Effects of Covid on the U.S. economy: update after 4 quarters of data

by

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Since April 2020 we have been applying a quarterly version of the USAGE model to generate forecasts for the U.S. economy for 2020 and 2021 focusing on the effects of COVID-19. USAGE is a detailed dynamic model of the U.S. economy. It generates results for macro, industry and regional variables. [1]

This note outlines the main finding from our third update on the effects of Covid-19. Detailed results for industries and regions are set out in the form of Power-point slides in Appendix A. An earlier paper with a more complete description of our methodology in includes as Appendix B.

1. Previous forecasts

The top half of Table 1 is reproduced from our second update report (December 12, 2020). In the bottom half, we have added recent forecasts by prominent macro forecasters.

Table 1. Forecasts for the U.S. and publication date (%, year-on-year)

Organization & publication	date	GDP		Employment	
		2020	2021	2020	2021
Centre of Policy Studies, working paper for DHS	Apr-20	-8.4	11.8	-8.4	11.1
World Bank, Global Economic Prospects	Jun-20	-6.1	4.0		
Deloitte, U.S. Economic forecast, baseline	Sep-20	-6.4	-1.7	-7.8	-1.4
OECD, Economic outlook, interim report	Sep-20	-3.8	4.0		
IMF, World economic outlook	Oct-20	-4.3	3.1	-6.9	2.7
Bloomberg consensus, Business Week	Oct-20	-3.9	3.8		
The Conference Board, Forecasts for the U.S	Nov-20	-3.6	3.4		
Goldman Sachs, Macro outlook for 2021	Nov-20	-3.5	5.3		
Centre of Policy Studies, second update report	Dec-20	-4.2	5.3	-6.1	4.6
Deloitte, U.S. Economic forecast, baseline	Dec-20	-3.6	2.0	-6.3	2.8
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[1] This material is part of the work required under Federal Award no. 17STQAC00001-04-01 (Amendment 03), Subaward no. ASUB00000508 issued by the U.S. Department of Homeland Security. The project is titled *Economic impacts of COVID-19 follow-on studies* and is being undertaken by the Centre of Policy Studies at Victoria University in Melbourne through the Center of Excellence for Accelerating Operational Efficiency (CAOE) at Arizona State University.

As explained in our December report, business investment in the first three quarters of 2020 was barely affected by COVID-19. This surprising resilience underpinned a much better economic performance in the first 3 quarters than had been anticipated early in 2020. In response, forecasters upgraded their projections for both 2020 and 2021. In the fourth quarter of 2020, the performance of the U.S. economy was consistent with the upgraded forecasts. Consequently, as can be seen from the bottom half of Table 1, most economic forecasters continued to predict strong growth for the U.S. economy in 2021.

2. Our macro forecasts for 2021

In making our own forecasts for 2021, we assumed the Biden administration is committed to strong growth and will attempt to implement a stimulus package of whatever size is required to achieve it. By strong growth, we mean a year-on-year increase in GDP of between 4 and 6 per cent.[2] In generating the detailed industry and regional forecasts presented later in this report, we assumed 5 per cent.

The USAGE model indicates that strong economic growth in 2021 is physically feasible: there is adequate under-used labour and capital that could be brought back on line to achieve growth of up to 6 per cent without significant inflationary pressure. Even with 6 per cent GDP growth, excess capital capacity at the end of 2021 is still greater than in the no-COVID baseline and employment is only slightly above the no-COVID baseline level.[3]

However, the model indicates that to achieve strong growth, fiscal stimulus will be required. As shown in Table 2, we used the model to calculate the stimulus that would be required to underpin growth in real GDP at 4 per cent, 5 per cent and 6 per cent. In making these calculations we assumed that all of the stimulus is in the form of payments to households, whereas the eventual package will involve considerable public consumption (direct purchases of goods and services by the government). Because public consumption carries a higher multiplier effect than supplements to household income, the calculations in Table 2 should be considered upper bounds on the size of the required stimulus package.

In Table 2, we adopt two different assumptions concerning the rate at which households spend stimulus payments. The assumption in the first row is that the fraction of each dollar of stimulus receipts spent by the household sector is the same as the fraction applying to all other forms of household income. The assumption in the second row is that the spending fraction applying to stimulus receipts is only half that applying to other forms of income. The possibility of a low-spending propensity out of stimulus payments is demonstrated by quantitative findings reported in the New York Times.[4]

As indicated by Table 2, higher growth requires larger stimulus, and more stimulus is required if the spending rate on stimulus payments is low. However, the main message from Table 2 is that the stimulus required to support strong growth is likely to be of the order of

[2] By year-on-year growth of *x* per cent in 2021 we mean that total GDP generated in the four quarters of 2021 is *x* per cent larger than total GDP generated in the four quarters of 2020.

[3] The no-COVID baseline is a forecast for 2020 and 2021 reflecting growth prospects as seen by the IMF in 2019 without COVID.

[4] See R. Chetty, J Friedman and M. Stepner, NYT, Feb 8, 2021, https://www.nytimes.com/interactive/2021/02/08/opinion/stimulus-checks-economy.html?action=click&module=Opinion&pgtype=Homepage .

Table 2. Required stimulus payments in 2021, $trillion

GDP growth 2021	4%	5%	6%
Stimulus payments are spent at the same rate as other household income	1.034	1.117	1.208
Stimulus payments are spent at half the rate of other household income	2.193	2.404	2.644

magnitude ($1.9 trillion) currently proposed by the Biden administration. On this basis, we think that strong growth is not only physically feasible, but also fiscally feasible. While the calculation of the size of the package is of interest, it makes no difference to our forecasts for 2021: these depend only on our assumption of 5 per cent GDP growth. The size of the package in 2021 may make a difference to U.S. prospects beyond 2021, but we do not investigate that possibility in this report.

3. USAGE forecast method: returning demand curves to normal positions and working-off disequilibria

Our current forecasts, completed in the second week of February 2021, have been informed by data for the four quarters of 2020 on: macro variables; output and employment by industry and state; exports and imports by broad commodity; and passenger throughput at U.S. airports. When we introduced these data to USAGE, the model not only shows us how the economy has been evolving under Covid conditions, but it also points to the likely future path. It does this by showing how Covid has moved various demand and supply curves away from their normal or baseline positions.

Beyond Y20Q4, we assume that the foreign demand curve for each U.S. commodity (not tourism) moves back towards its baseline position subject to overall growth in the world economy being consistent with the IMF forecast of 5.5 per cent (*Table 1 World Economic Outlook Update, January 2021*). Similarly, beyond Y20Q4, we assume that the U.S. demand curve for each imported commodity (not tourism) moves back towards its baseline position.

For domestic and international tourism, we assume that Covid will continue to be a strong inhibiting factor to the middle of 2021. After that, we assume that tourism activities will gradually recover but will still be well below their no-Covid baseline levels at the end of 2021.

Investment in 2020 fell by less than could be expected on the basis of developments in the rest of the economy, indicating an increase in investor confidence. Through 2021 we assume that investor confidence returns to normal levels.

Employment data up to Y20Q4 and output data up to Y20Q3 indicate that employment in many industries and regions has not fully adjusted to reduced output, that is there was disequilibrium employment in Y20Q4. We assume that disequilibrium employment in each industry and region is gradually eliminated through 2021. For industries and regions with positive disequilibrium employment, USAGE implies that employment in 2021 grows slowly relative to output.

As explained already, we assume that fiscal stimulus will be sufficient to generate 5 per cent year-on-year GDP growth in 2021. This takes place with quarter-on-quarter growth through 2021 of 1.22 per cent. In view of our assumption that stimulus is in the form of payments to

households, we assume that public consumption grows at a subdued rate, namely its baseline rate of 0.17 per cent per quarter. Alternatively we could have assumed a higher rate of growth for public expenditure and lower payments to households. However, under the assumption that the stimulus package, whatever its nature, will be the size necessary to generate 5 per cent GDP growth, the split of the package between public consumption and supplements to household income is of little importance to our macro forecasts. Nevertheless, it may mean that we slightly overestimate the stimulation of industries producing goods for private consumption relative to those producing goods for public consumption.

4. Key forecast results

Given the assumptions outlined in section 3, USAGE produces the macro picture in Table 3. In year-on-year terms, there is strong growth in 2021 in GDP, employment, investment and household consumption. Growth in trade is subdued. Exports are inhibited by stimulation of domestic demand and consequent real appreciation. Imports in the second half of 2020 were elevated above the level we would expect on the basis of developments in the rest of the economy. Unwinding of this disequilibrium in 2021 gives slow import growth despite strong growth of the domestic economy.

As shown in Table 4, macro recovery translates into recovery for most industries. By the end of 2021, output in most industries is within 5 per cent of where it would have been in the absence of Covid. Exceptions are the travel-related industries listed at the top of the table. We assume that both domestic and international travel remain severely restricted to mid-2021 and then recover gradually.

The state results in Table 5 follow in a relatively straight-forward manner from the industry results. By the end of 2021, employment in nearly all states recovers to within 2 per cent of its pre-pandemic level in Y19Q4. The main exceptions are Hawaii and Nevada which remain depressed through 2021, awaiting the recovery of tourism.

Table 3. Year-on-year and quarter-on-quarter percentage growth rates: data for Y20Q1 to Y20Q4 and USAGE forecasts for Y21Q1 to Y21Q4

	Year20	Year21	Y20Q1	Y20Q2	Y20Q3	Y20Q4	Y21Q1	Y21Q2	Y21Q3	Y21Q4
GDP	-3.50	5.00	-1.28	-8.89	7.36	0.92	1.22	1.22	1.22	1.22
Employment	-5.73	4.36	0.10	-12.26	5.39	1.31	1.77	1.52	1.50	1.59
Investment[1]	-0.81	4.42	-0.02	-6.94	5.89	3.72	-1.37	0.78	1.60	2.27
H'hold consump.	-5.33	5.34	-1.76	-9.59	8.97	0.62	1.07	1.04	1.53	1.72
Exports	-12.96	1.78	-2.45	-22.75	12.41	5.10	0.18	-0.51	-0.80	-1.32
Imports	-9.29	0.59	-3.98	-17.68	17.87	6.67	-6.04	-2.53	0.69	2.24
Gov consumption	0.33	-0.62	-0.04	0.85	-1.67	-0.57	0.17	0.17	0.17	0.17

[1] Public plus private investment, excluding inventories

Table 4. Percentage deviations from no-Covid baseline in outputs of selected industries: data[1] for Y20Q1 to Y20Q4 and USAGE forecasts for Y21Q1 to Y21Q4

	Y20Q1	Y20Q2	Y20Q3	Y20Q4	Y21Q1	Y21Q2	Y21Q3	Y21Q4
Export tourism[2]	-29	-95	-90	-86	-86	-86	-75	-60
Foreign vacation[2]	-26	-91	-87	-78	-78	-78	-71	-62
Domestic vacation[2]	-31	-88	-70	-63	-64	-64	-51	-32
Air transport, international	-19	-67	-60	-49	-53	-55	-48	-40
Air transport, domestic	-24	-69	-55	-48	-49	-50	-40	-27
Urban gr'd passenger trans	-9	-44	-42	-26	-14	-9	-6	-4
… … …								
Hotels & restaurants	-10	-41	-20	-15	-11	-9	-7	-4
Entertainment & recreation	-4	-17	-13	-13	-8	-6	-4	-3
Apparel & textiles	-3	-12	-5	-10	-6	-3	-2	-1
… … …								
Production of gov't services	-5	-10	-9	-7	-7	-7	-7	-6
… … …								
Machinery	-4	-20	-2	-6	-4	-2	-2	-2
… … …								
Truck transport	0	-15	-6	-4	-4	-3	-2	-2
… … …								
Medical equip & services	-2	-13	-5	-3	-1	0	2	3
Utilities	0	-1	-2	-2	-2	-2	-1	0
Wholesale & retail	-2	-10	-1	-2	-2	-2	-1	-1
Agriculture	0	-3	-1	-1	-2	-1	-1	-1
Food, beverages & tobacco	0	-3	0	-1	-2	-2	-2	-1
Construction	2	-3	-2	-1	-3	-2	-1	0
… … …								
Courier services	2	3	15	9	2	-1	-2	-2

[1] The BEA has published output movements for 56 industries in Y20Q1 to Y20Q3. We map these data to USAGE industries. In forming output movements for Y20Q4 we referred to BLS employment data for 59 industries. Again, a mapping was necessary.

[2] Foreign vacation is an artificial industry consisting of U.S. and foreign airline services and other services acquired by U.S. residents when they take a vacation abroad. Export tourism consists of expenditures by foreigners taking a vacation in the U.S. Domestic vacation consists of expenditures by U.S. residents taking a vacation in the U.S.

Table 5. Percentage deviations in employment in selected states from the pre-pandemic level of Y19Q4: data for Y20Q1 to Y20Q4 and USAGE forecasts for Y21Q1 to Y21Q4

	Year 2020				Year 2021			
State	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
12 Hawaii	0	-22	-16	-11	-20	-25	-21	-14
22 Massachusetts	-1	-21	-14	-10	-5	-2	0	2
29 Nevada	-1	-26	-12	-10	-15	-18	-14	-8
33 NewYork	0	-15	-10	-9	-5	-3	-1	1
… … …								
5 California	-1	-16	-12	-7	-6	-5	-3	-1
14 Illinois	-1	-14	-9	-7	-4	-2	0	2
… … …								
10 Florida	-1	-17	-9	-6	-9	-10	-8	-4
… … …								
39 Pennsylvania	0	-11	-8	-6	-3	0	1	2
… … …								
9 DC	1	-9	-7	-5	-5	-5	-4	-2
… … …								
28 Nebraska	1	-3	-1	0	0	1	1	2
13 Idaho	1	-6	0	0	-1	0	0	1

5. Concluding remarks

The macro-economic outlook for 2021 is favorable.

At this stage it seems likely that the Covid downturn will be mild relative to the GFC and will not be long-lived, see Figure 1.

Over the 2 years from Y20Q1 to Y21Q4, the pandemic will cost the U.S. economy about 8 per cent of a year's GDP. This is the loss of output measured by the difference between what the U.S. economy would have produced without the pandemic compared with what it is producing with the pandemic. Present indications are that by 2022 GDP will be back close to its no-Covid path.

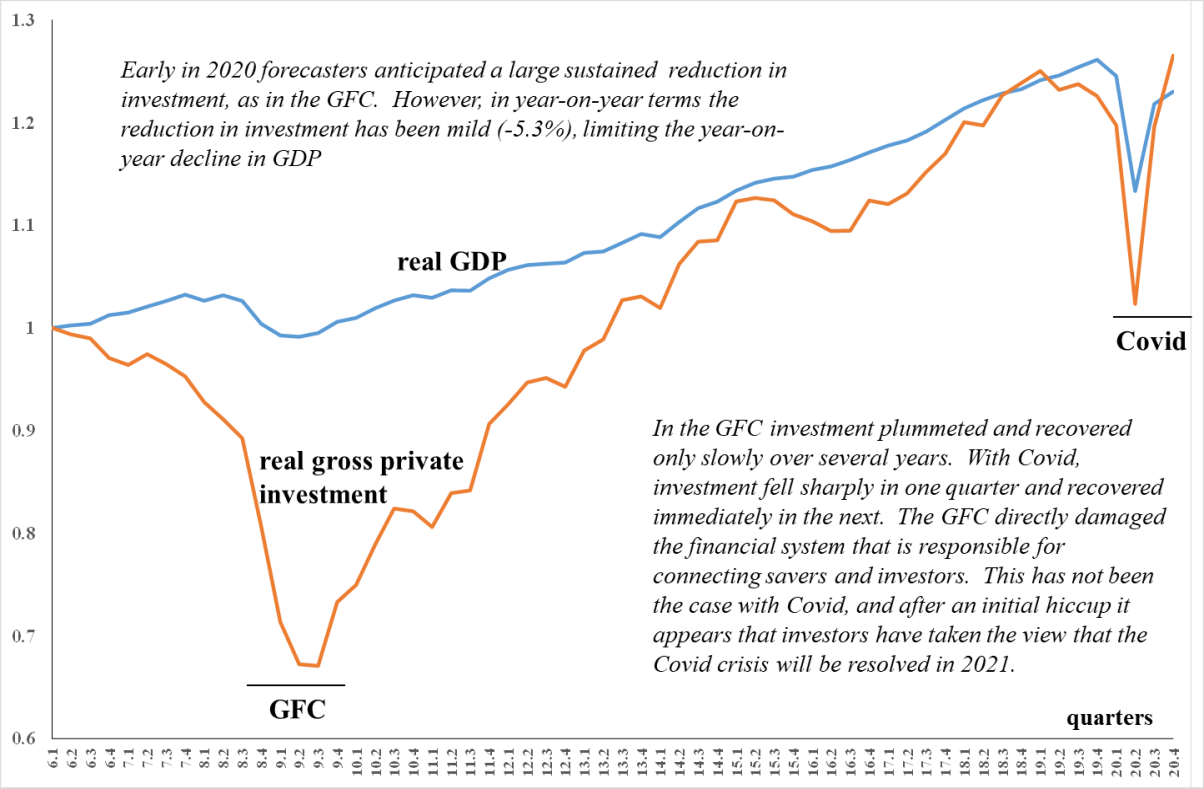
By comparison, over the two years from Y08Q3 to Y10Q2, the GFC cost the U.S. economy about 9.4% of a year's GDP, and the negative effects continued for at least another two years.

Through 2021, tourism-related industries and regions will remain depressed, but the rest of the economy is likely to recover.

In making our forecasts for 2021, we assumed that the Biden administration will implement a stimulus package sufficient to generate 5 per cent year-on-year growth in GDP. The size of the required package depends on reactions of households and other actors in the economy. If households are willing to spend income supplements in the way in which they spend normal household income, then a relatively small package will be adequate, a little over $1 trillion. On the other hand, if households adopt a consumption propensity on stimulus payments that is half of that on normal income, then a package of over $2 trillion will be required. One interpretation of the Biden proposal for $1.9 trillion is that it is a request to have the freedom

to support strong growth. If stimulus is successful and strong growth emerges, then it may not be necessary to use the entire package.

Figure 1. Real GDP and private investment in the U.S. from 1st quarter 2006 to 4th quarter 2020 (index numbers, 1st quarter 2006)



Appendix A. Slides for the February 2021 Covid update

Effects of Covid on the U.S. economy: update after 4 quarters of data

CoPS

Presentation prepared by
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Centre of Policy Studies, Victoria University

February 19, 2021

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1

The project

CoPS

Aim. Produce monthly updates on the effects of Covid on U.S. macroeconomic, industry and regional variables.

Method. Compare two runs of the USAGE model:

(a) no-Covid baseline run showing how the economy was expected to evolve before the onset of Covid; and

(b) Covid run incorporating data up to February 5, 2021 and projections reflecting the Covid environment.

USAGE. This is a detailed computable general equilibrium model that has been developed over the last 20 years and applied in studies for the U.S. International Trade Commission, and the U.S. Departments of Agriculture, Commerce, Energy, Homeland Security and Transportation.

2

No-Covid baseline run

The no-Covid baseline run is a bland forecast based on data available in 2019 (pre-Covid). The main input is IMF forecasts from *World Economic Outlook, 2019*.

In the no-Covid baseline, employment grows at 0.24 per cent per quarter or 0.9 per cent per year for the 8 quarters starting January 1, 2020 and ending December 31, 2021, and real GDP grows at 0.47 per cent per quarter or 1.9 per cent a year.

