out: • 27% of respondents said they definitely would not eat at a restaurant if restrictions were lifted, another 29% said they probably wouldn't eat out (4/30-5/6) • 27% said they are "not likely at all" to eat at a restaurant if restrictions were lifted, and an additional 28% said they are "not so likely" to do so (4/29-30) • 26% believe it will be safe for theaters, restaurants, and bars to open in several weeks, 35% believe it will be safe in several months, and 17% believe it will be safe in six or more months (4/23-29)	ABC News/Ipsos Poll (May 1) Morin (May 8) Reuters/Ipsos Poll (Apr 29) Voter Study Group (May 13) ABC News/Ipsos Poll (May 1) Morin (May 8)
Avoiding Public Transportation	• 44% of respondents said they definitely would not take public transit if restrictions were lifted, another 28% said they probably wouldn't do it (4/30-5/6)	Voter Study Group (May 13)

Avoidance Responses	Percent Who Avoid	Data Source
	• 67% said traveling on airplane or mass transit was a large risk, and another 23% said it was a moderate risk (5/1-4)	Axios/Ipsos Poll (May 5)
Canceling Travel Plans	Airplane trips: • 41% of respondents said they definitely would not fly if restrictions were lifted, another 27% said they probably wouldn't do it (4/30-5/6) • 44% said they are "not likely at all" to fly if restrictions were lifted, and an additional 25% said they are "not so likely" to do so (4/29-30)	Voter Study Group (May 13) ABC News/Ipsos Poll (May 1)
General Avoidance Behavior	• 35% say it won't be safe to lift stay-at-home orders for several weeks, 30% say it would take several months, and 12% say six or more months (4/23-29) • Thirty-five percent believe it won't be safe to lift those orders for several weeks, 30% believe it won't be safe for several months, and 12% believe it won't be safe to lift until six or more months. • 29% say that it will be safe to end social distancing measures and reopen businesses as normal in several months, 15% say it would take a year or longer (5/3-5) • 41% of respondents said they would not go back to their normal routine even if their state relaxed stay-at-home orders (4/23-28) • 51% say they could only follow social distancing or shelter at home orders for another three months or less, 43% say they could do it for four months or longer (4/15-20)	Morin (May 8) Morin (May 8) The Economist/YouGov (May) Marketplace-Edison (May 5) Kaiser (April)

In our scenario analysis, three levels (low, moderate, high) of avoidance behavior are simulated with respect to the magnitude and length of such behaviors. Appendix Table D3 summarize the parameters we estimated based on the various public opinion polls reviewed above. We adopted the following methods to translate the survey results in each study to low, moderate, and high estimates.

ABC News/Ipsos Poll (May 1): Use the % of "not likely at all" as the low estimate; use sum of "not likely at all" and "not so likely" as the high estimate; use the average of the low and high estimates as the moderate estimate.

Morin (May 8): Use the % of respondents that indicate the most conservative and prudent behavior in terms of the length of avoidance they will take as the low estimate; add the next group of respondents with shorter stated avoidance duration as the moderate estimate; the high estimate is the sum of all respondents that indicated some length of intended avoidance.

Voter Study Group (May 13): Low: definitely wouldn't do activity if restrictions lifted; High: definitely wouldn't + probably wouldn't. Excludes people who said "I would not have done this before coronavirus" from the denominator. Moderate: average of Low and High.

Reuters/Ipsos Poll (April 29): Use the response to survey questions such as "Please indicate how much you agree or disagree with the following statements: Professional sports (NFL, MLB, NBA, etc.) should hold competitions again with live audiences before a vaccine is available". Use % that responded "Strongly Disagree" as the low estimate; use "Strongly Disagree" + "Somewhat Disagree" as the high estimate; use the average of low and high as moderate.