3

The economy with Covid: Covid run

The Covid run incorporates data for:

- **Employment in 59 industries for the 4 quarters of 2020 (Y20Q1, Y20Q2, Y20Q3, Y30Q4).**
  Source: BLS, Table B-1, Employment situation – February 2021
  https://www.bls.gov/webapps/legacy/cesbtab1.htm
- **Output in 56 industries for Y20Q1, Y20Q2 and Y20Q3**
  Source: BEA, Real gross output by industry – December 2020
  https://www.bea.gov/data/industries/gross-output-by-industry
- **Macro variables (GDP, C, I, G and Inventories) for Y20Q1, Y20Q2, Y20Q3, Y20Q4**
  Source: BEA, NIPA tables 1.1.6 and 3.9.6 – January 2021
  https://apps.bea.gov/iTable/index_nipa.cfm
- **Exports in 14 categories and imports in 13 categories for Y20Q1, Y20Q2, Y20Q3, Y20Q4**
  Source: BEA, NIPA tables 4.2.3 – January 2021
  https://apps.bea.gov/iTable/index_nipa.cfm
- **Visitor arrivals in the U.S. and Passenger throughput at U.S. airports for Y20Q1,Y20Q2, Y20Q3 and Y20Q4**
  Sources: Data published by the International Trade Administration in Dept. of Commerce (up to end Nov 2020) and the TSA (up to end Jan 2021), see
  https://www.trade.gov/visitor-arrivals-program-i-94-data & https://www.tsa.gov/coronavirus/passenger-throughput
- **Share of saving in household disposable income for 4 quarters of 2020 (Y20Q1, Y20Q2, Y20Q3, Y20Q4).**
  Source: BEA, NIPA table 2.1– January 2021
  https://apps.bea.gov/iTable/index_nipa.cfm
- **Output by detailed agricultural industry for 2020**
  Source: The Food and Agricultural Policy Research Institute (FAPRI), Report #04-20 (August 2020)
  https://www.fapri.missouri.edu/wp-content/uploads/2020/08/August-2020-Baseline-Outlook-Update.pdf
- **Foreign student enrolment in U.S. education to end of 2020**
  Source: https://www.iie.org/en/Research-and-Insights/Publications/Fall-2020-International-Student-Enrollment-Snapshot
- **Employment by state for the four quarters of 2020, Y20Q1 – Y20Q4**
  Source: BLS compressed data at https://www.bls.gov/web/laus.supp.toc.htm

4

The economy with Covid: strong GDP growth in 2021

CoPS

We assume year-on-year GDP growth in 2021 of 5 per cent:

- **Strong growth in 2021 is physically feasible: underemployed capital and labor can be brought back on line.**
- **Strong growth in 2021 is fiscally feasible: it will require a stimulus package between $1 and $2 trillion, within the range of current political discussions.**
- **Strong growth in 2021 is consistent with a continuation of the V-shaped recovery developed in 2020**

5

What other macro forecasters have been saying about 2021

CoPS

Starting in the second half of 2020, macro forecasters have been adjusting upwards as rapid recovery of the U.S. economy became apparent in Y20Q3 and was sustained in Y20Q4

Percentage growth year-on-year

Organization & publication	date	GDP		Employment	
		2020	2021	2020	2021
Centre of Policy Studies, working paper for DHS	Apr-20	-8.4	11.8	-8.4	11.1
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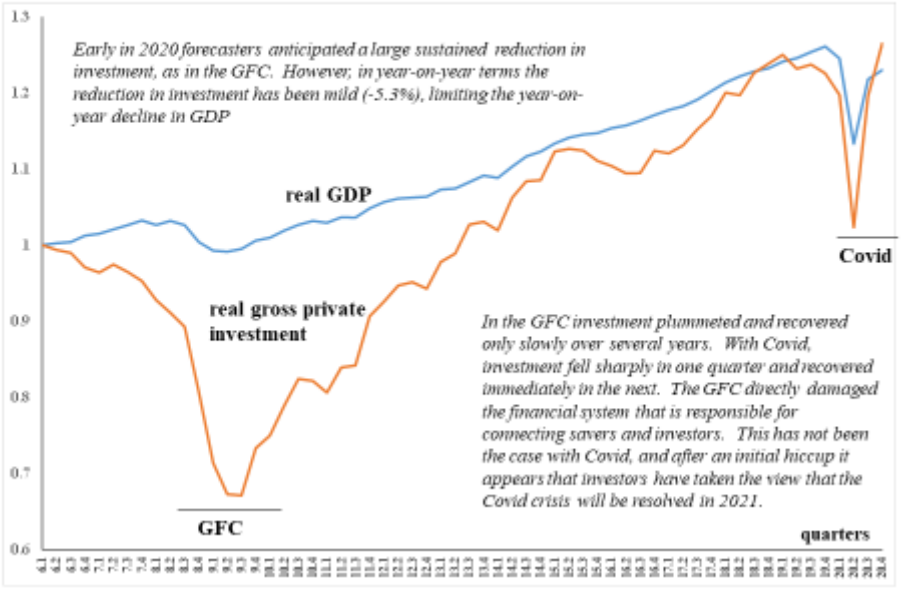
In April 2020 we anticipated a year-on-year reduction in investment in 2020 of 27 per cent. Now it appears that investment will fall by only about 5.3 per cent.

6

Why forecasters have been becoming more optimistic about 2021

CoPS

(index numbers, for real GDP and gross private investment)



7

The economy with Covid: inputs to USAGE

CoPS

Our main assumptions for the quarters beyond the data are:

- **Real GDP grows in each quarter of Y21 by 1.6 per cent (giving 5 per cent year-on-year growth).**
- **The fiscal stimulus package will be sufficient to raise private consumption to the level necessary to achieve the assumed rate of growth of GDP. USAGE indicates that the required package will be between $1.1 and $1.5 trillion, depending on the extent to which households increase their spending in response to stimulus.**
- **Investment in 2020 fell by less than could be expected on the basis of developments in the rest of the economy, indicating an increase in investor confidence. Through 2021 we assume that investor confidence returns to normal levels.**
- **Employment data up to Y20Q4 and output data up to Y20Q3 indicate that employment in many industries has not fully adjusted to reduced output, that is there was disequilibrium employment in Y20Q4. We assume that disequilibrium employment in each industry is gradually eliminated through 2021. For industries with positive disequilibrium employment, USAGE implies that employment in 2021 grows slowly relative to output.**

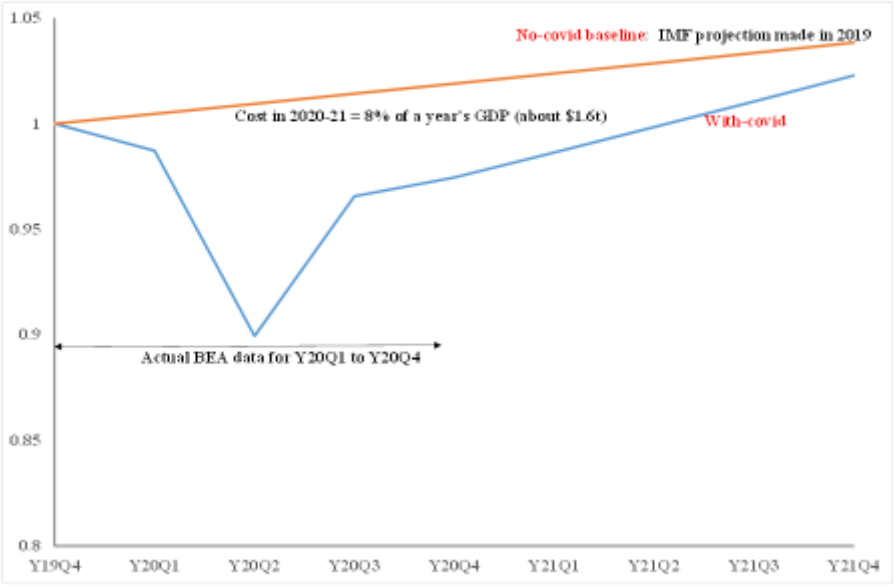
8

The economy with Covid: inputs to USAGE

- Covid will be a strong inhibitor of domestic and international tourism to the middle of 2021. Tourism activities will gradually recover in the second half of 2021.
- Beyond Y20Q4, the foreign demand curve for each U.S. commodity (not tourism) moves back towards its baseline position subject to overall growth in the world economy being consistent with the IMF forecast of 5.5 per cent (*Table 1 World Economic Outlook Update, January 2021*) https://www.imf.org/en/Publications/WEO/Issues/2021/01/26/2021-world-economic-outlook-update
  Thus, USAGE implies that exports of commodities such as aircraft that have been particularly depressed in 2020 will grow more quickly than aggregate exports in 2021.
- Beyond Y20Q4, the U.S. demand curve for each imported commodity (not tourism) moves back towards its baseline position.
- Beyond Y20Q4, public consumption grows at its baseline rate, 0.17 per cent per quarter.

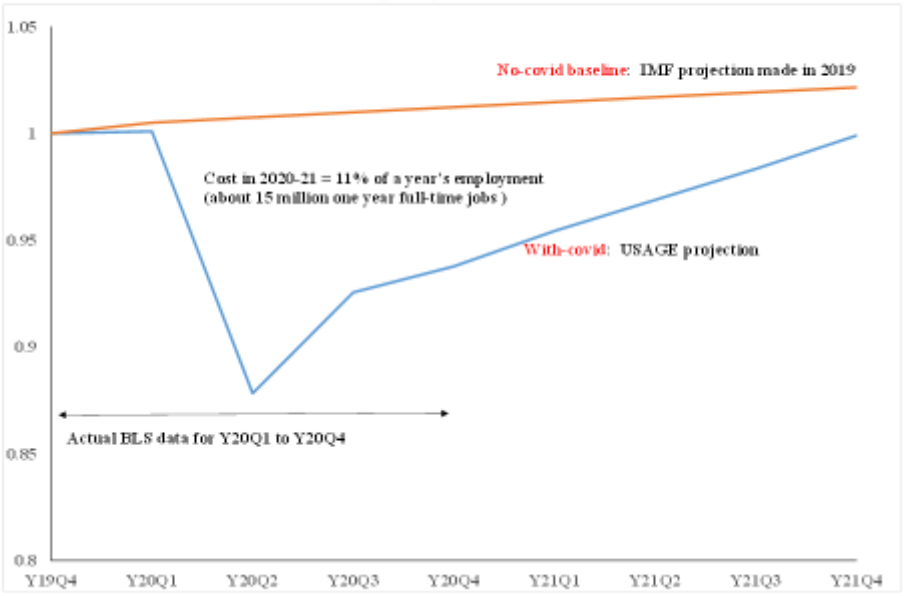
9

What Covid is doing to the U.S. economy: GDP



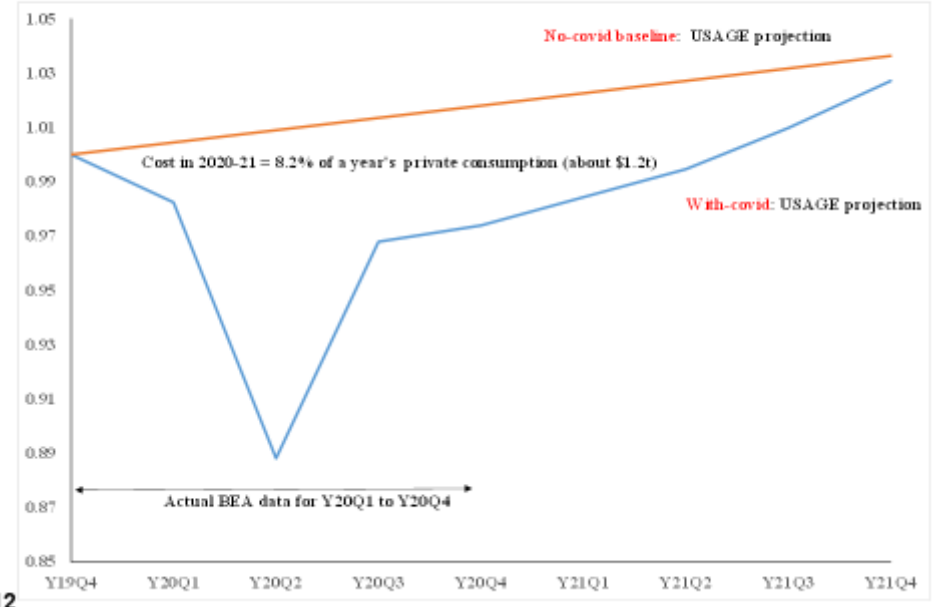
10

What Covid is doing to the U.S. economy: Employment



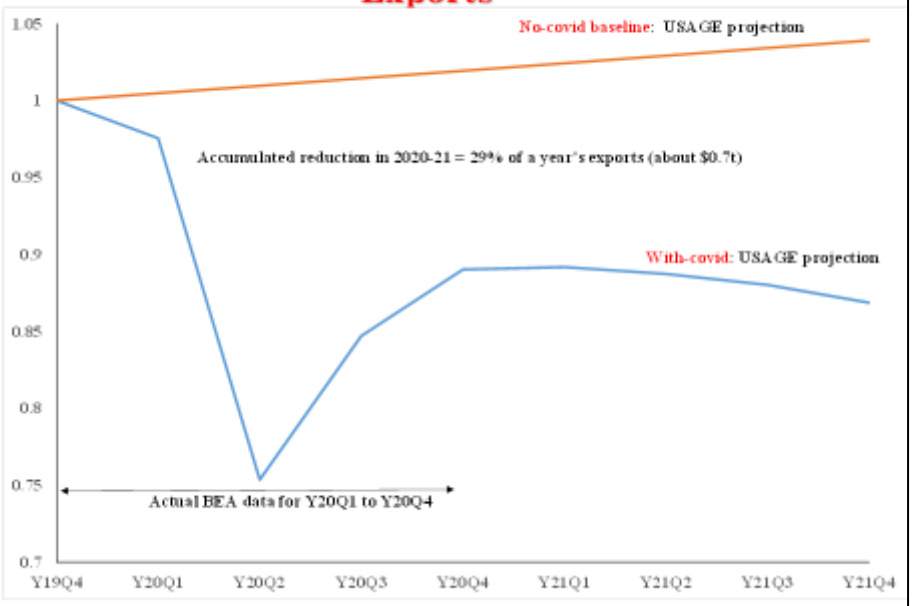
11

What Covid is doing to the U.S. economy: Private consumption



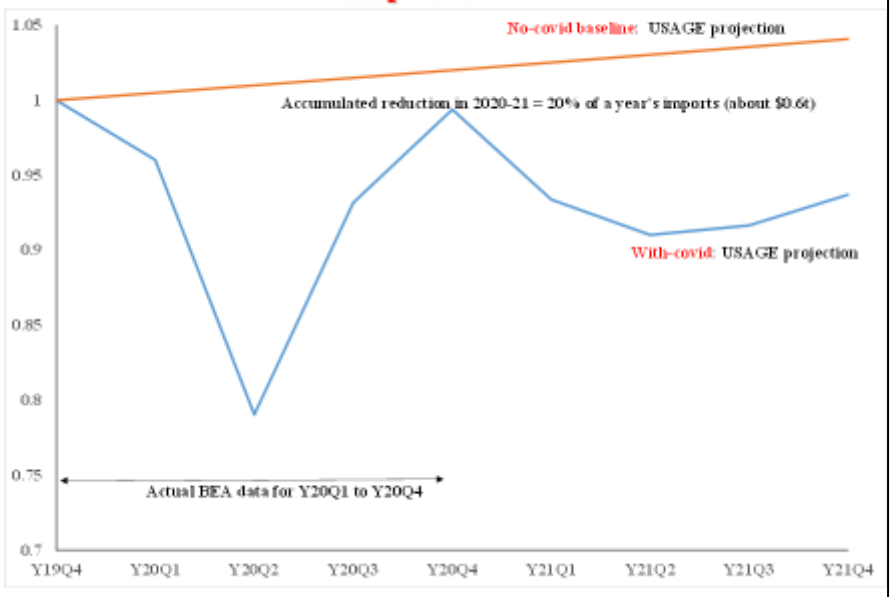
12

What Covid is doing to the U.S. economy: Exports



13

What Covid is doing to the U.S. economy: Imports



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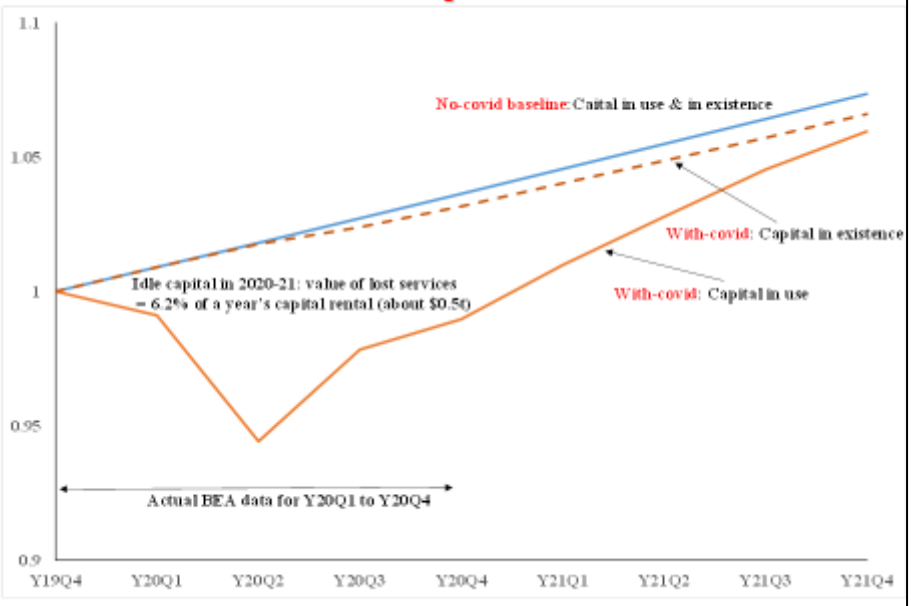
What Covid is doing to the U.S. economy: Idle capital



15

Year-on-year and quarter-on-quarter percentage growth rates with and without Covid

	Year20	Year21	Y20Q1	Y20Q2	Y20Q3	Y20Q4	Y21Q1	Y21Q2	Y21Q3	Y21Q4
GDP, covid	-3.50	5.00	-1.28	-8.89	7.36	0.92	1.22	1.22	1.22	1.22
GDP, no-covid	1.19	1.90	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47
Employment, covid	-5.73	4.36	0.10	-12.26	5.39	1.31	1.77	1.52	1.50	1.59
Employment, no-covid	0.87	0.93	0.50	0.25	0.24	0.24	0.23	0.23	0.22	0.22
Investment, covid	-0.81	4.42	-0.02	-6.94	5.89	3.72	-1.37	0.78	1.60	2.27
Investment, no-covid	2.04	3.28	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81
Hhold consumption, covid	-5.33	5.34	-1.76	-9.59	8.97	0.62	1.07	1.04	1.53	1.72
Hhold consumption, no-covid	1.12	1.80	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Exports, covid	-12.06	1.78	-2.45	-22.75	12.41	5.10	0.18	-0.51	-0.80	-1.32
Exports, no-covid	1.21	1.94	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48
Imports, covid	-9.29	0.59	-3.98	-17.68	17.87	6.67	-6.04	-2.53	0.69	2.24
Imports, no-covid	1.24	2.03	0.49	0.50	0.50	0.50	0.50	0.51	0.51	0.51
Gov consumption, covid	0.33	-0.62	-0.04	0.85	-1.67	-0.57	0.17	0.17	0.17	0.17
Gov consumption, no-covid	0.44	0.70	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
Capital in existence, covid	2.05	2.97	0.90	0.85	0.61	0.76	0.84	0.81	0.81	0.84
Capital in use, covid	-2.42	6.13	-0.89	-4.73	3.62	1.15	2.04	1.77	1.71	1.36
Capital, existence & use, no-covid	2.27	3.82	0.90	0.90	0.89	0.89	0.89	0.89	0.88	0.88