Appendix Table D3. Magnitude and Duration of Avoidance Behaviors in Response to Coronavirus Pandemic

Avoidance Responses	Percent Who Avoid			Duration of Avoidance			Source
	Low	Moderate	High	Low	Moderate	High	Data Source
Staying Home from work	13%	17.5%	22%				ABC News/Ipsos Poll (May 1)
Keeping children from school	36%	45.5%	55%				ABC News/Ipsos Poll (May 1)
	22%	64%	80%	several weeks	several months	six months or more	Morin (May 8)
	37%	50%	63%				Voter Study Group (May 13)
Reducing shopping	Go to the mall: 34%	47.5%	61%				Voter Study Group (May 13)
Avoiding Local Leisure Activities	57%	67.5%	78%				ABC News/Ipsos Poll (May 1)
	23%	59%	80%	several weeks	several months	six months or more	Morin (May 8)
	Sports: 36% Concerts: 32% Amusement parks: 38%	47% 44% 48.5%	58% 56% 59%			a year or more	Reuters/Ipsos Poll (April 29)

Avoidance Responses	Percent Who Avoid			Duration of Avoidance			Source
Avoiding Dining Out	27%	41%	55%				ABC News/Ipsos Poll (May 1)
	27%	41.5%	56%				Voter Study Group (May 13)
Avoiding public transportation	44%	58%	72%				Voter Study Group (May 13)
Cancelling Travel Plans	Airplane trips: 44%	56.5%	69%				ABC News/Ipsos Poll (May 1)
	Airplane trips: 41%	54.5%	68%				Voter Study Group (May 13)
General avoidance behavior	Stay-at-home orders: 12%	42%	77%	several weeks	several months	six months or more	Morin (May 8) The Economist /YouGov (May)

Appendix E. Estimated Impact on Revenue of Communication Sectors

517311   Wired Telecommunications Carriers

Estimate of instantaneous impact on revenue: 0% - 0.5% change due to COVID-19

Broadband internet providers like Charter and Comcast saw year-over-year increases of approximately 9.5% in internet revenues in the first quarter of 2020, but Comcast had experienced similarly high growth the previous quarter, and Charter had actually seen an 11.5% growth in revenue. Therefore, the increase in revenue cannot be attributed to COVID-19. OpenVault, a data analytics and broadband solutions company, notes that some users have upgraded to higher speed plans since the lockdowns, but that increase is unlikely to amount to a large revenue increase.

517312   Wireless Telecommunications Carriers (except Satellite)

Estimate of instantaneous impact on revenue: -0.25% - 0.25% change due to COVID-19

Carriers like AT&T and Verizon saw year-over-year increases in service revenue of 2 to 2.5% in the first quarter, but those increases were offset by lower equipment sales. Wireless revenues were flat year-over-year. AT&T noted that across all its divisions, COVID-19 led to approximately $600M in losses (1.4% of quarterly revenues), mostly from lower advertising and wireless equipment sales.

518   Data Processing, Hosting, and Related Services

Estimate of instantaneous impact on revenue: 0% - 2% increase

The cloud service divisions of Amazon, Google, and Microsoft experienced rapid year-over-year growth in the first quarter of 2020, but that growth was similar or slightly lower than what they had reported the previous quarter. In the earnings call, executives from Google suggested that growth has kept pace, even during March as lockdown orders were implemented. Synergy Research Group predicts that COVID-19 is having a "mildly positive impact" on the cloud services market.

51913   Internet Publishing and Broadcasting and Web Search Portals

Estimate of instantaneous impact on revenue: -30% to -10%

Companies such as Google and Facebook experienced significantly lower year-over-year revenue growth compared to previous quarters. Executives in both companies said they saw abrupt declines in advertisement revenue in March. Those declines resulted in year-over-year revenue growth of 17.6% for Facebook (relative to 25% last quarter), and 8.7% for Google (relative to 16.6%). Assuming revenue growth would have followed a trajectory similar to the previous quarter absent COVID-19 and that the abrupt drop started around March 7, the immediate impact of COVID-19 was a 27% drop in Google Search advertisement and a 24% drop in Facebook advertisement. Netflix, which one was expected to benefit from the closure of cinemas and the lack of entertainment options, also saw year-over-year revenue growth in the U.S. and Canada (19.8%) lower than in the previous quarter (23.6%). The slowdown would imply that COVID-19 had an instantaneous impact of 12% in revenues.

Appendix F. Data on Pent-Up Demand

Appendix Table F1 presents the estimates of pent-up consumer demand resulting from the COVID-19 related lockdowns across a range of key sectors, goods, and services in the U.S. The estimates provided were calculated using micro-level data from three distinct online sources: Opportunity Insights, Unacast, and SafeGraph.

Based at Harvard University, Opportunity Insights is a consortium of researchers, policy analysts, and outside collaborators working together to analyze new data and create a platform for local stakeholders to make more informed decisions. The consumption data gathered from this source was aggregated via Opportunity Insight's COVID-19 economic tracker and corresponding research paper. The economic tracker is a publicly available platform that tracks economic activity at a granular level in real-time using anonymized data from private companies to construct indices of spending, employment, and other metrics. Consumer spending is measured using purchase data collected by Affinity Solutions Inc., a company that aggregates consumer card-spending information. The pent-up demand estimates using this data were calculated by measuring the percentage-point increase in card-spending on a particular good/service from either the lowest point in the time-series or the point corresponding to May 1 up until June 18, as a percentage of the total decline in card-spending at the Lowest or May 1 point. For example, the largest dip in restaurant dining as measured by card spending occurred around the end of March and was a decline of 60% from January 2020 levels, and as of June 18, the decline was around 35% from January 2020 levels. This represents a 25 percentage-point increase from that farthest decline, or indicates an approximately 42% gain as a percentage of that 60% decline. The way this can be interpreted is that 42% of the decline in restaurant spending precipitated by the lockdown restrictions came back in the form of pent-up demand.

Unacast collects human mobility information from GPS and other map data sources to support business intelligence. Consumption data for the table is provided by Unacast's COVID-19 Retail Impact Scoreboard, which compares current foot traffic levels at retail locations across a variety of industries to foot traffic levels at the beginning of February 2020 (pre-COVID). The pent-up demand estimates using this data were calculated by measuring the percentage-point increase in foot traffic at retail locations in a particular industry/service group from either the lowest point in the time-series or the point corresponding to May 1 up until June 12, as a percentage of the total decline in foot traffic at the lowest or May 1 point. For example, the largest dip in automobile purchases as measured by foot traffic at auto dealers occurred around mid-April and was a decline of about 70% compared to February 2020 levels,

and as of June 12, the decline was around 15% from February 2020 levels. This represents a 55 percentage-point increase from the farthest decline, or indicates an approximately 79% gain as a percentage of that 70% decline. The way this can be interpreted is that 79% of the decline in automobile spending precipitated by the lockdown restrictions came back in the form of pent-up demand.

SafeGraph's points-of-interest and foot traffic data is used by businesses for a variety of use cases. The consumption data used for the pent-up demand table is sourced from COVID-specific foot traffic data intended to give insight into how the US is opening up following the end of lockdowns. The dashboard is built from SafeGraph Places Patterns data, an aggregated, anonymized summary of foot traffic to 6 million points-of-interest in North America with data on over 5,500 retail chains and 3-million mom-and-pop businesses. The pent-up demand estimates using this data were calculated similarly to the estimates using the Unacast data, by measuring percentage-point increases in foot traffic at retail locations across a range of industries/services/goods from either the lowest point in the series or the May 1 point up until June 14, as a percentage of the total decline in foot traffic at the lowest or May 1 point. The baseline used is January 2020 foot-traffic levels. As an example, the largest drop in air travel as measured by foot traffic at airports occurred around mid-April and was an 87% drop compared to January 2020 levels, and as of June 14, the decline was around 72% from January 2020 levels. This represents a 15 percentage-point increase from the farthest decline, or indicates an approximately 17% gain as a percentage of that 87% decline. The way this can be interpreted is that 17% of the decline in air travel precipitated by the lockdown restrictions came back in the form of pent-up demand.