These results show percentage differences in the value of a variable in a year or quarter from the value it had in the previous year or quarter

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Macro effects of Covid in the U.S.: percentage deviations from no-Covid baseline

CoPS

	Year20	Year21	Y20Q1	Y20Q2	Y20Q3	Y20Q4	Y21Q1	Y21Q2	Y21Q3	Y21Q4
GDP	-4.64	-1.73	-1.74	-10.90	-4.79	-4.36	-3.65	-2.94	-2.22	-1.50
Employment	-6.54	-3.37	-0.15	-12.60	-8.12	-7.13	-5.71	-4.49	-3.28	-1.96
Investment	-2.79	-1.72	-0.83	-8.46	-3.84	-1.06	-3.20	-3.23	-2.47	-1.06
Hhold consumption	-6.38	-3.13	-2.20	-11.97	-4.50	-4.34	-3.74	-3.17	-2.12	-0.88
Exports	-14.00	-14.13	-2.92	-25.37	-16.51	-12.67	-12.93	-13.79	-14.88	-16.40
Imports	-10.41	-11.67	-4.45	-21.74	-8.21	-2.57	-8.91	-11.66	-11.50	-9.98
Gov consumption	-0.11	-1.42	-0.22	0.46	-1.39	-2.12	-2.12	-2.12	-2.12	-2.12
Capital in existence	-0.21	-1.02	0.00	-0.04	-0.32	-0.46	-0.51	-0.59	-0.65	-0.70
Capital in use	-4.58	-2.45	-1.78	-7.26	-4.75	-4.50	-3.41	-2.56	-1.76	-1.30

These results show percentage differences in the value of a variable in a year or quarter under Covid conditions from its value in the same year or quarter in the no-Covid baseline

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Effects of Covid on industry outputs (31-order) in the U.S.: percentage deviations from no-Covid baseline

CoPS

	Year20	Year21	Y20Q1	Y20Q2	Y20Q3	Y20Q4	Y21Q1	Y21Q2	Y21Q3	Y21Q4
Export tourism	-74.99	-76.79	-29.06	-94.91	-89.70	-86.31	-86.33	-86.36	-74.56	-59.89
Foreign vacation	-70.65	-72.17	-26.43	-91.40	-86.75	-78.00	-78.14	-78.27	-70.77	-61.51
Domestic vacation	-62.86	-52.76	-31.09	-87.76	-69.54	-63.43	-63.62	-63.80	-51.25	-32.39
Air transport, international	-48.76	-48.79	-19.32	-66.83	-59.50	-49.41	-53.00	-54.59	-47.91	-39.67
Air transport, domestic	-48.78	-41.54	-23.77	-68.92	-54.85	-47.59	-49.14	-49.74	-40.48	-26.82
Other non-resident spending	-23.13	-26.61	-8.28	-31.88	-25.90	-26.45	-26.67	-26.69	-26.58	-26.49
Urban g' d passenger trans	-30.24	-8.16	-8.63	-44.30	-41.95	-26.07	-13.63	-8.94	-6.08	-3.97
Water transport, domestic	-25.31	-7.92	-8.77	-36.92	-39.19	-24.37	-13.18	-7.94	-5.74	-4.84
Water transport, international	-24.91	-8.43	0.72	-38.73	-39.33	-22.32	-11.77	-7.31	-6.75	-7.91
Export education	-9.25	-24.39	-2.48	-4.94	-7.45	-22.14	-22.20	-22.28	-22.38	-30.72
Mining	-17.32	-13.43	-1.30	-22.33	-27.20	-18.47	-15.43	-13.24	-12.50	-12.55
Hotels & restaurants	-21.58	-7.66	-10.18	-41.28	-19.52	-15.35	-10.76	-8.81	-6.68	-4.40
Entertainment & recreation	-11.69	-5.22	-3.92	-17.25	-12.82	-12.76	-8.00	-5.72	-4.23	-2.93
Apparel & textiles	-7.49	-3.01	-2.86	-12.26	-4.64	-10.20	-6.12	-3.07	-1.79	-1.07
Rail transport	-8.52	-3.47	0.03	-20.67	-9.92	-7.50	-5.06	-3.40	-2.74	-2.70
Education	-7.40	-1.02	-1.59	-12.29	-8.48	-7.26	-3.10	-1.03	-0.07	0.14
Production of gov't services	-7.54	-6.58	-5.01	-9.68	-8.61	-6.85	-6.75	-6.65	-6.53	-6.38
Pipeline	-7.37	-4.33	-1.49	-14.58	-8.36	-5.85	-4.93	-4.30	-4.26	-4.65
Machinery	-7.90	-2.42	-3.86	-20.42	-1.74	-5.57	-3.76	-2.44	-1.88	-1.59
Wood & metal products	-4.63	-2.18	-0.31	-8.85	-4.27	-5.09	-3.75	-2.24	-1.56	-1.18
Truck transport	-6.38	-2.65	-0.18	-14.93	-6.03	-4.56	-3.64	-2.88	-2.33	-1.73
Chemical products	-5.04	-2.85	-1.18	-8.69	-6.18	-4.09	-3.60	-2.74	-2.50	-2.55
Other services	-3.85	-1.63	-0.64	-7.49	-3.90	-3.36	-2.64	-1.98	-1.28	-0.61
Medical equip & services	-5.68	1.14	-1.81	-13.14	-4.83	-2.95	-0.90	0.47	1.79	3.19
Utilities	-1.34	-1.31	-0.23	-1.26	-1.94	-1.91	-2.31	-1.90	-1.06	0.04
Wholesale & retail	-3.79	-1.53	-1.77	-10.38	-1.32	-1.70	-2.12	-1.94	-1.42	-0.63
Agriculture	-1.63	-1.42	-0.43	-3.26	-1.37	-1.45	-1.52	-1.39	-1.35	-1.40
Food, beverages & tobacco	-0.78	-1.57	0.50	-2.70	0.01	-0.93	-2.00	-2.01	-1.53	-0.75
Construction	-8.92	-1.35	1.98	-2.51	-2.28	-0.88	-2.56	-2.05	-1.10	0.32
Warehousing	-2.04	-1.02	-1.96	-9.01	0.74	2.07	-0.31	-1.21	-1.40	-1.15
Other transport serv (e.g. couriers)	7.22	-0.83	1.79	3.12	15.15	8.82	2.30	-0.94	-2.22	-2.45

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Effects of Covid on employment in U.S. industries (59-order): percentage deviations from no-Covid baseline

CoPS

	Industry	Year20	Year21	Y20Q1	Y20Q2	Y20Q3	Y20Q4	Y21Q1	Y21Q2	Y21Q3	Y21Q4
1	Farms	-2.88	-1.58	-0.77	-6.37	-2.33	-2.04	-1.98	-1.60	-1.41	-1.33
2	Logging	-3.48	-2.01	1.14	-5.03	-5.45	-4.58	-4.01	-2.19	-1.21	-0.64
3	Coal, oil & gas	-3.28	-4.94	-1.18	-5.72	-3.94	-2.27	-4.18	-4.66	-5.18	-5.72
4	Other Mining	-1.82	-3.57	0.26	-3.05	-2.52	-1.97	-3.74	-3.53	-3.53	-3.47
5	Mining support	-20.76	-32.74	-4.26	-21.68	-28.70	-28.39	-32.10	-32.80	-33.21	-32.87
6	Utilities	-1.06	-1.93	-0.11	-1.19	-1.38	-1.54	-2.79	-2.64	-1.79	-0.49
7	Non-res construction	-6.09	-1.79	0.05	-9.70	-7.72	-7.00	-4.66	-2.44	-0.79	0.73
8	Resid construction	-3.35	-2.13	0.43	-9.13	-3.27	-1.46	-4.61	-3.58	-1.67	1.25
9	Wood products	-4.73	-2.04	-0.49	-7.60	-8.30	-4.55	-3.88	-2.47	-1.46	-0.35
10	Non-metal min prods	-4.98	-2.17	0.03	-8.54	-6.00	-5.40	-4.22	-2.54	-1.45	-0.47
11	Primary metals	-7.98	-2.61	-1.44	-10.46	-10.52	-9.49	-5.41	-2.44	-1.38	-1.21
12	Fabricated metal prods	-5.82	-2.77	-0.84	-7.73	-7.67	-7.03	-4.99	-2.98	-1.89	-1.21
13	Machinery	-6.27	-3.46	-1.27	-8.48	-8.03	-7.28	-5.40	-3.52	-2.70	-2.24
14	Computers	0.88	-0.96	1.21	1.30	0.54	0.48	-1.54	-1.39	-0.86	-0.07
15	Other electronic equip	-0.92	-1.38	0.30	-1.47	-1.46	-1.03	-1.80	-1.35	-1.20	-1.18
16	Semicond & components	-1.80	-1.34	-0.48	-1.73	-2.47	-2.51	-2.04	-1.11	-0.96	-1.25
17	Electrical prods	-5.35	-3.62	-0.41	-8.24	-7.25	-7.48	-5.62	-3.56	-2.76	-2.53
18	Motor vehicles	-10.05	-1.40	0.94	-26.29	-8.15	-6.69	-3.89	-1.66	-0.46	0.39
19	Other transport equip	-5.20	-3.34	-0.84	-5.57	-6.93	-8.27	-3.97	-2.91	-3.02	-3.48
20	Furniture	-8.70	-3.11	-0.53	-14.98	-10.19	-9.10	-6.56	-3.93	-1.83	-0.10
21	Other misc manu	-4.97	-2.18	0.09	-11.52	-4.86	-3.61	-3.23	-2.30	-1.79	-1.39
22	Food, bev & tobacco	-2.77	-1.55	-0.40	-5.19	-3.32	-2.16	-2.37	-2.00	-1.35	-0.48
23	Clothing & textiles	-12.21	-3.75	-1.76	-20.25	-14.57	-12.26	-7.53	-4.10	-2.21	-1.15
24	Paper & printing	-7.05	-3.13	-0.86	-10.32	-8.91	-8.10	-5.22	-3.27	-2.30	-1.73
25	Petrol & coal prods	-3.48	-5.26	1.78	-8.08	-6.33	-3.27	-5.53	-6.32	-5.47	-3.71
26	Chemical & pharmaceut	-1.66	-1.42	-0.27	-2.61	-1.86	-1.89	-1.96	-1.35	-1.18	-1.19
27	Plastic & rubber	-2.44	-1.63	0.52	-6.21	-2.87	-1.20	-2.05	-1.71	-1.53	-1.21
28	Wholesale trade	-4.94	-2.56	-0.37	-8.83	-8.51	-6.04	-4.24	-2.93	-1.96	-1.11
29	Retail trade	-5.79	-2.47	-0.52	-12.42	-5.63	-4.58	-4.26	-3.47	-2.01	-0.13

Table continues …

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Effects of Covid on employment in U.S. industries (59-order): percentage deviations from no-Covid baseline

CoPS

Table continued …

	Industry	Year20	Year21	Y20Q1	Y20Q2	Y20Q3	Y20Q4	Y21Q1	Y21Q2	Y21Q3	Y21Q4
30	Air transport	-16.25	-48.15	0.65	-21.48	-20.79	-23.39	-43.74	-54.22	-52.75	-41.88
31	Rail transport	-8.80	-6.38	-3.11	-9.33	-11.23	-11.54	-8.40	-6.49	-5.79	-4.82
32	Water transport	-12.91	-6.84	-2.57	-15.01	-17.91	-16.13	-9.97	-5.68	-4.04	-4.49
33	Truck transport	-4.99	-2.72	-0.75	-7.21	-6.89	-5.29	-4.32	-3.21	-2.18	-1.19
34	Ground passenger transport	-23.53	-7.59	0.21	-37.88	-31.89	-24.56	-14.77	-8.73	-4.88	-1.99
35	Pipelines	-2.67	-5.89	-0.69	-2.07	-3.55	-4.37	-5.18	-5.55	-6.16	-7.07
36	Other transport	-8.20	-3.19	0.52	-4.67	-1.38	4.72	-8.85	-5.52	-4.30	-4.10
37	Warehousing	0.59	-0.57	0.79	-4.58	0.57	5.59	0.98	-0.83	-1.34	-1.10
38	Publish, movies & records	-34.03	-11.81	1.72	-51.91	-45.20	-40.73	-22.52	-12.68	-7.47	-4.58
39	Broadcast & telco	-3.77	-2.57	-0.78	-4.18	-4.93	-5.21	-3.97	-3.10	-2.17	-1.05
40	Data info services	2.48	-1.57	2.43	1.99	2.24	3.28	-0.35	-1.86	-2.19	-1.88
41	Banking & finance	-0.50	-1.44	0.18	-0.90	-0.83	-0.43	-1.47	-1.71	-1.52	-1.06
42	Insurance	0.01	-0.45	0.11	-0.29	-0.08	0.31	-0.87	-1.08	-0.47	0.64
43	Real estate	-0.24	6.47	1.71	-2.99	-0.81	1.13	3.80	5.72	7.36	9.01
44	Asset leasing	-13.51	-6.56	-0.33	-19.74	-17.77	-16.21	-10.54	-7.17	-5.06	-3.47
45	Legal services	-3.75	-1.79	0.07	-5.68	-4.98	-4.41	-3.16	-2.18	-1.35	-0.49
46	Prof, sci & tech services	-3.11	-2.17	0.19	-5.24	-4.21	-3.18	-2.96	-2.56	-1.97	-1.18
47	Research develop serv	-0.07	-1.35	0.44	-2.12	-0.43	1.81	-0.92	-1.71	-1.66	-1.10
48	Waste managem ent	-8.90	-3.38	-0.38	-16.09	-11.35	-7.75	-5.20	-3.69	-2.79	-1.82
49	Education	-7.83	-2.44	0.11	-11.83	-8.74	-10.85	-5.62	-2.54	-1.04	-0.58
50	Ambulatory health	-4.97	-1.03	0.00	-11.99	-4.88	-3.03	-2.40	-1.75	-0.67	0.69
51	Hospitals	-1.85	4.97	0.20	-2.77	-2.62	-2.22	1.66	4.10	6.11	8.03
52	Nursing & resid care	-5.42	-1.51	-0.35	-5.36	-7.50	-8.46	-4.84	-2.58	-0.41	1.78
53	Social assistance	-8.07	-3.89	0.11	-14.22	-9.85	-8.32	-5.57	-3.87	-2.27	-0.64
54	Arts, entertain & rec	-28.42	-10.96	-0.63	-48.54	-34.30	-30.21	-19.29	-12.63	-7.90	-4.03
55	Accommodation	-28.21	-10.76	-1.06	-43.80	-36.31	-31.70	-19.67	-12.53	-7.48	-3.38
56	Restaurants	-19.26	-8.69	-1.30	-37.32	-20.17	-18.26	-13.50	-10.35	-7.11	-3.78
57	Other services	-9.24	-3.33	-0.53	-18.52	-9.64	-8.25	-5.90	-4.20	-2.49	-0.72
58	Federal govt	4.54	-1.78	1.30	2.43	9.38	5.04	0.58	-1.65	-2.75	-3.28
59	State & local govt	-4.52	-8.65	0.23	-6.30	-5.51	-6.49	-7.87	-8.57	-8.96	-9.20

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Quarter-on-quarter percentage growth rates for employment by state: BLS data for the 4 quarters of 2020 followed by USAGE model projections

CoPS

	State	Year 2020 Q1	Q2	Q3	Q4	Year 2021 Q1	Q2	Q3	Q4
1	Alabama	-0.57	-8.85	6.17	1.87	1.20	1.27	0.81	0.68
2	Alaska	0.01	-9.37	3.46	7.77	-4.84	-1.96	0.20	1.59
3	Arizona	-0.42	-7.73	2.94	1.43	-1.36	-0.12	1.53	2.52
4	Arkansas	0.17	-9.16	3.07	2.33	2.28	1.82	1.10	0.85
5	California	-1.01	-15.25	4.91	5.35	1.27	1.27	1.88	2.29
6	Colorado	-1.12	-9.84	4.61	2.19	0.34	0.82	1.57	2.14
7	Connecticut	0.31	-11.71	5.02	0.35	4.47	2.81	1.59	1.09
8	Delaware	-1.09	-12.63	11.40	0.59	1.83	1.54	1.10	0.97
9	District of Columbia	0.79	-9.38	1.73	2.59	-0.69	0.11	1.29	1.87
10	Florida	-0.61	-16.45	9.03	2.93	-3.25	-1.07	2.48	4.25
11	Georgia	-0.20	-10.96	4.69	4.88	-0.21	0.50	1.03	1.52
12	Hawaii	0.24	-22.68	8.08	6.36	-10.57	-5.42	4.72	9.12
13	Idaho	0.60	-6.82	6.17	0.48	-0.72	0.27	0.59	0.85
14	Illinois	-1.04	-13.25	5.50	2.55	3.46	2.43	1.71	1.54
15	Indiana	-0.92	-11.75	8.47	2.50	2.19	1.87	1.16	0.92
16	Iowa	-0.79	-10.28	1.01	2.01	4.70	3.04	1.77	1.23
17	Kansas	0.64	-7.16	2.80	4.08	0.21	0.58	0.48	0.56
18	Kentucky	-0.47	-9.94	0.95	3.91	3.01	2.14	1.37	1.16
19	Louisiana	0.02	-13.26	9.85	1.19	0.04	0.70	0.82	1.00
20	Maine	0.05	-10.00	4.52	1.19	0.98	1.12	1.56	1.86
21	Maryland	0.36	-10.14	3.56	-0.95	4.36	2.76	1.67	1.23
22	Massachusetts	-0.55	-20.54	8.83	4.88	5.20	3.25	2.24	1.80
23	Michigan	-0.20	-19.54	16.31	2.45	2.40	1.89	1.14	0.94
24	Minnesota	-0.11	-7.09	2.43	0.55	2.00	1.67	1.39	1.47
25	Mississippi	-0.26	-12.25	8.59	3.83	0.59	1.01	0.72	0.67
26	Missouri	0.36	-8.93	4.44	0.37	2.41	1.87	1.25	1.06

Table continues …

21 **These results show percentage differences in the value of a variable in a quarter from the value it had in the previous quarter**

Quarter-on-quarter percentage growth rates for employment by state: BLS data for the 4 quarters of 2020 followed by USAGE model projections

CoPS

Table continued …

	State	Year 2020 Q1	Q2	Q3	Q4	Year 2021 Q1	Q2	Q3	Q4
27	Montana	0.31	-7.98	5.33	1.66	-0.93	0.04	0.76	1.26
28	Nebraska	0.69	-3.70	2.06	0.55	0.31	0.71	0.63	0.72
29	Nevada	-0.51	-25.88	18.83	3.09	-6.41	-2.77	4.45	7.73
30	New Hampshire	-0.20	-17.26	10.00	3.78	3.26	2.36	1.67	1.41
31	New Jersey	0.64	-13.80	5.91	1.69	3.60	2.47	1.69	1.44
32	New Mexico	-0.16	-9.65	-1.01	4.57	1.93	1.58	1.35	1.34
33	New York	-0.26	-14.69	5.40	1.16	4.18	2.66	1.97	1.72
34	North Carolina	-0.95	-13.00	6.55	3.39	2.24	1.81	1.30	1.15
35	North Dakota	0.42	-6.60	2.04	1.67	0.85	0.95	0.95	1.05
36	Ohio	-0.70	-10.92	5.41	4.23	1.99	1.66	1.01	0.81
37	Oklahoma	-0.08	-10.95	8.98	1.30	-0.03	0.63	0.58	0.75
38	Oregon	0.22	-9.53	1.58	6.50	0.13	0.78	1.16	1.47
39	Pennsylvania	-0.27	-11.22	3.39	2.98	3.38	2.37	1.51	1.18
40	Rhode Island	0.26	-16.37	8.39	2.63	3.94	2.61	1.61	1.18
41	South Carolina	0.18	-8.24	5.52	-0.21	0.65	0.97	1.04	1.19
42	South Dakota	0.43	-6.00	3.56	1.39	0.48	0.82	0.82	0.91
43	Tennessee	0.03	-12.87	6.40	6.11	0.75	1.08	0.99	1.06
44	Texas	-0.75	-12.49	10.03	0.24	0.75	1.03	0.97	1.13
45	Utah	-0.20	-6.34	5.87	1.01	-2.20	-0.54	0.83	1.69
46	Vermont	-0.31	-9.29	3.00	0.59	1.25	1.22	1.51	1.72
47	Virginia	-0.01	-9.72	3.23	1.00	2.60	1.84	1.16	0.98
48	Washington	-0.52	-9.99	6.00	1.54	0.60	0.77	1.08	1.41
49	West Virginia	0.78	-12.46	3.92	3.09	3.22	2.23	1.27	0.88
50	Wisconsin	-0.10	-9.29	6.01	2.31	0.98	1.23	0.99	0.98
51	Wyoming	0.54	-4.68	1.59	1.83	-3.42	-1.10	0.56	1.58