Appendix Table F1. Pent-up Demand in the U.S. by Major Consumption Category

Good/Service	Opportunity Insights (Private card spending, 6/18)	Unacast (Foot traffic, 6/12)	SafeGraph (Foot traffic, 6/14)	Notes
Automobiles	N/A	Lowest Point: 79% May 1: 71%	N/A	*Unacast estimates include Auto dealerships & car rentals*
Real Estate	N/A	N/A	N/A	
Air Travel	N/A	Lowest Point: 47% May 1: 38%	Lowest point: 17% May 1: 14%	*Unacast estimates include Travel & Hospitality*
Restaurant Dining	Lowest Point: 42% May 1: 32%	Lowest Point: 63% May 1: 40%	Lowest Point: 63% May 1: 38%	*Opportunity Insights estimates include Restaurant & Hotel*
Live Experience Events	Lowest Point: 27% May 1: 24%	Lowest Point: 50% May 1: 41%	N/A	*Opportunity Insights estimates include Arts, entertainment, and recreation; Unacast includes Entertainment & Hobby*
Apparel	Lowest Point: 75% May 1: 59%	Lowest Point: 44% May 1: 40%	N/A	*Opportunity Insights estimates include Apparel & General Merchandise*

General Merchandise	Lowest Point: 75% May 1: 59%	Lowest Point: 52% May 1: 22%	Lowest Point: 96% May 1: 88%	*Opportunity Insights estimates include Apparel & General Merchandise; Unacast: General Retail*
Hotels and other Hospitality	Lowest Point: 42% May 1: 32%	Lowest Point: 47% May 1: 38%	Lowest Point: 73% May 1: 68%	*Opportunity Insights estimates include Restaurant & Hotel; Unacast: Travel & Hospitality*
Wellness and Fitness	N/A	Lowest Point: 54% May 1: 33%	N/A	

Appendix G.

In this Appendix, we illustrate the difference between our static formulation and a dynamic one. We repeat our scenarios, though with more detail about the time-phasing. In the comparative static model, these timings cannot be captured, so we take the total changes due to the mandatory closures, avoidance etc., over our time horizon, approximately a year after the beginning of the pandemic. For instance, in the case of the mandatory closures we reduce production of the industry by the effective amount of time and the share of businesses that are impacted by the closures.

Shortly after the pandemic begins, non-essential businesses are closed and real GDP starts to decline. We track actual shutdowns up to May 25, 2020, so all three scenarios initially show the same rate of decline. After May 25, as economies begin to open-up, our three scenarios diverge.

In Scenario, 1, the mandatory closures have been successful at reducing the number of COVID-19 cases. As cases continue to decline the economy is free to open-up, workers laid off due to the closures are now able to return to work and real GDP rises back towards the baseline. Growth is then likely to reverts to baseline growth, although the level of GDP is likely to be lower.

In Scenario, 2, as the economy begins to open up after the first round of mandatory closures, cases of COVID-19 begin to rise and the re-opening process is slowed down considerably. The rate at which GDP increases slows considerably. Assumptions regarding the possibility of pent-up demand mean that real GDP may temporarily rise above Scenario 1a or even baseline, before settling at a lower level.

In Scenario 3, cases of COVID again rise and the economy is put in lockdown again, causing GDP to fall once again (double dip). Re-opening is gradual, as in Scenario 1c and again there is extensive pent up demand, which causes GDP to rise temporarily and then fall back to a lower equilibrium level.

Figure 1. Expected Time-Path of Impacts on GDP for COVID-19 Scenarios