22 **These results show percentage differences in the value of a variable in a quarter from the value it had in the previous quarter**

Employment by state: percentage deviations from level in 4th quarter of 2019

CoPS

(BLS data for the 4 quarters of 2020 followed by USAGE model projections)

	State	Year 2020 Q1	Q2	Q3	Q4	Year 2021 Q1	Q2	Q3	Q4
1	Alabama	-0.57	-9.37	-3.78	-1.98	-0.80	0.46	1.27	1.96
2	Alaska	0.01	-9.36	-6.22	1.06	-3.83	-5.71	-5.52	-4.03
3	Arizona	-0.42	-8.12	-5.42	-4.06	-5.37	-5.48	-4.04	-1.62
4	Arkansas	0.17	-9.01	-6.21	-4.03	-1.84	-0.05	1.04	1.90
5	California	-1.01	-16.11	-11.99	-7.28	-6.10	-4.91	-3.12	-0.90
6	Colorado	-1.12	-10.85	-6.74	-4.70	-4.37	-3.58	-2.07	0.03
7	Connecticut	0.31	-11.44	-6.99	-6.66	-2.49	0.25	1.84	2.95
8	Delaware	-1.09	-13.58	-3.73	-3.16	-1.39	0.13	1.23	2.21
9	District of Columbia	0.79	-8.66	-7.08	-4.68	-5.34	-5.23	-4.01	-2.21
10	Florida	-0.61	-16.96	-8.96	-6.30	-9.34	-10.31	-8.08	-4.18
11	Georgia	-0.20	-11.14	-6.97	-2.43	-2.63	-2.15	-1.14	0.36
12	Hawaii	0.24	-22.49	-16.23	-10.90	-20.32	-24.64	-21.08	-13.88
13	Idaho	0.60	-6.26	-0.48	0.00	-0.72	-0.45	0.13	0.98
14	Illinois	-1.04	-14.15	-9.43	-7.12	-3.91	-1.57	0.11	1.65
15	Indiana	-0.92	-12.56	-5.16	-2.78	-0.66	1.20	2.38	3.32
16	Iowa	-0.79	-10.99	-10.09	-8.28	-3.97	-1.05	0.70	1.94
17	Kansas	0.64	-6.57	-3.95	-0.03	0.18	0.76	1.24	1.80
18	Kentucky	-0.47	-10.36	-9.51	-5.97	-3.15	-1.08	0.28	1.45
19	Louisiana	0.02	-13.24	-4.70	-3.56	-3.53	-2.85	-2.06	-1.08
20	Maine	0.05	-9.96	-5.88	-4.76	-3.83	-2.76	-1.24	0.60
21	Maryland	0.36	-9.82	-6.61	-7.49	-3.46	-0.79	0.86	2.10
22	Massachusetts	-0.55	-20.98	-14.00	-9.80	-5.11	-2.03	0.17	1.97
23	Michigan	-0.20	-19.70	-6.60	-4.32	-2.02	-0.16	0.98	1.92
24	Minnesota	-0.11	-7.19	-4.94	-4.41	-2.50	-0.87	0.51	1.98
25	Mississippi	-0.26	-12.48	-4.96	-1.32	-0.74	0.26	0.99	1.67
26	Missouri	0.36	-8.60	-4.54	-4.19	-1.88	-0.05	1.20	2.27

Table continues …

To see how the results in slides 23 & 24 are related to those in 21 & 22, consider an example. In Y20Q2, this table shows that employment in Alabama is 9.37% less than it was in Y19Q4. This is consistent with Alabama's quarter-on-quarter growth rates of -0.57 and -8.85 for Y20Q1 and Y20Q2 in slide 21: -9.37 = 100*[(1-0.0057)*(1-0.0885)-1)]

23

Employment by state: percentage deviations from level in 4th quarter of 2019

CoPS

(BLS data for first 4 quarters of 2020 followed by USAGE model projections)

Table continued …

	State	Year 2020 Q1	Q2	Q3	Q4	Year 2021 Q1	Q2	Q3	Q4
27	Montana	0.31	-7.69	-2.77	-1.16	-2.08	-2.04	-1.30	-0.06
28	Nebraska	0.69	-3.04	-1.04	-0.49	-0.19	0.52	1.15	1.88
29	Nevada	-0.51	-26.26	-12.37	-9.66	-15.45	-17.80	-14.14	-7.50
30	New Hampshire	-0.20	-17.43	-9.17	-5.73	-2.67	-0.37	1.30	2.73
31	New Jersey	0.64	-13.25	-8.12	-6.57	-3.20	-0.81	0.86	2.32
32	New Mexico	-0.16	-9.79	-10.71	-6.62	-4.82	-3.32	-2.01	-0.70
33	New York	-0.26	-14.91	-10.32	-9.28	-5.48	-2.97	-1.06	0.64
34	North Carolina	-0.95	-13.83	-8.18	-5.07	-2.94	-1.19	0.10	1.25
35	North Dakota	0.42	-6.21	-4.29	-2.70	-1.87	-0.93	0.02	1.07
36	Ohio	-0.70	-11.54	-6.76	-2.81	-0.88	0.76	1.78	2.61
37	Oklahoma	-0.08	-11.02	-3.03	-1.77	-1.80	-1.18	-0.61	0.14
38	Oregon	0.22	-9.33	-7.90	-1.91	-1.79	-1.03	0.13	1.60
39	Pennsylvania	-0.27	-11.46	-8.46	-5.73	-2.55	-0.24	1.27	2.47
40	Rhode Island	0.26	-16.15	-9.12	-6.73	-3.06	-0.53	1.07	2.27
41	South Carolina	0.18	-8.07	-3.00	-3.20	-2.58	-1.63	-0.60	0.58
42	South Dakota	0.43	-5.60	-2.24	-0.88	-0.40	0.41	1.24	2.17
43	Tennessee	0.03	-12.84	-7.27	-1.60	-0.86	0.21	1.20	2.28
44	Texas	-0.75	-13.15	-4.43	-4.21	-3.48	-2.49	-1.55	-0.43
45	Utah	-0.20	-6.53	-1.04	-0.04	-2.24	-2.77	-1.97	-0.31
46	Vermont	-0.31	-9.57	-6.86	-6.31	-5.14	-3.99	-2.53	-0.85
47	Virginia	-0.01	-9.73	-6.81	-5.88	-3.43	-1.65	-0.50	0.47
48	Washington	-0.52	-10.46	-5.09	-3.62	-3.04	-2.30	-1.25	0.15
49	West Virginia	0.78	-11.78	-8.32	-5.49	-2.44	-0.26	1.00	1.89
50	Wisconsin	-0.10	-9.38	-3.93	-1.72	-0.76	0.46	1.45	2.45
51	Wyoming	0.54	-4.17	-2.64	-0.86	-4.25	-5.30	-4.77	-3.26

24

Appendix B.

The effects of COVID-19 on the U.S. macro economy, industries, regions and National Critical Functions

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July 10, 2020

This is the modeling report (fifth deliverable) required by June 30, 2020 under Federal Award no. 17STQAC00001-03-00, Subaward no. ASUB00000508 issued by the U.S. Department of Homeland Security. The project is titled *Economic Modeling of the impacts of COVID-19*, and is being undertaken by the Centre of Policy Studies at Victoria University in Melbourne through the Center of Excellence for Accelerating Operational Efficiency (CAOE) at Arizona State University. The report has benefited from comments by end-users and other stakeholders on three earlier reports submitted in April and May 2020. Minor revisions to the modeling results are incorporated in this report to accommodate recent economic data.

Summary

The Cybersecurity and Infrastructure Security Agency (CISA) is sponsoring a project on the economic effects in the United States of COVID-19. The project is being conducted through the Center for Accelerating Operational Efficiency (CAOE). It aims to quantify COVID-19 effects on the macro economy, industries, regions, transportation systems and National Critical Functions (NCF). This is a report on the project.

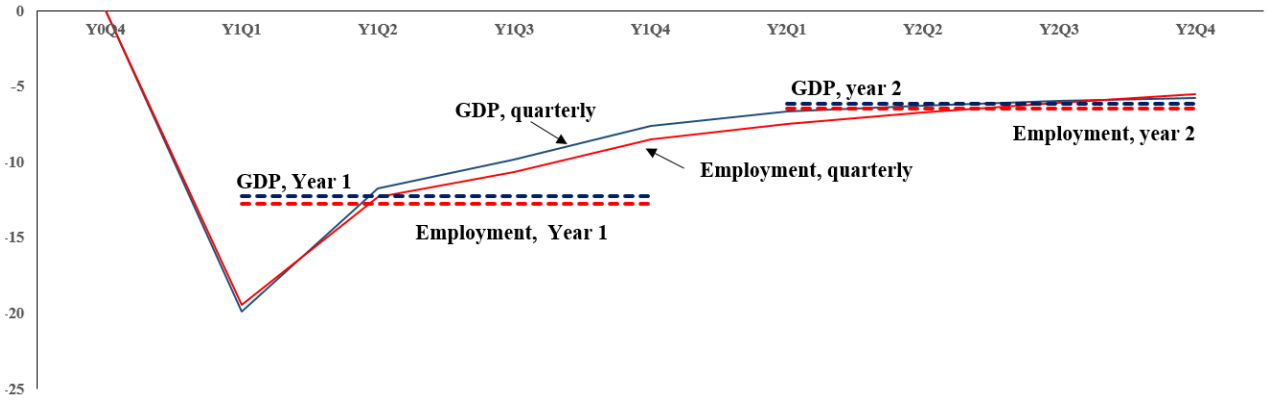
(1) To help understand the likely economic effects of COVID-19, we built USAGE-Q. This is a quarterly model of the U.S. economy that pays particular attention to unemployment and capital shutdown by industry.

(2) According to the CDC, social-distancing aims to flatten the infection curve to buy time for production and distribution of a vaccine, and to decrease the pandemic peak. Thunstrom *et al.* (2020) estimate large benefits from this health policy in terms of reduced morbidity and mortality. We take the public health interventions as a given. Our focus is the economic trough created by the interventions. This paper provides model projections of the trough and recovery that may be experienced by the U.S. economy over the eight quarters starting March 1, 2020.

Macro projections

(3) In the scenario simulated in this paper (figure below), COVID-19 reduces U.S. GDP over the next year by 12.3 percent ($2.6 trillion) and employment by 12.7 percent (22.8 million one-year jobs). These annual numbers disguise an even more serious short-run problem. USAGE-Q shows a 19 percent reduction in employment in the quarter starting March 1, 2020 (denoted by Y1Q1): a loss in the quarter of 30 million full-time equivalent jobs.

Effects of COVID-19 on GDP and Employment: % deviations from no-COVID baseline



(4) While most of the research underlying this project was undertaken in April to June, the results for Y1Q1 were informed by BLS employment data up to July 2, 2020.

(5) In generating the economic recovery shown above, we assumed that widespread shutdowns will not be reintroduced over extended periods in the coming months. This will allow many businesses and workers to pick up approximately where they left off, with only moderate loss of capital. As recognized in the Coronavirus Aid, Relief and Economic Security (CARES) Act, this requires policies that assist businesses to remain solvent and laid-off workers to remain linked to their employers for ready re-employment in the upswing.

(6) Although in our scenario the economy shows steady recovery, GDP and employment in year 2 remain about 6 percent below baseline (where they would have been in the absence of COVID).

Industry projections

(7) The tourism industries are the worst affected by COVID-19. Vacation activities are almost eliminated in Y1Q1. U.S. airlines suffer output losses in Y1Q1 of about 68 percent.

(8) The output for Hotels & restaurants in Y1Q1 is down by 64 percent.

(9) Medical equipment & services show an output gain of 13.4 percent in Y1Q1 reflecting the CARES increase in government purchases of these items. Food, beverages & tobacco also have a positive result (0.9 percent) in Y1Q1. Industries that suffer relatively light damage in Y1Q1 are Agriculture (-3.7 percent) and Production of government services (-1.3 percent).

(10) Most industries show substantial recovery through the simulation period. However Construction is slow to recover and its output is still 24 percent below baseline in Y2Q4. We assume that investment will stay depressed through an adverse confidence effect.

Air and rail transport projections

(11) Although we are projecting considerable recovery in the airline industry through 2020 and 2021, the total projected COVID-induced loss of sales for the industry over the 12 months starting March 1, 2020 is $109 billion: $47 billion on the international market and $62 billion on the domestic market.

(12) The majority of airline losses in year 1 are sales to passengers (tourists and business travelers). International freight sales move approximately with merchandise trade (particularly high-tech equipment exports) and domestic freight sales move approximately with GDP. Both merchandise trade and GDP exhibit simulated downturns, but not nearly as sharp as those for tourism and business travel.

(13) Domestic and international travel remain depressed through the simulation period. However, U.S. airlines providing international services gain some relief from foreign competition in year 2 through real devaluation of the U.S. currency.

(14) The COVID-induced deviations in the rail output variables are similar to those in GDP.

Regions

(15) The worst affected states are Hawaii and Nevada, reflecting their dependence on tourism. In Y1Q1, both employment and gross regional product (GRP) in these states shrink by about 40 percent.

(16) By Y2Q4, the GRP and employment deviations for all regions have moved close to the national deviations of about -6 percent. Regional differences are muted by the gradual recovery of tourism. At the same time, differences across states in the early quarters caused by regional differences in the incidence of COVID-19 disappear as the epidemic recedes.

National Critical Functions

(17) CISA advises the government on the capability of the economy to maintain National Critical Functions (NCF). Using the USAGE-Q results for industries, we calculated COVID effects on the economy's capability to support each function.

(18) The most adversely affected NCF capabilities in Y1Q1 are for: NCF 21 (*Educate and train*); NCF 13 (*Transport cargo and passengers by air*); NCF 15 (*Transport cargo and passengers by road*); NCF 11 (*Maintain supply chains*); NCF 54 (*Research and development*), and NCF 46 (*Manufacture equipment*).

(19) For NCF 21 (*Educate and train*), the adverse impact in Y1Q1 can be traced to the sharp contraction in output of the USAGE-Q Education industry.

(20) The adverse Y1Q1 impact for NCF 54 (*Research and development*) is largely due to output contractions in industries that supply heavily to investment activities.

(21) The capability indicator for NCF 46 (*Manufacture equipment*) is largely determined by output movements for machinery industries. These industries are adversely affected in Y1Q1 by dependence on investment and shutdowns in the supply of consumer durables.

(22) For NCF 13 (*Transport cargo and passengers by air*), the adverse capability impact in Y1Q1 arises mainly from the sharp contractions in the outputs of USAGE-Q industries Air transport domestic and Air transport international.

(23) For NCF 15 (*Transport cargo and passengers by road*), the adverse capability impact in Y1Q1 is largely attributable to output contraction in the *Motor vehicle manufacturing* sector.

(24) For NCF 11 (*Maintain supply chains*), the adverse capability impact in Y1Q1 arises mainly from output contractions in the retail and wholesale trade sectors, which are subject to adverse shutdown shocks.

(25) From Y1Q3 onwards, the capability indicators for most NCF categories return towards their baseline values. However, for five categories, there are persistent relatively large negative deviations through the simulation period. These are: NCF 31 (*Provide and maintain infrastructure*); NCF 20 (*Develop and maintain public works and services*); NCF54 (*Research and development*); NCF 51 (*Provide housing*); and NCF 43 (*Exploration and extraction of fuels*). The persistent negatives for these NCFs can be traced to continuing negative deviations for investment.

Concluding remarks

(26) In this paper we investigate just one scenario leading to a deep economic trough in Y1Q1 followed by steady but incomplete recovery over the next seven quarters.

(27) For modeling research to be of sustained value to policy, it needs to be adjustable and timely. The scenario used in USAGE-Q can be adjusted as events unfold. As demonstrated in this paper, USAGE-Q projections can be updated in response to data releases by the BLS and other statistical agencies as they occur.

(28) Each agency of the U.S. government has different policy levers relevant to its area of responsibility. In operating these levers in response to COVID-19, agencies require a view of how COVID-19 will impact their areas of interest. A model such as USAGE-Q doesn't tell us how agencies should operate their policy levers. However, results generated by such models can inform policy decisions.

(29) Projections for state and county economies are required by state and local governments and federal agencies with responsibilities for identifying regions whose economies may be particularly adversely affected by COVID-19. Understanding the likely depth and longevity of relative disadvantage for each region might be helpful in allocating federal funds between regions. Within regions, USAGE-Q could be used to identify employment and output effects for each industry. This might help state and local governments to identify possibilities for using their state fiscal levers for assisting disadvantaged industries and sub-state regions in which these industries are located.

(30) USAGE-Q results suggest that throughout the U.S., hotels are likely to be underused for at least the next 6 months. This raises the possibility of finding policy levers through which hotels could be used to isolate potential COVID-19 carriers for whom other isolation options are unavailable. Another possibility is to make hotel rooms available to health workers for whom living at home presents risks to family members.

(31) Persistent excess capacity indicated by USAGE-Q for transport networks might, with appropriate levers, be used in transporting workers to remote mining sites in a way that meets social-distancing requirements (e.g. filling only a third of the seats).

(32) The persisting weakness of the Export education industry projected by USAGE-Q suggests that it may be fruitful to look for policy levers that would lead to productive use of excess physical and teaching capacity in higher education.

(33) Post COVID-19, there will be difficult financial problems associated with public and private debts that are being accumulated at present. Analyzing these problems in a formal model and developing policies to cope with them is a major and urgent challenge.

1. Introduction

COVID-19 presents a difficult tradeoff. According to the U.S. Centers for Disease Control (CDC), the goals of social-distancing measures are to flatten the infection curve in order to delay the growth in infections and buy time for production and distribution of a vaccine, decrease the peak of the pandemic, and ultimately reduce morbidity and mortality[5]. These policies also generate an economic trough, with more flattening being associated with a deeper trough. This paper projects the trough and recovery that may be experienced by the U.S. economy. It does not estimate the costs or benefits of public health interventions, which others have estimated to have large net benefits given the morbidities and mortalities avoided through such interventions, see for example Thunstrom *et al.* (2020).

Understanding the depth of the trough is a necessary part of preparing government and private-sector organizations for the enormous task required to support people who lose their incomes in the short run and to position businesses so that they can spring back when the pandemic eases.

The U.S. response to COVID-19 includes restrictions on non-essential travel and the shutdown of many activities. It also includes a large increase in public expenditure. To help understand likely economic effects, we have built USAGE-Q. This is a model of the U.S. economy that has two features not present in the standard version of USAGE.[6] First, USAGE-Q is quarterly rather than annual. Second, it allows for under-use of existing capital (excess capacity). Both these features are valuable for studying the economic effects of pandemics. They allow us to project the effects of disease-related shutdowns that last for much less than a year, and to incorporate the effects of leaving buildings unused and machines idle.

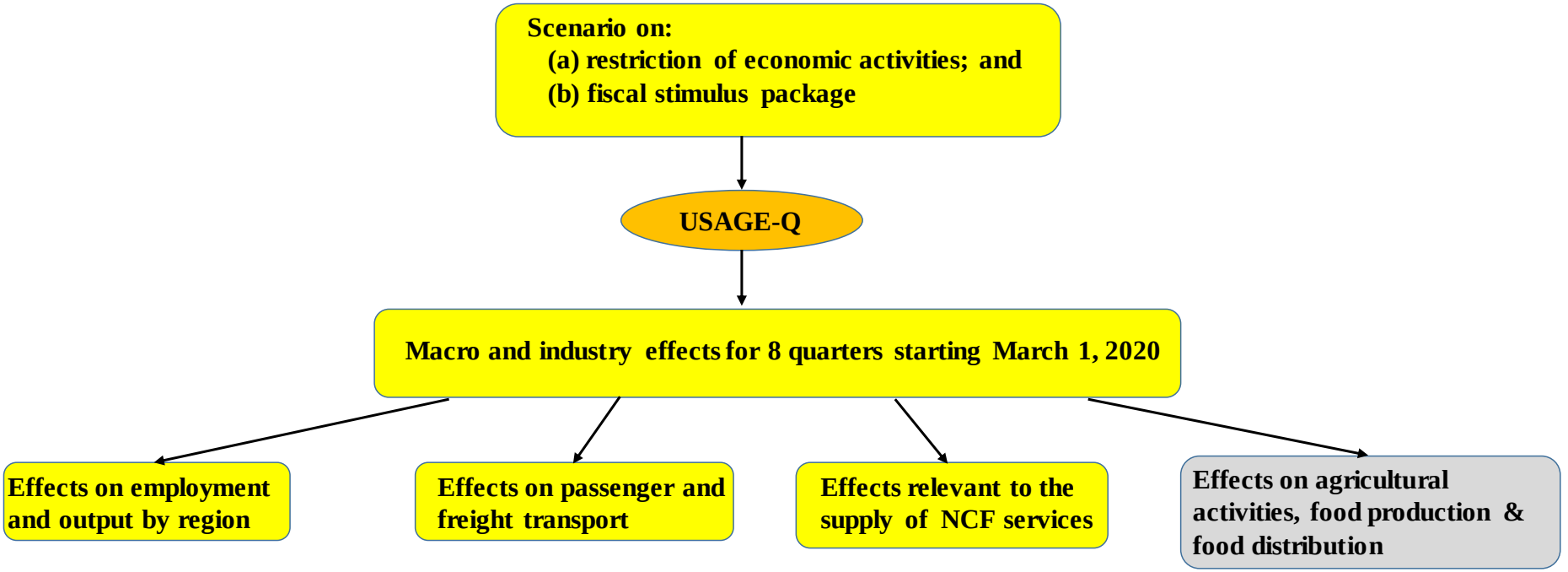
As shown in Figure 1, USAGE-Q takes a scenario of COVID-related restrictions on economic activities and stimulus responses and translates it into projections for the macro economy and industries. These projections go quarter-by-quarter for 8 quarters starting March 1, 2020. Then using the macro and industry projections, we can trace out implications for variables of interest to particular policy groups. Here, we report COVID-19 effects on: the economies of states , a dimension of interest to regional groups in the Federal Emergency Management Agency (FEMA); the volumes of passenger and freight traffic, a dimension of interest to the Transportation Security Administration (TSA); and activities supporting National Critical Functions (NCF), a dimension of interest to the Cybersecurity and Infrastructure Security Agency (CISA). In an extension of this project, we are using USAGE-Q to look at COVID-19 implications for U.S. agriculture disaggregated into ten farm industries. We have also built a facility for disaggregating state results to counties.

Readers of the paper need not be familiar with USAGE or USAGE-Q, but it will be helpful to understand that a simulation with these models consists of two runs: a baseline run and a perturbation run. The baseline run is intended to show how the economy would develop in the absence of the event (in this case the COVID-19 epidemic) under consideration. The baseline used in this paper depicts a business-as-usual scenario over 2 years (eight quarters) starting March 1, 2020. In this baseline, employment grows at 0.224 percent per quarter or 0.9 percent per year,

[5] See, for example, Johns-Hopkins University (2020).

[6] USAGE has been used over the last 20 years in studies of a wide variety of topics for several departments of the U.S. government, see for example, Dixon *et al.* (2013). The closest previous application to the one described here was concerned with the H1N1 virus, see Dixon *et al.* (2010).

Figure 1. Applying USAGE-Q to simulate the economic effects of COVID-19



and real GDP grows at 0.472 percent per quarter or 1.9 percent a year. These forecasts are consistent with the forecast made in mid-2019 by the IMF, see IMF (2019). The perturbation run introduces shocks representing the event under consideration. These are applied to the model and results are generated as deviations from the baseline.

Section 2 outlines shocks used in this paper to represent COVID-19, including shutdowns and the fiscal policy response. Section 3 describes the effects of the shocks on macro and industry variables. Sections 4 quantifies the effects of the shocks on state economies. It also describes the add-on facility for taking the state results to the county level. Sections 5 and 6 present results for passenger & freight transport, and the supply of NCF services. Concluding remarks are in Section 7.

The paper contains four appendices. Appendix 1 shows how we have used monthly employment data from the Bureau of Labor Statistics to ensure that the results in the paper reflect the current situation (up to the beginning of July). Appendix 2 provides technical details on the shutdown and fiscal shocks. Appendix 3 shows how we used epidemiological modeling from the U.S. Department of Health and Human Services to calculate shocks to labor-supply. Appendix 4 gives details of our calculations for NCF services and outlines plans for improving these calculations.

2. Shocks to represent a COVID-19 scenario

The scenario we analyze in this paper is represented by two sets of shocks. The first set is concerned with shutdowns of particular activities imposed either by governments or arising from behavior of households and businesses. The second set introduces the main macro policy response, the CARES Act. Details of both sets are in Appendix 2.

The main features of the first set of shocks are:

- almost complete cessation of international travel for tourism and business into and out of the U.S. in Y1Q1 and Y1Q2. In later quarters, international travel recovers substantially but remains subdued to the end of the two year simulation period.
- almost complete cessation of domestic travel for tourism and business in Y1Q1. Domestic travel picks up in Y1Q2, but as with international travel remains subdued to the end of the simulation period.
- a 40 percent reduction in aggregate investment in Y1Q1 followed by gradual recovery in subsequent quarters. Investor confidence remains low through the simulation period and investment is still 23.5 percent below baseline in Y2Q4.
- a 15 percent inward shift in demand curves for U.S. exports in year 1. In year 2, the demand curves stay in their depressed positions but real devaluation allows exports to recover approximately to their baseline paths.
- a 26.7 percent reduction in Y1Q1 in the average propensity to consume (the ratio of household spending to household income). This is brought about by inability to spend on vacations, restaurants and other consumer goods of choice during the period of most intense shutdown. Subsequently, the average propensity to consume recovers to normal levels.
- up to 90 per cent shutdown-related reductions in household spending in Y1Q1 on non-essential products such as Entertainment and Hotels & restaurants. Shutdown

reductions ease in Y1Q2. Spending on these products returns to normal levels in relation to income from Y1Q3 onwards.

The main features of the second set of shocks (the CARES Act, March 27, 2020) are:

- additional purchases by the government of goods and services worth $190 billion. These purchases are concentrated almost entirely in Y1Q1 and Y1Q2 and are predominantly medical related.
- transfers from the government to households worth $1636 billion. These transfers include payments to households such as wage replacement for workers who have lost their jobs, and tax relief measures such as temporary suspension of payroll taxes. While the bulk of transfers are in Y1Q1 and Y1Q2, there are considerable transfers in the rest of the simulation period.

3. Core USAGE-Q results

3.1. Macro variables

Table 1 shows USAGE-Q results for the macro-economic effects of the shocks described in Section 2 and detailed in Appendix 2, Tables A2.1 and A2.2. The results are percentage deviations from baseline expressed in annual terms. For example, the year-1 result for employment means that on average over the year starting March 1, 2020, we are projecting that COVID-19 will reduce aggregate employment by 12.74 percent below baseline (row 1, Table 1). Put another way, instead of growing at 0.9 percent, with COVID-19 we project that employment will decline by 11.95 percent.[7] A decline in employment of 11.95 percent is equivalent to a loss of about 18.6 million one-year jobs. As we will see shortly, this disguises much sharper losses in employment in Y1Q1 and Y1Q2.

Despite high levels of unemployment there is little change in real wage rates (an increase in 0.84 per cent in year 1 and a decline of 0.45 per cent in year 2). Declines in nominal wages, reflecting the weakness of the labor market are broadly matched by declines in prices.

Table 1. COVID-19 effects:
% deviations from baseline in macro-economic variables

		Year 1	Year 2
1	Aggregate employment	-12.74	-6.45
2	Average real wage rate	0.84	-0.45
3	Quantity of physical capital in use	-9.57	-4.19
4	Quantity of physical capital in existence	-1.27	-3.65
5	Real GDP	-12.27	-6.17
6	Real investment	-33.21	-25.73
7	Real private consumption	-12.92	-4.01
8	Real household disposable income	-1.22	-3.91
9	Real public consumption	5.79	0.65
10	Real exports	-13.11	-0.58
11	Real imports	-28.22	-13.85

[7] -11.95 = 100*{1.009*(1-0.1274)-1}

COVID-19 will cause considerable under-use of the U.S. capital stock (that is, temporary closure of offices and factories, and idling of machines). This is shown in rows 3 and 4 of Table 1. Whereas COVID-19 causes capital in existence in years 1 and 2 to fall 1.27 and 3.65 percent below baseline, the corresponding falls for capital in use are 9.57 and 4.19 percent. Put another way, COVID-19 causes considerable additional excess capacity in year 1 followed by mild excess capacity in year 2. The negative deviations for capital in existence in both years reflect large negative deviations for investment (row 6) together with moderate loss of capital through business closures.[8]

Weakness of the world economy causes U.S. exports to move well below baseline in year 1, row 10. The bounce-back in exports in year 2 is facilitated by improvement in U.S. competitiveness generated by real devaluation (that is a reduction in the U.S. price level relative to that of its trading partners after correction for exchange rate movements). Real devaluation follows from the U.S. being one of the countries worst affected by the pandemic and the consequent reduction in foreign willingness to finance U.S. trade deficits. In both simulation years, there are sharp reductions in U.S. imports below baseline, row 11. Real devaluation makes imports expensive in the U.S. and explains why the deviations in imports are below those in GDP.

By replacing lost income for unemployed workers and assisting businesses to stay viable, the CARES recovery package limits the fall in real household disposable income in year 1 to 1.22 per cent (row 8). Nevertheless, real private consumption falls 12.92 per cent below baseline (row 7). The recovery package enables households to maintain essential expenditures on items such as food, rent and mortgage repayments but the stimulatory effect on private consumption is muted by the inability of households to spend on vacations and other non-essentials.

Extra public consumption in year 1 (row 9) limits the fall in U.S. GDP to 12.27 percent below baseline (row 5). In year 2, GDP partially recovers (a negative deviation of 6.17 percent). The partial recovery of GDP in year 2 is assisted by recovery of exports and partial recovery of private consumption. Release of pent-up consumer demand from year 1 makes partial recovery of private consumption ahead of GDP plausible.

Figures 2 to 4 present quarterly results for variables in Table 1. These quarterly results underline the huge economic challenge posed for the U.S. by COVID-19. While a 12.74 percent negative deviation for employment over a year is a serious problem, Chart 2 shows an even more serious problem, a 19 percent reduction in employment in the first quarter, a loss of 30 million jobs relative to baseline. Such a reduction in employment has the potential to severely strain public and private support networks for people who lose their jobs.

On June 5, the Bureau of Labor Statistics (BLS) announced that unemployment for May according to their U-4 measure was 13.3 percent (see https://www.bls.gov/news.release/pdf/empsit.pdf). U-4 is the sum of the number of people that are unable to find a job *plus* those discouraged by the state of the economy from looking for a job expressed as a percentage of the civilian labor force including discouraged workers.[9] As

[8] We introduced loss of capital through business closures by assuming that idle capital depreciates at a faster rate than does capital in use.

[9] See Table A-15 in BLS (2020b).

explained by the BLS, there were a large number of people absent from work in May who were represented in the survey by people who answered the question about employment status by saying they were employed. While they still had a job, they were not actually contributing labor input. They were waiting to be called back into work. BLS estimated that this biased the unemployment rate down by 3 percentage points. On this basis we can think of the unemployment rate as being about 16.3 percent (= 13.3 + 3). Our 19 percent is an hours measure rather than a people measure: it is a measure of lost labor input. It includes reductions in hours of work and loss of second jobs. Conceptually it is closest to the BLS U-6 measure of unemployment which showed rates of 22.4 and 20.7 per cent in April and May 2020.[10] Corrected for the 3 per cent problem, these U-6 measures would have been 25.4 and 23.7 per cent. With baseline U-6 unemployment being about 6 per cent, the COVID-19 labor loss caused by U-6 is close to our projection of 19 per cent.

On July 2, the BLS released unemployment figures for June (see https://www.bls.gov/news.release/pdf/empsit.pdf). On their U-4 measure June unemployment was 11.6 percent (down from 13.3 percent in May). On their U-6 measure, June unemployment was 18.3 percent (down from 20.7 percent in May). In Figure 2, aggregate employment is 12.3 percent below baseline in Y1Q2 (June-August 2020), up from 19.4 per cent below baseline in Y1Q1. The recovery in employment shown in Figure 2 is consistent with the steady reduction in unemployment apparent in the BLS figures.

3.2. Industry variables

Table 2 shows COVID-19 effects on industry outputs. To keep the presentation manageable, we aggregated USAGE-Q outputs for the 91 commodities listed in Table A2.3 in Appendix 2 into results for 31 industries. In this aggregation, we retained key vulnerable industries in their un-aggregated state.

The table ranks the 31 industries by damage in Y1Q1 (shaded in the table). At the top of the table (worst affected) are the three tourism industries: Export tourism (vacations in the U.S. by foreigners); Foreign vacation (foreign vacations by U.S. residents); and Domestic vacation (vacations by U.S. residents in the U.S.). We expect these vacation activities to be almost completely eliminated in Y1Q1.

U.S. airlines providing international and domestic services suffer output losses of 73.0 and 65.0 percent in Y1Q1. This reflects cuts in tourism and the general reduction in business activity.

Hotels & restaurants suffer a 64.2 percent negative deviation in Y1Q1. This strongly negative result follows from reduction in tourism in the U.S. and shutdown of household expenditures on local hotels and restaurants.

At the bottom of the table, Medical equipment & services shows a positive deviation (13.4 percent) reflecting the CARES increase in government purchases of these items. Food, beverages & tobacco also has a positive result in Y1Q1 (0.9 percent). This reflects diversion of expenditure by households away from unavailable commodities due to shutdown. Industries that suffer relatively light damage are Agriculture (-3.7 percent), and Production of government services (-1.3 percent).

[10] See Table A-15 in BLS (2020b).

Figure 2. Effects of COVID-19 on aggregate employment and the average real wage rate (% deviations from baseline)

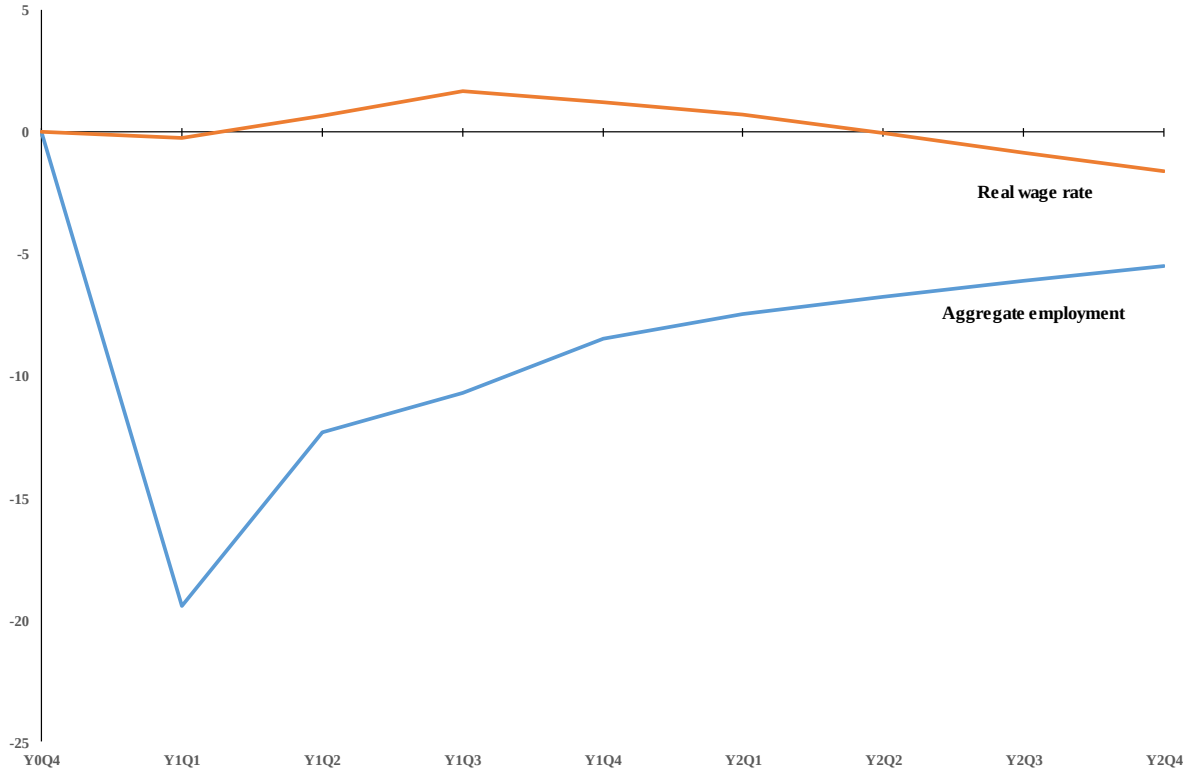


Figure 3. Effects of COVID-19 on capital in existence and capital in use (% deviations from baseline)

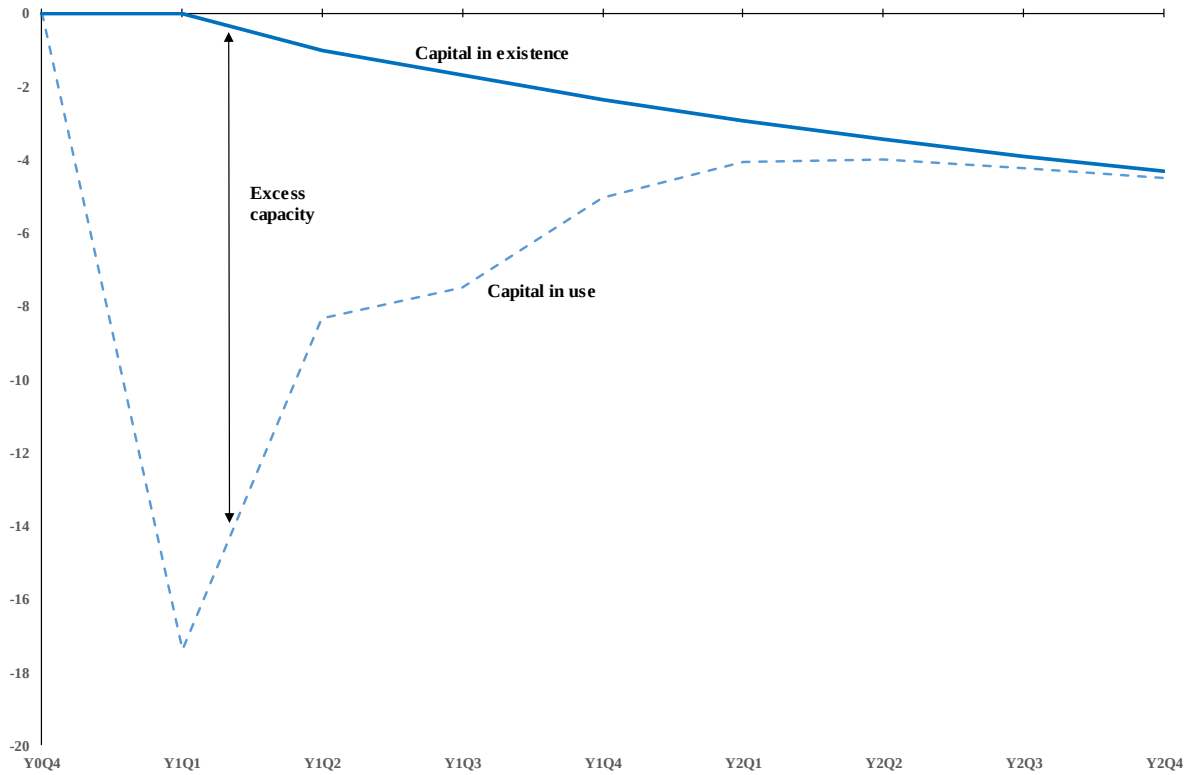
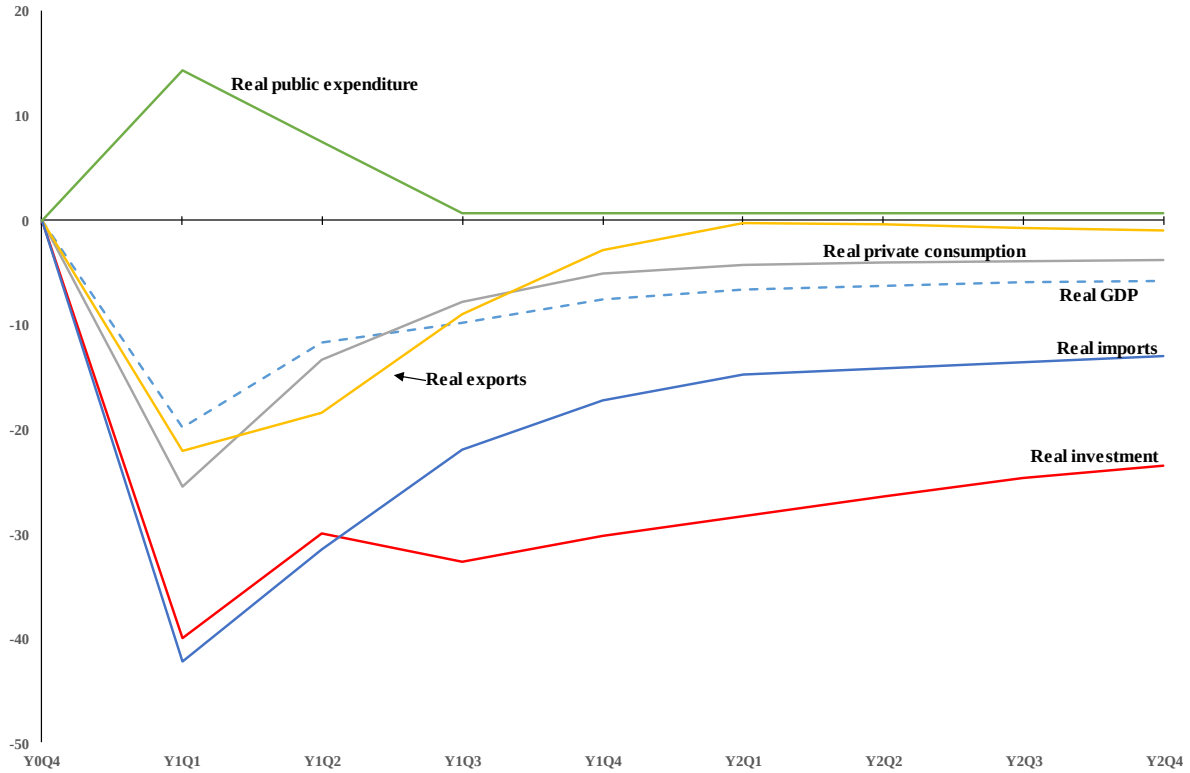


Figure 4. Effects of COVID-19 on real GDP and macro expenditure aggregates (% deviations from baseline)



Looking across Table 2, we see that most industries show substantial recovery by Y1Q4. However, the tourism industries remain depressed, especially Export tourism and Foreign vacation. This explains the poor outcome for Air transport international which still has output 16.8 percent below baseline in Y1Q4.

Construction is slow to recover and shows a deviation of -29.2 percent at the end of year 1. Its output stays around 25 percent below baseline through year 2. This follows from our assumption that COVID-19 will reduce investment via an adverse confidence effect.

4. Regional results

Tables 3 and 4 show COVID-19 effects on gross regional product (GRP) and employment for the 51 states (incudes District of Columbia). The tables were generated by a modified top-down method starting from the national results for output and employment by industry. As explained in Appendix 1, the modification introduced BLS employment data by state for May 2020 published in June.

The top-down method takes account of the industrial composition of output and employment in each state, local multiplier effects and regional connections via trade.[11] If a state specializes in the production of traded goods and services that do badly at the national level, then on this account the top-down projection will indicate outcomes for the state's gross regional product (GRP) and employment that are worse than those for GDP and aggregate

[11] The top-down method is described in USITC (2004) and Dixon *et al.* (2007).

Table 2. Effects of COVID-19 on industry outputs: percentage deviations from baseline

	Year 1				Year 2			
	Y1Q1	**Y1Q2**	**Y1Q3**	**Y1Q4**	**Y2Q1**	**Y2Q2**	**Y2Q3**	**Y2Q4**
Export tourism	-95.4	-95.1	-49.3	-23.7	-11.4	-11.9	-12.3	-12.7
Foreign vacation	-95.0	-95.0	-50.0	-25.0	-10.0	-10.0	-10.0	-10.0
Domestic vacation	-95.0	-47.5	-25.0	-10.0	-10.0	-10.0	-10.0	-10.0
Air transport, international	-73.0	-70.3	-36.1	-16.8	-9.9	-10.1	-10.2	-10.3
Education	-67.8	-35.3	-6.4	-4.5	-3.5	-3.1	-2.8	-2.5
Air transport, domestic	-65.0	-47.2	-26.3	-13.0	-11.3	-11.2	-11.1	-11.0
Hotels & restaurants	-64.2	-33.3	-8.5	-5.7	-5.0	-4.7	-4.4	-4.2
Export education	-40.4	-45.4	-48.5	-23.0	-8.2	-7.9	-7.7	-7.4
Other non-resident spending	-39.3	-33.6	-31.9	-16.6	-16.0	-16.0	-16.2	-16.3
Machinery	-34.4	-19.2	-12.5	-9.9	-8.7	-8.0	-7.4	-6.9
Entertainment & recreation	-34.3	-17.6	-9.4	-7.2	-6.3	-6.1	-6.0	-5.9
Construction	-34.1	-29.9	-32.0	-29.2	-27.4	-25.9	-24.5	-24.0
Wholesale & retail	-29.9	-17.3	-11.0	-8.7	-7.9	-7.5	-7.1	-6.8
Mining	-28.0	-16.4	-12.2	-9.3	-8.4	-8.2	-8.1	-8.3
Warehousing	-26.0	-14.8	-9.3	-7.0	-6.2	-5.8	-5.4	-5.1
Wood & metal products	-25.7	-15.4	-11.3	-8.7	-7.6	-7.0	-6.5	-6.3
Apparel & textiles	-24.7	-12.1	-5.7	-3.4	-2.7	-2.2	-1.8	-1.5
Water transport, domestic	-22.4	-13.0	-7.8	-5.6	-4.9	-4.8	-4.7	-4.7
Truck transport	-22.4	-13.8	-11.5	-8.9	-7.9	-7.5	-7.2	-6.9
Other transport services	-21.3	-13.6	-9.5	-6.1	-5.1	-4.8	-4.5	-4.3
Other services	-20.5	-10.9	-10.2	-7.7	-6.6	-6.1	-5.7	-5.5
Chemical products	-20.3	-11.4	-7.1	-4.8	-4.3	-4.3	-4.3	-4.3
Rail transport	-20.0	-12.0	-8.9	-6.5	-5.7	-5.2	-5.2	-5.2
Pipeline	-17.8	-10.8	-8.0	-5.6	-4.8	-4.8	-4.9	-5.1
Utilities	-13.6	-9.4	-10.0	-7.1	-6.0	-5.4	-4.9	-5.0
Urban gr'd passenger trans	-12.1	-8.0	-9.2	-6.4	-5.4	-4.9	-4.7	-4.5
Water transport, international	-10.5	-6.7	-4.3	-2.6	-2.1	-2.2	-2.3	-2.5
Agriculture	-3.7	-4.2	-6.0	-3.8	-3.2	-3.2	-3.2	-3.3
Production of gov't services	-1.3	-0.7	-0.5	-0.3	-0.3	-0.3	-0.2	-0.2
Food, beverages & tobacco	0.9	-2.4	-5.7	-3.6	-3.0	-2.8	-2.6	-2.5
Medical equip & services	13.4	3.9	-6.8	-4.9	-4.3	-4.0	-3.7	-3.4

national employment. The bad news from the state's traded industries is accentuated in the top-down calculation via local multiplier effects that take account of the links between regional income and the demand in the region for non-traded goods and services such as retail trade. If state r relies strongly on state j for sales of its products, then the top-down projection method recognizes that a poor outcome for state j has a negative impact on the outcome of state r.

The dominant influence in the results in Tables 3 and 4 in the early quarters is tourism connection. The two states with greatest dependence on tourism are Hawaii and Nevada. In Y1Q1, GRP and employment in Hawaii fall 46.18 per cent and 44.25 percent below baseline. For Nevada the negative deviations are 39.79 percent and 39.83 percent. Florida is another region with relatively high dependence on tourism, giving it GRP and employment results in Y1Q1 (-26.32 per cent and -26.02 percent) that are considerably worse than the national results (-19.9 percent and -19.4 percent).

Table 3. Effects of COVID-19 on gross regional product (GRP) by state & D.C.: percentage deviations from baseline

		Year 1				Year 2			
	State	**Y1Q1**	**Y1Q2**	**Y1Q3**	**Y1Q4**	**Y2Q1**	**Y2Q2**	**Y2Q3**	**Y2Q4**
1	Alabama	-16.34	-8.81	-7.51	-6.03	-5.44	-5.17	-4.98	-4.83
2	Alaska	-21.40	-12.22	-9.24	-6.93	-6.34	-6.22	-6.17	-6.20
3	Arizona	-18.56	-10.29	-8.61	-6.70	-6.26	-6.16	-6.14	-6.17
4	Arkansas	-16.56	-8.46	-8.32	-6.39	-5.66	-5.27	-4.95	-4.68
5	California	-21.19	-11.60	-9.91	-7.72	-7.09	-6.87	-6.74	-6.67
6	Colorado	-18.64	-11.44	-9.57	-7.84	-7.27	-7.06	-6.95	-6.92
7	Connecticut	-17.55	-12.86	-11.48	-8.92	-7.28	-6.47	-5.88	-5.52
8	Delaware	-18.60	-10.63	-9.79	-7.19	-5.94	-5.29	-4.79	-4.44
9	District of Columbia	-21.21	-12.73	-10.01	-7.26	-6.12	-5.53	-5.07	-4.76
10	Florida	-26.32	-15.14	-11.35	-8.17	-7.43	-7.30	-7.24	-7.23
11	Georgia	-17.68	-10.43	-8.86	-6.93	-6.21	-5.90	-5.68	-5.52
12	Hawaii	-46.18	-27.03	-15.67	-8.66	-7.21	-7.12	-7.08	-7.11
13	Idaho	-16.13	-8.38	-7.50	-5.88	-5.37	-5.20	-5.09	-5.02
14	Illinois	-18.51	-11.73	-10.22	-8.15	-7.17	-6.70	-6.36	-6.14
15	Indiana	-16.95	-10.28	-8.32	-6.72	-5.98	-5.67	-5.45	-5.30
16	Iowa	-16.84	-9.05	-8.41	-6.64	-5.98	-5.67	-5.45	-5.27
17	Kansas	-16.20	-8.29	-8.12	-6.44	-5.80	-5.48	-5.19	-4.97
18	Kentucky	-17.05	-9.29	-7.93	-6.07	-5.36	-5.02	-4.75	-4.53
19	Louisiana	-18.89	-12.38	-8.96	-7.00	-6.15	-5.84	-5.66	-5.58
20	Maine	-20.27	-10.15	-9.32	-6.58	-5.73	-5.35	-5.06	-4.82
21	Maryland	-17.73	-11.30	-10.34	-8.15	-6.96	-6.34	-5.86	-5.55
22	Massachusetts	-20.93	-15.13	-12.80	-9.82	-8.03	-7.13	-6.46	-6.03
23	Michigan	-20.43	-13.73	-10.73	-8.42	-7.10	-6.45	-5.98	-5.66
24	Minnesota	-16.84	-9.18	-8.99	-7.18	-6.52	-6.19	-5.94	-5.76
25	Mississippi	-17.67	-9.86	-7.23	-5.77	-5.14	-4.87	-4.68	-4.55
26	Missouri	-16.94	-9.07	-7.70	-6.22	-5.67	-5.42	-5.23	-5.08
27	Montana	-19.05	-8.96	-8.40	-6.00	-5.44	-5.23	-5.08	-4.94
28	Nebraska	-14.45	-7.51	-8.00	-6.33	-5.78	-5.55	-5.34	-5.17
29	Nevada	-39.79	-22.20	-13.52	-9.29	-8.71	-8.57	-8.51	-8.52
30	New Hampshire	-19.81	-10.93	-10.06	-7.98	-7.07	-6.64	-6.32	-6.10
31	New Jersey	-17.90	-13.84	-12.03	-9.36	-7.72	-6.88	-6.31	-5.98
32	New Mexico	-18.42	-9.92	-8.25	-6.34	-5.70	-5.45	-5.27	-5.15
33	New York	-19.82	-14.10	-11.57	-8.58	-6.94	-6.17	-5.61	-5.26
34	North Carolina	-18.39	-9.48	-8.56	-6.37	-5.55	-5.13	-4.81	-4.52
35	North Dakota	-17.90	-8.64	-9.47	-6.96	-6.13	-5.73	-5.41	-5.11
36	Ohio	-17.45	-9.68	-8.45	-6.65	-5.87	-5.48	-5.20	-4.98
37	Oklahoma	-18.31	-10.01	-8.82	-7.02	-6.31	-6.00	-5.77	-5.61
38	Oregon	-17.92	-9.60	-8.89	-7.23	-6.74	-6.56	-6.43	-6.35
39	Pennsylvania	-17.21	-11.21	-10.17	-7.81	-6.57	-5.96	-5.50	-5.20
40	Rhode Island	-20.00	-13.72	-11.61	-8.71	-7.02	-6.17	-5.56	-5.15
41	South Carolina	-18.14	-9.79	-7.42	-5.75	-5.19	-4.99	-4.86	-4.77
42	South Dakota	-16.79	-7.91	-7.94	-5.87	-5.21	-4.92	-4.67	-4.46
43	Tennessee	-17.12	-9.14	-7.87	-6.28	-5.73	-5.47	-5.29	-5.14
44	Texas	-18.85	-10.42	-8.72	-6.93	-6.37	-6.19	-6.09	-6.02
45	Utah	-17.42	-9.57	-7.95	-6.37	-5.99	-5.91	-5.87	-5.88
46	Vermont	-21.37	-11.73	-8.75	-6.11	-5.19	-4.83	-4.61	-4.45
47	Virginia	-16.96	-9.35	-8.39	-6.62	-5.87	-5.50	-5.23	-5.04
48	Washington	-18.27	-10.64	-9.66	-7.71	-6.96	-6.62	-6.37	-6.20
49	West Virginia	-18.46	-8.97	-9.25	-6.94	-5.99	-5.45	-4.98	-4.58
50	Wisconsin	-17.10	-9.25	-8.78	-7.06	-6.39	-6.08	-5.84	-5.66
51	Wyoming	-18.37	-11.02	-8.70	-7.05	-6.66	-6.64	-6.71	-6.87

Table 4. Effects of COVID-19 on regional employment: percentage deviations from baseline

		Year 1				Year 2			
	State	**Y1Q1**	**Y1Q2**	**Y1Q3**	**Y1Q4**	**Y2Q1**	**Y2Q2**	**Y2Q3**	**Y2Q4**
1	Alabama	-15.76	-9.23	-8.24	-6.78	-6.05	-5.47	-4.93	-4.43
2	Alaska	-19.28	-11.88	-9.92	-7.80	-7.09	-6.67	-6.25	-5.84
3	Arizona	-18.23	-11.19	-9.51	-7.64	-7.06	-6.66	-6.26	-5.90
4	Arkansas	-15.90	-8.85	-9.15	-7.23	-6.34	-5.64	-4.95	-4.32
5	California	-21.05	-12.66	-10.90	-8.77	-8.04	-7.49	-6.94	-6.46
6	Colorado	-18.29	-12.07	-10.40	-8.77	-8.12	-7.61	-7.11	-6.69
7	Connecticut	-17.52	-13.21	-12.17	-9.74	-8.10	-7.03	-6.10	-5.38
8	Delaware	-18.30	-11.10	-10.87	-8.29	-6.86	-5.89	-5.04	-4.35
9	District of Columbia	-19.88	-11.98	-9.69	-7.16	-6.07	-5.35	-4.69	-4.11
10	Florida	-26.02	-16.10	-12.22	-9.11	-8.28	-7.84	-7.39	-6.99
11	Georgia	-17.33	-11.04	-9.67	-7.79	-6.94	-6.33	-5.75	-5.22
12	Hawaii	-44.25	-27.03	-15.98	-9.22	-7.64	-7.24	-6.84	-6.50
13	Idaho	-16.21	-9.28	-8.40	-6.74	-6.08	-5.58	-5.06	-4.60
14	Illinois	-18.37	-12.33	-11.09	-9.09	-8.01	-7.24	-6.53	-5.94
15	Indiana	-16.89	-11.00	-9.41	-7.78	-6.85	-6.18	-5.57	-5.03
16	Iowa	-16.70	-9.64	-9.31	-7.55	-6.74	-6.12	-5.51	-4.95
17	Kansas	-15.54	-8.68	-8.91	-7.27	-6.52	-5.89	-5.21	-4.61
18	Kentucky	-16.39	-9.66	-8.80	-6.90	-5.98	-5.33	-4.70	-4.12
19	Louisiana	-17.84	-12.62	-10.00	-8.11	-7.04	-6.31	-5.72	-5.20
20	Maine	-19.31	-10.64	-10.17	-7.41	-6.44	-5.77	-5.12	-4.50
21	Maryland	-17.10	-11.55	-10.74	-8.72	-7.53	-6.69	-5.89	-5.24
22	Massachusetts	-20.91	-15.55	-13.54	-10.65	-8.85	-7.69	-6.68	-5.88
23	Michigan	-20.02	-14.02	-11.51	-9.28	-7.90	-6.96	-6.13	-5.45
24	Minnesota	-16.58	-9.93	-10.06	-8.25	-7.41	-6.74	-6.10	-5.53
25	Mississippi	-16.86	-10.10	-7.91	-6.47	-5.70	-5.13	-4.60	-4.12
26	Missouri	-16.56	-9.70	-8.68	-7.15	-6.42	-5.85	-5.29	-4.78
27	Montana	-17.91	-9.23	-9.20	-6.83	-6.15	-5.64	-5.10	-4.55
28	Nebraska	-14.01	-7.90	-8.81	-7.20	-6.55	-6.03	-5.42	-4.83
29	Nevada	-39.83	-23.42	-14.71	-10.35	-9.61	-9.15	-8.71	-8.31
30	New Hampshire	-19.79	-12.01	-11.07	-8.99	-7.98	-7.23	-6.51	-5.90
31	New Jersey	-17.67	-14.11	-12.63	-10.16	-8.56	-7.49	-6.56	-5.87
32	New Mexico	-17.11	-9.88	-8.75	-6.97	-6.22	-5.67	-5.12	-4.59
33	New York	-19.56	-14.33	-12.14	-9.27	-7.63	-6.61	-5.72	-5.02
34	North Carolina	-18.11	-10.17	-9.50	-7.29	-6.29	-5.55	-4.88	-4.24
35	North Dakota	-16.85	-8.65	-10.23	-7.75	-6.81	-6.11	-5.42	-4.74
36	Ohio	-17.07	-10.33	-9.48	-7.67	-6.73	-6.00	-5.34	-4.75
37	Oklahoma	-16.83	-9.89	-9.39	-7.73	-6.90	-6.30	-5.72	-5.18
38	Oregon	-17.72	-10.50	-9.80	-8.14	-7.51	-6.99	-6.46	-6.00
39	Pennsylvania	-16.99	-11.82	-11.14	-8.79	-7.42	-6.51	-5.69	-5.00
40	Rhode Island	-19.55	-14.09	-12.17	-9.39	-7.69	-6.60	-5.66	-4.89
41	South Carolina	-17.48	-10.25	-8.12	-6.47	-5.78	-5.28	-4.80	-4.37
42	South Dakota	-16.19	-8.23	-8.87	-6.79	-5.96	-5.32	-4.69	-4.11
43	Tennessee	-16.90	-9.92	-8.96	-7.30	-6.54	-5.95	-5.38	-4.87
44	Texas	-18.31	-10.98	-9.82	-8.06	-7.32	-6.79	-6.28	-5.80
45	Utah	-16.90	-10.23	-8.78	-7.25	-6.70	-6.29	-5.89	-5.53
46	Vermont	-20.93	-12.43	-9.66	-6.96	-5.91	-5.23	-4.62	-4.08
47	Virginia	-16.52	-9.94	-9.02	-7.33	-6.50	-5.85	-5.23	-4.70
48	Washington	-17.78	-11.25	-10.38	-8.53	-7.71	-7.06	-6.43	-5.89
49	West Virginia	-16.79	-8.73	-9.72	-7.45	-6.38	-5.58	-4.78	-4.00
50	Wisconsin	-16.87	-10.03	-9.76	-8.04	-7.24	-6.60	-5.97	-5.40
51	Wyoming	-17.47	-11.23	-9.35	-7.83	-7.37	-7.11	-6.81	-6.49

Nebraska, Idaho, Kansas, Arkansas, South Dakota, Minnesota, Iowa and Missouri all have GRP and employment deviations for Y1Q1 that are considerably less negative than the national average. The common theme for these states is a greater than average dependence on agriculture (a relatively mildly affected sector) and a very low dependence of tourism.

In our initial work on this project, before the availability of the employment data for May, we had West Virginia and Washington DC among the states least adversely affected in Y1Q1 by COVID-19. We attributed this to their high dependence on Production of government services for which we projected only a small contraction in output (-1.3 per cent, see Table 2). However, despite apparent high levels of public-sector activity required to organize support programs at both the federal and state & local levels, the BLS employment figures for May show that the level of government employment fell by 1.6 million between March and May 2020 [see Table B-1 in BLS (2020b)]. Thus, the BLS employment data for states does not show benign outcomes for states with high levels of government employment. Consequently, when we introduced these data into our state projections (see Appendix 1), results for West Virginia, Washington DC and other states with a large public-sector presence were adjusted downward.

By Y2Q4, the GRP and employment deviations for all regions have moved close to the national deviations of about -6 percent. Regional differences are muted by the gradual recovery of tourism and by the phasing out of the differences across regions in their APC deviations.

We have created a second-tier to the top-down method for calculating regional results. This generates county-level GRP and employment results from the state-level results. The county-level top-down method takes account of the industrial composition of economic activity within each county, while assuming that movements in activity for industry j within county r move in proportion with industry j for the state in which county r is located. On this basis, if a county is specialized in the production of products that are doing badly at the level of the state in which the county is located, then GRP and employment outcomes in the county will tend to be worse than those for the state in which the county is located. County-level results, and the decomposition of these results into the contributions of movements in activity of individual industries within each county, are reported in set of supplementary spreadsheets to this report.

5. Air and Rail industries

Table 5 gives results for the outputs of U.S. air and rail industries. For the airline industry as a whole, the table shows a deviation of -67.8 percent in Y1Q1. The industry remains depressed through the two-year simulation period. Its output is still 10.6 percent below baseline in Y2Q4. The quicker recovery of domestic flights in year1 than international flights reflects our assumption that domestic tourism will recover more quickly than international tourism. By the end of year 2, the trough for international flights is shallower than for domestic flights (-10.3 percent compared with -11.0 percent). In the international market U.S. airlines compete with foreign airlines. Real devaluation (see Section 3.1) assists U.S. airlines in competition with foreign airlines on international routes.

Table 5. Effects of COVID-19 on airline and railway outputs: percentage deviations from baseline

	Year 1				Year 2			
	Y1Q1	**Y1Q2**	**Y1Q3**	**Y1Q4**	**Y2Q1**	**Y2Q2**	**Y2Q3**	**Y2Q4**
U.S. Air transport total	-67.8	-55.4	-29.8	-14.3	-10.7	-10.7	-10.7	-10.6
Domestic flights	-65.0	-47.2	-26.3	-13.0	-11.3	-11.2	-11.1	-11.0
International flights	-73.0	-70.3	-36.1	-16.8	-9.9	-10.1	-10.2	-10.3
Air transport passenger total	-81.9	-68.6	-36.2	-16.5	-12.0	-12.0	-12.1	-12.2
Domestic flights	-76.1	-56.4	-30.8	-14.5	-12.6	-12.5	-12.4	-12.4
International flights	-93.5	-93.2	-47.2	-20.7	-11.3	-11.7	-11.9	-12.2
Air transport freight	-23.5	-13.6	-9.5	-7.4	-6.7	-6.3	-6.0	-5.8
Domestic flights	-25.1	-14.1	-10.1	-7.7	-6.9	-6.5	-6.1	-5.8
International flights	-21.2	-12.9	-8.7	-6.9	-6.4	-6.1	-6.0	-5.8
U.S. Rail transport total	-20.0	-12.0	-8.9	-6.5	-5.7	-5.2	-5.2	-5.2
Rail transport passenger	-18.5	-11.0	-8.8	-6.2	-5.1	-4.4	-4.7	-5.3
Rail transport freight	-20.6	-12.4	-9.0	-6.7	-5.9	-5.6	-5.3	-5.2

The volume of U.S. air freight traffic is not as badly damaged by COVID-19 as the volume of passenger traffic. International freight sales move approximately with merchandise trade (particularly high-tech equipment exports) and domestic freight sales move approximately with GDP. Both merchandise trade and GDP exhibit simulated downturns, but not nearly as sharp as those for tourism and business travel.

The COVID-induced deviations in the rail output variables in Table 5 are similar to those in GDP.

6. COVID-19 and National Critical Functions

CISA has responsibility to advise the government on the ability of the economy to maintain National Critical Functions (NCF). These functions are divided into the 55 categories shown as row labels in Table 6. Using a draft report by the Homeland Security Operational Analysis Center (2020) as a guide, we made a judgement for each critical function concerning its reliance on the outputs of the 91 goods and services identified in the USAGE-Q model (Table A2.3, Appendix 2). These judgements are shown quantitatively in Table A4.1 in Appendix 4. For example, the table shows that delivery of NCF 20 (*Develop and maintain public works and services*) has 18 percent dependence on USAGE-Q industry 17 (Power generation), 7 percent dependence on USAGE-Q industry 18 (Gas, water & sewage) and 19 percent on USAGE-Q industry 19 (Non-residential construction). As explained in Appendix 4, in making these quantitative assessments we relied on data for value-added by each industry in the USAGE-Q database.

As we have seen in Section 3.2, the effect of COVID-19 varies widely across U.S. industries. For Y1Q1, Table 2 shows results varying from almost complete elimination of tourism activities, with sharp reductions in the outputs of related industries such as airlines, to a substantial increase in the output of Medical equipment & services. Using the dependence weights from Table A4.1 and the COVID-induced percentage effects on the outputs of each of the 91 USAGE-Q commodities, we created Table 6.

We interpret the entries in Table 6 as indicators of the effects of COVID-19 on the capability of the U.S. economy to support NCFs. On this basis, we see that the most adversely affected NCF capabilities in Y1Q1 are: NCF 21 (*Educate and train*), -63.22; NCF 13 (*Transport cargo and passengers by air*), -31.72; NCF 15 (*Transport cargo and passengers by road*), -29.72; NCF 11 (*Maintain supply chains*), -29.09; NCF 54 (*Research and development*), -28.70; and NCF 46 (*Manufacture equipment*), -28.23.

For NCF 21 (*Educate and train*), the severe adverse impact can be traced to the sharp contraction in output of the USAGE-Q Education industry (see Table 2). The Education industry is among the most adversely affected due to contractions in domestic and international access to education services (see Appendix 2).

In Table A4.1 we see that movements in the capability indicator for NCF 46 (*Manufacture equipment*) are largely determined by movements in the output of 6 industries in the Machinery sector (USAGE-Q industries 27 – 32). These industries sell comparatively high proportions of their output to investment activities, and thus are exposed to loss in investor confidence. In addition, they are in the set of "consumer durables", which are subject to substantial shutdowns in Y1Q1 (see Appendix 2).

The adverse Y1Q1 impact for NCF 54 (*Research and development*) is attributable to movements in the output of industry 69 (*Research and development services*). In USAGE-Q, this industry is very exposed to investor sentiment: approximately 90 percent of sales of *Research and development services* are used as inputs to investment.

For NCF 13 (*Transport cargo and passengers by air*), the severe adverse capability impact in Y1Q1 arises mainly from sharp contractions in the outputs of USAGE-Q industries Air transport domestic and Air transport international.

In Table A4.1 we see that movements in the capability indicator for NCF 15 (*Transport cargo and passengers by road*) are determined by movements in the output of industries 32 (*motor vehicle manufacturing*), 44 (*petroleum refining*), and 54 (*truck transport*). Of these three industries, the main contributor to the low ranking outcome for NCF 15 is the contraction in output of industry 32 (*motor vehicle manufacturing*). This sector sells a significant proportion of its output to investment activities, and is thus exposed to the loss in investor confidence. In addition, it falls within the set of "consumer durables", which are subject to substantial shutdowns in Y1Q1 (see Appendix 2).

The capability indicator for NCF 11 (*Maintain supply chains*) is mainly determined by movements in the output of industries 49 and 50 (*wholesale trade* and *retail trade*) (see Table A4.1). As described Appendix 2, both of these trade sectors are subject to large shutdown shocks in Y1Q1.

Table 6. Effects of COVID-19 on capability indicators for the delivery of National Critical Functions

National Critical Function			Year 1				Year 2			
			Y1Q1	Y1Q2	Y1Q3	Y1Q4	Y2Q1	Y2Q2	Y3Q3	Y2Q4
Connect	1	Operate core network	-21.30	-10.78	-8.76	-6.60	-5.72	-5.46	-5.36	-5.27
	2	Provide cable access network services	-21.66	-10.73	-8.83	-6.62	-5.72	-5.51	-5.47	-5.44
	3	Provide internet based content, info., & communic. services	-22.20	-11.49	-9.59	-7.41	-6.44	-6.07	-5.83	-5.62
	4	Provide internet routing, access, and connection services	-21.66	-10.73	-8.83	-6.62	-5.72	-5.51	-5.47	-5.44
	5	Provide positioning, navigation and timing services	-21.66	-10.73	-8.83	-6.62	-5.72	-5.51	-5.47	-5.44
	6	Provide radio broadcast access network services	-21.66	-10.73	-8.83	-6.62	-5.72	-5.51	-5.47	-5.44
	7	Provide satellite access network services	-21.66	-10.73	-8.83	-6.62	-5.72	-5.51	-5.47	-5.44
	8	Provide wireless access network services	-21.66	-10.73	-8.83	-6.62	-5.72	-5.51	-5.47	-5.44
	9	Provide wireline access network services	-21.66	-10.73	-8.83	-6.62	-5.72	-5.51	-5.47	-5.44
Distribute	10	Distribute electricity	-15.72	-10.54	-10.82	-7.74	-6.55	-5.83	-5.29	-5.47
	11	Maintain supply chains	-29.09	-16.77	-10.63	-8.23	-7.45	-7.04	-6.67	-6.37
	12	Transmit electricity	-15.72	-10.54	-10.82	-7.74	-6.55	-5.83	-5.29	-5.47
	13	Transport cargo and passengers by air	-31.72	-22.91	-14.27	-9.00	-7.34	-7.32	-7.28	-7.24
	14	Transport cargo and passengers by rail	-24.58	-14.16	-8.52	-6.07	-5.43	-5.48	-5.58	-5.67
	15	Transport cargo and passengers by road	-29.72	-16.81	-10.65	-8.08	-7.27	-6.99	-6.73	-6.49
	16	Transport cargo and passengers by vessel	-24.75	-14.19	-8.16	-5.75	-5.17	-5.32	-5.43	-5.52
	17	Transport materials by pipeline	-11.68	-8.27	-8.44	-5.98	-5.13	-4.74	-4.46	-4.44
	18	Transport passengers by mass transit	-16.72	-10.42	-9.18	-6.64	-5.72	-5.24	-5.12	-5.09
Manage	19	Conduct elections	-6.68	-3.86	-2.21	-1.71	-1.51	-1.39	-1.29	-1.22
	20	Develop and maintain public works and services	-23.08	-19.06	-20.21	-17.84	-16.48	-15.50	-14.65	-14.42
	21	Educate and train	-63.22	-33.23	-7.68	-5.75	-4.69	-4.24	-3.82	-3.46
	22	Enforce law	-6.68	-3.86	-2.21	-1.71	-1.51	-1.39	-1.29	-1.22
	23	Maintain access to medical records	1.20	-1.17	-4.80	-3.55	-3.12	-2.90	-2.69	-2.50
	24	Manage hazardous materials	-18.58	-10.40	-8.76	-6.64	-5.77	-5.33	-5.04	-4.83
	25	Manage wastewater	-9.80	-7.48	-8.55	-6.06	-5.18	-4.69	-4.30	-4.19
	26	Operate government	-6.68	-3.86	-2.21	-1.71	-1.51	-1.39	-1.29	-1.22

Table 6 continues …

Table 6 continued

	27	Perform cyber incident management capabilities	-17.79	-10.31	-8.52	-6.88	-6.13	-5.62	-5.16	-4.80
	28	Prepare for and manage emergencies	-6.68	-3.86	-2.21	-1.71	-1.51	-1.39	-1.29	-1.22
	29	Preserve constitutional rights	-7.77	-4.39	-2.93	-2.26	-1.98	-1.81	-1.66	-1.55
	30	Protect sensitive information	-17.89	-10.34	-8.52	-6.87	-6.12	-5.61	-5.15	-4.79
	31	Provide and maintain infrastructure	-22.45	-15.35	-15.15	-12.86	-11.73	-11.10	-10.64	-10.51
	32	Provide capital markets and investment activities	-19.29	-9.17	-7.45	-5.09	-4.36	-4.01	-3.71	-3.45
	33	Provide consumer and commercial banking services	-19.29	-9.17	-7.45	-5.09	-4.36	-4.01	-3.71	-3.45
	34	Provide funding and liquidity services	-19.29	-9.17	-7.45	-5.09	-4.36	-4.01	-3.71	-3.45
	35	Provide identity manage't & assoc'd trust support services	-22.93	-13.24	-10.92	-8.79	-7.82	-7.16	-6.58	-6.11
	36	Provide insurance services	-18.10	-8.39	-9.11	-6.30	-5.29	-4.90	-4.54	-4.22
	37	Provide medical care	7.56	1.11	-7.09	-5.13	-4.51	-4.19	-3.88	-3.58
	38	Provide payment, clearing and settlement services	-19.29	-9.17	-7.45	-5.09	-4.36	-4.01	-3.71	-3.45
	39	Provide public safety	-1.40	-1.71	-3.40	-2.59	-2.31	-2.17	-2.03	-1.91
	40	Provide wholesale funding	-19.29	-9.17	-7.45	-5.09	-4.36	-4.01	-3.71	-3.45
	41	Store fuel and maintain reserves	-23.77	-14.32	-10.97	-8.68	-7.87	-7.49	-7.15	-6.87
	42	Support community health	9.74	2.06	-7.16	-5.22	-4.57	-4.23	-3.91	-3.60
Supply	43	Exploration and extraction of fuels	-26.55	-15.33	-10.96	-8.19	-7.32	-7.28	-7.34	-7.50
	44	Fuel refining and processing fuels	-22.91	-13.27	-7.86	-5.33	-4.80	-5.14	-5.40	-5.61
	45	Generate electricity	-15.72	-10.54	-10.82	-7.74	-6.55	-5.83	-5.29	-5.47
	46	Manufacture equipment	-28.23	-16.21	-12.58	-10.02	-8.78	-8.03	-7.38	-6.79
	47	Produce and provide agricultural products and services	-3.42	-4.01	-5.90	-3.66	-3.19	-3.22	-3.31	-3.41
	48	Produce & provide human & animal food prod's and serv's	0.98	-2.36	-5.64	-3.60	-3.03	-2.81	-2.66	-2.56
	49	Produce chemicals	-18.31	-9.63	-6.24	-4.16	-3.83	-3.64	-3.48	-3.33
	50	Provide metals and materials	-25.76	-15.51	-11.48	-8.81	-7.78	-7.41	-7.19	-7.12
	51	Provide housing	-19.88	-10.23	-13.96	-10.24	-8.17	-7.73	-7.88	-8.19
	52	Provide information technology products and services	-23.38	-13.48	-11.08	-8.91	-7.92	-7.25	-6.65	-6.18
	53	Provide materiel and operational support in defence	-5.16	-3.06	-2.51	-2.00	-1.71	-1.57	-1.43	-1.32
	54	Research and development	-28.70	-16.70	-17.45	-15.62	-14.28	-12.84	-11.45	-10.33
	55	Supply water	-9.80	-7.48	-8.55	-6.06	-5.18	-4.69	-4.30	-4.19

From Y2Q2 onwards, the capability indicators for most NCF categories gradually return towards their baseline values. This is consistent with the gradual recoveries in output experienced by most industries (see Table 2). However, the recovery is not uniform. In Table 6 we see that five NCF categories experience persistent relatively large negative deviations in their capability indicators, albeit much attenuated relative to Y1Q1 and Y1Q2 lows. These 5 are: NCF 20 (*Develop and maintain public works and services*), -14.42 in Y2Q4; NCF 31 (*Provide and maintain infrastructure*), -10.51; NCF 54 (*Research and development*), -10.33; NCF 51 (*Provide housing*), -8.19; and NCF 43 (*Exploration and extraction of fuels*), -7.50. The persistent negatives for these NCF categories can be traced to the post-crisis macroeconomic effects discussed in Section 3. In particular, as reported in Figure 4, real investment ends the simulation period approximately 23 per cent below its baseline value. This negative deviation in national real investment is responsible, in the main, for the persistence of the significant negative deviations in the capability indicators for NCF categories 20, 31, 54, 51 and 43.

We also calculate NCF impacts at the state level, using the technique outlined in Appendix 4, applied at the level of individual states. We report state level NCF impacts in a set of supplementary spreadsheets to this report.

7. Concluding remarks

The USAGE-Q projections in this paper paint a troubling picture for the U.S. economy. But in one respect it may be considered optimistic. While it shows an extremely deep trough in the first quarter, this is followed by a steady recovery. Employment and GDP fall about 19 per cent below baseline in Y1Q1, and then they return to within about 6 percent below baseline by Y2Q4.

In generating this economic recovery, we assumed that widespread shutdowns will not be reintroduced over extended periods in the coming months. This will allow many businesses and workers to pick up approximately where they left off, with only moderate loss of capital. As recognized in the Coronavirus Aid, Relief and Economic Security (CARES) Act, this requires policies that assist businesses to remain solvent and laid-off workers to remain linked to their employers for ready re-employment in the upswing.

Our macro picture for year 1 is similar to the central forecast recently published by Deloitte (2020). However, Deloitte projects negative GDP growth in year 2 and a return to positive growth only in year 3. While in our projections GDP remains below baseline in year 2, it exhibits positive growth (a return towards baseline).

As indicated by Figure 1, USAGE-Q takes in a scenario that specifies COVID-related restrictions on economic activity and macro-economic support measures. For any scenario, USAGE-Q generates implications for the macro-economy and industries. These results can be extended to embrace variables of interest to different sections of the U.S. government with their different policy levers and areas of responsibility. In this paper we have extended USAGE-Q results to cover states, transport activities and National Critical Functions. We have also built a facility for disaggregating state results to counties.

Projections for the state and county economies are required by state and local governments and federal agencies with responsibilities for identifying regions, such as Hawaii and Nevada,

whose economies may be particularly adversely affected by COVID-19. Understanding the likely depth and longevity of relative disadvantage for each region might be helpful in allocating federal funds between regions. Within regions, USAGE-Q identifies the contributions made by individual industries to the aggregate GRP and employment outcomes for each state and county. These contributions are reported in a set of supplementary spreadsheets to this report. These tables might help state and local governments to identify possibilities for using their state fiscal levers for assisting particularly disadvantaged industries and sub-state regions in which these industries are located.

Projections for transport activities are required by agencies with responsibilities for managing, maintaining and regulating U.S. transport networks. Our USAGE-Q results suggest that U.S. airlines may require support over a long period to remain viable. Projections for the supply of inputs to National Critical Functions are required by agencies responsible for monitoring and maintaining these functions. USAGE-Q highlights several NCFs whose delivery may be threatened by COVID-19.

USAGE-Q results suggest that throughout the U.S., hotels are likely to be underused for at least the next 6 months. This raises the possibility of finding policy levers through which hotel accommodation could be used to isolate potential COVID-19 carriers for whom other isolation options are unavailable. Another possibility is to make hotel rooms available to health workers for whom living at home presents risks to family members. Persisting excess capacity indicated by USAGE-Q for the transport network might, with appropriate policy levers, be used in transporting workers to remote mining sites in a way that is compatible with social-distancing requirements (e.g. filling only a third of the seats).

The persisting weakness of the Export education industry projected by USAGE-Q suggests that it may be fruitful to look for policy levers that would lead to productive use of excess physical and teaching capacity in higher education.

A model such as USAGE-Q doesn't tell us how agencies should operate their policy levers. However, the results generated by such models can inform policy decisions. While investigation of the practicality of any of these suggestions made here is beyond the scope of this paper, we hope that they indicate the potential role that USAGE-Q can play in policy formulation.

In the longer term, there will be difficult financial problems associated with the enormous, but unavoidable, public and private debts that are being accumulated at present. Analyzing these problems in a formal model and developing policies to cope with them is a major and urgent challenge.

For modeling research to be of sustained value to policy it needs to be adjustable and timely. The scenario used in USAGE-Q can be adjusted as events unfold. As demonstrated in Appendix 1, USAGE-Q projections can be updated in response to data releases by the BLS and other statistical agencies as they occur.

Appendix 1. Modifying state employment results to take account of monthly employment numbers

Producing and analysing model results is a time consuming process. Consequently there is always a possibility that events will overtake results before a report is released. Much of the research underlying this report was undertaken in April and May. We received valuable feedback on a preliminary versions of the report supplied to CISA on April 20 and May 8. BLS unemployment numbers for May (published on June 5) indicated that our initial projection of the employment trough in Y1Q1 (March-May, 2020) was too pessimistic. Whereas we initially projected a COVID-induced 23 percent loss of labor input, on the basis of the BLS figures for May we revised our projections in a way that generated a 19 percent loss of labor input (see Section 3.1). BLS unemployment numbers for June (published on July 2) didn't indicate that further revisions were required (Section 3.1).

We used the BLS employment and unemployment data for states published on June 19 (see https://www.bls.gov/news.release/laus.toc.htm) to revise our initial employment and gross regional product (GRP) projections for states.

As described in Section 4, we generate projections for states by a top-down modeling method that disaggregates national results to the state level. When state employment results became available, on June 19 we used them to adjust the top-down model results for Y1Q1. Then we made consistent modifications to the projections for the later quarters.

A1.1. Revising the state results for employment in the first quarter

Let x1(r) be the percentage deviation in employment for Y1Q1 in state r generated by top-down modeling using inputs from our national model.

We fit the following regression:

$$x1(r) = \alpha_0 + \alpha_1 * \text{EmpBLS}(r) + \alpha_2 * \text{TourismIndex}(r)\,,\ r = 1, 2, \ldots, 51 \qquad \text{(A1.1)}$$

where

α_0, α_1, α_2 are regression coefficients;
EmpBLS(r) is the percentage change in employment from May 2019 to May 2020 in state r obtained from https://www.bls.gov/news.release/laus.t01.htm/
TourismIndex(r) is the share of the nation's tourism activity (Domestic vacation, Export tourism and Export education) that takes place in state r divided by the share of the nation's employment in state r.

The result for this regression is

$$x1(r) = -13.50 + 0.29 * \text{EmpBLS}(r) - 1.86 * \text{TourismIndex}(r)\ ,\ R^2 = 0.80 \qquad \text{(A1.2)}$$

and is illustrated in Figure A1.1.

We use the fitted results (orange dashed line in Figure A1.1) as our estimates of regional employment effects instead of the pure top-down modeling results. The simple national average for the fitted results is the same as the simple national average for the top-down modeling results. Consequently the replacement of the top-down modeling results with the fitted results doesn't produce a noticeable inconsistency with the national employment result.

But why adopt the fitted results? Why not move entirely to the BLS numbers or stay with the top-down modeling results?

We shouldn't move entirely to the BLS results because they refer to a significantly different measure of employment to the one being used in our modeling. The BLS concept is a count of people. Ours is a measure of labor input. BLS does not account for changes in hours of work or loss of second jobs, or changes in the composition of employment towards or away from high-wage jobs. Labor input includes all these effects.

We think that the BLS count measure is particularly misleading as a measure of labor-input loss in casualized industries such as tourism. Consequently we included the tourism index on the right-hand side of the regression which allows the adjustment from the top-down modeling result to the fitted result to be large for Hawaii and Nevada.

Why not use the pure top-down model numbers? The BLS employment numbers contain valuable information that we haven't accounted for in the modeling. For example, the BLS numbers indicate a reduction in government employment. We have no reason to think that this is unrealistic. Because we didn't take it into account, the top-down modeling may be overestimating the strength of employment in government dominated states such as DC and West Virginia. This is corrected using our fitted regression which adjusts DC and West Virginia downwards.

As can be seen in Section A1.2, our adjusted results become successively closer to the top-down modeling results as we move to later quarters.

We also need to revise the GRP numbers. We do this for each quarter according to the equation

$$\text{fitted\_grp(r)} = \text{topdown\_grp(r)} + \left[\text{fitted\_emp(r)} - \text{topdown\_emp(r)}\right], \text{r} = 1, 2, \ldots, 51 \tag{A1.3}$$

A1.2. Filling the revised employment deviations for Q2 to Q8 (Y1Q2 to Y2Q4)

Let the top-down modeling deviation of employment in region r from baseline in quarter j be xj(r) for $j \in (1, 2, \ldots, 8)$

Suppressing the r argument, we write the levels form for top-down modeling employment in quarter j as

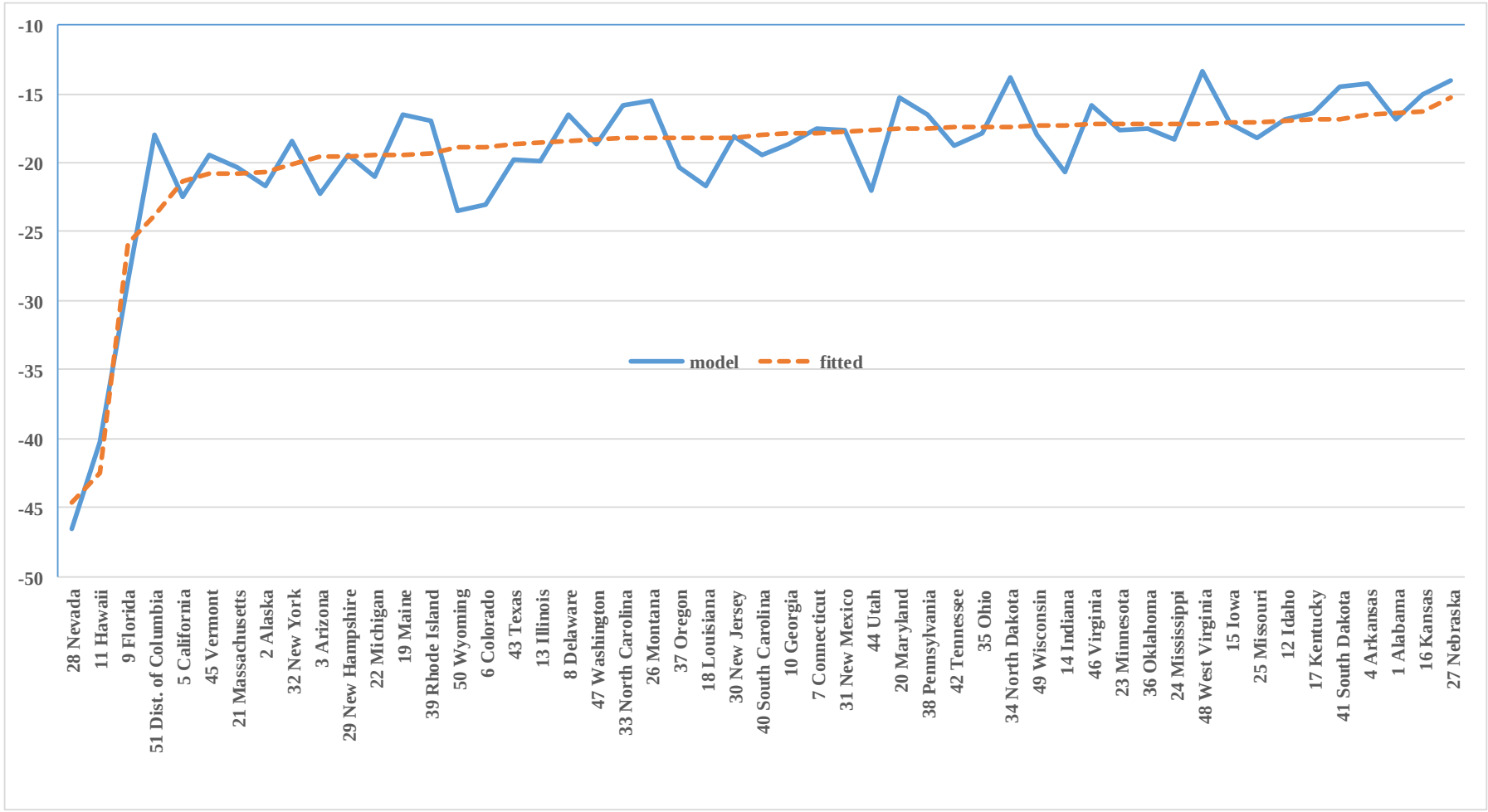
$$Xj = 1 + \frac{xj}{100} \ . \tag{A1.4}$$

In (A1.4), we assume without loss of generality that baseline employment is one. We have a revised estimate (our fitted value, F1) for employment under COVID in Q1. We set our revised estimate for Q8, F8, as F8 = X8.

How should we fill in the revised estimates Fj for $j \in (2, 3, \ldots, 7)$?

And consequently how should we fill in the revised percentage deviations in employment fj for $j \in (2, 3, \ldots, 7)$?

Figure A1.1. Percentage employment deviations in Y1Q1: top-down regional model results compared with fitted results from regression



Answer:

For Qj , j∈(2, 3, …, 7) we assume that the ratio of the gap between Fj and F1 to the gap between F8 and F1 is the same as the ratio of the gap between Xj and X1 to the gap between X8 and X1:

$$\frac{Fj-F1}{F8-F1}=\frac{Xj-X1}{X8-X1} \tag{A1.5}$$

In percentage change terms:

$$\frac{\left(1+\frac{fj}{100}\right)-\left(1+\frac{f1}{100}\right)}{\left(1+\frac{f8}{100}\right)-\left(1+\frac{f1}{100}\right)}=\frac{\left(1+\frac{xj}{100}\right)-\left(1+\frac{x1}{100}\right)}{\left(1+\frac{x8}{100}\right)-\left(1+\frac{x1}{100}\right)} \tag{A1.6}$$

Simplifying

$$\frac{fj-f1}{fj-f1}=\frac{xj-x1}{xj-x1} \tag{A1.7}$$

Solving (A1.7) for fj

$$fj=f1+\left(\frac{xj-x1}{f8-x1}\right)*\left(f8-f1\right) \tag{A1.8}$$

Tables A1.1 and Table A1.2 show ratios of fitted to top-down results (fj/xj) for GRP and employment. The entries in these tables are adjustment factors introduced by our use of BLS state employment data for May 2020. For example, in deriving the Y1Q1 employment result for West Virginia shown in Table 4 in Section 4 we multiplied the top-down modeling result by 1.439. For most regions, the Y1Q1 adjustment factors for both employment and GRP are between 0.8 and 1.2. The adjustment factors move steadily towards 1 as we go from Y1Q1 to Y2Q4.

Table A1.1. Adjustment factors for gross regional product (GRP) by state & D.C

		Year 1				Year 2			
	State	**Y1Q1**	**Y1Q2**	**Y1Q3**	**Y1Q4**	**Y2Q1**	**Y2Q2**	**Y2Q3**	**Y2Q4**
1	Alabama	0.971	0.977	0.978	0.984	0.987	0.990	0.996	1.000
2	Alaska	0.988	0.991	0.991	0.994	0.997	0.997	0.998	1.000
3	Arizona	0.834	0.867	0.889	0.928	0.947	0.964	0.982	1.000
4	Arkansas	1.157	1.116	1.127	1.098	1.074	1.052	1.025	1.000
5	California	0.941	0.954	0.961	0.974	0.981	0.987	0.994	1.000
6	Colorado	0.809	0.849	0.872	0.908	0.931	0.953	0.977	1.000
7	Connecticut	1.001	1.001	1.001	1.001	1.000	1.000	1.000	1.000
8	Delaware	1.125	1.104	1.109	1.088	1.066	1.045	1.021	1.000
9	District of Columbia	1.178	1.144	1.127	1.093	1.070	1.047	1.024	1.000
10	Florida	0.920	0.933	0.947	0.970	0.979	0.986	0.993	1.000
11	Georgia	0.948	0.958	0.961	0.972	0.978	0.985	0.993	1.000
12	Hawaii	1.147	1.135	1.105	1.052	1.026	1.017	1.007	1.000
13	Idaho	0.956	0.965	0.968	0.977	0.982	0.989	0.994	1.000
14	Illinois	0.930	0.943	0.947	0.959	0.969	0.980	0.989	1.000
15	Indiana	0.819	0.845	0.857	0.885	0.912	0.940	0.970	1.000
16	Iowa	0.977	0.984	0.984	0.987	0.990	0.993	0.996	1.000
17	Kansas	1.077	1.055	1.060	1.045	1.036	1.026	1.012	1.000
18	Kentucky	1.042	1.035	1.034	1.025	1.019	1.014	1.006	1.000
19	Louisiana	0.871	0.883	0.894	0.915	0.938	0.959	0.981	1.000
20	Maine	1.228	1.182	1.183	1.127	1.094	1.064	1.033	1.000
21	Maryland	1.160	1.130	1.123	1.097	1.072	1.050	1.023	1.000
22	Massachusetts	1.027	1.024	1.022	1.019	1.014	1.010	1.005	1.000
23	Michigan	0.970	0.974	0.976	0.980	0.985	0.991	0.995	1.000
24	Minnesota	0.955	0.966	0.966	0.973	0.980	0.986	0.993	1.000
25	Mississippi	0.966	0.971	0.976	0.981	0.985	0.990	0.996	1.000
26	Missouri	0.928	0.943	0.947	0.960	0.969	0.978	0.989	1.000
27	Montana	1.230	1.162	1.173	1.113	1.086	1.059	1.030	1.000
28	Nebraska	1.034	1.022	1.026	1.019	1.016	1.011	1.006	1.000
29	Nevada	0.855	0.873	0.908	0.955	0.969	0.979	0.991	1.000
30	New Hampshire	1.020	1.016	1.015	1.011	1.009	1.006	1.003	1.000
31	New Jersey	0.992	0.993	0.993	0.995	0.996	0.997	0.998	1.000
32	New Mexico	1.048	1.037	1.035	1.026	1.020	1.013	1.008	1.000
33	New York	1.078	1.069	1.064	1.051	1.039	1.027	1.013	1.000
34	North Carolina	1.162	1.131	1.129	1.098	1.074	1.049	1.026	1.000
35	North Dakota	1.292	1.179	1.241	1.170	1.127	1.087	1.044	1.000
36	Ohio	0.975	0.980	0.980	0.984	0.988	0.991	0.996	1.000
37	Oklahoma	1.047	1.034	1.035	1.026	1.019	1.014	1.007	1.000
38	Oregon	0.881	0.912	0.918	0.941	0.956	0.970	0.985	1.000
39	Pennsylvania	1.042	1.037	1.037	1.029	1.022	1.015	1.007	1.000
40	Rhode Island	1.179	1.161	1.148	1.120	1.090	1.060	1.030	1.000
41	South Carolina	0.931	0.942	0.950	0.965	0.972	0.982	0.992	1.000
42	South Dakota	1.160	1.111	1.129	1.095	1.072	1.049	1.024	1.000
43	Tennessee	0.914	0.931	0.935	0.952	0.963	0.973	0.987	1.000
44	Texas	0.955	0.967	0.969	0.977	0.983	0.989	0.995	1.000
45	Utah	0.791	0.834	0.859	0.901	0.926	0.950	0.975	1.000
46	Vermont	1.096	1.086	1.076	1.055	1.040	1.028	1.013	1.000
47	Virginia	1.074	1.059	1.054	1.041	1.032	1.020	1.010	1.000
48	Washington	0.981	0.985	0.987	0.990	0.993	0.995	0.997	1.000
49	West Virginia	1.384	1.267	1.329	1.248	1.188	1.131	1.066	1.000
50	Wisconsin	0.951	0.963	0.964	0.972	0.979	0.985	0.993	1.000
51	Wyoming	0.783	0.834	0.868	0.919	0.942	0.958	0.978	1.000

Table A1.2. Adjustment factors for regional employment

		Year 1				Year 2			
	State	**Y1Q1**	**Y1Q2**	**Y1Q3**	**Y1Q4**	**Y2Q1**	**Y2Q2**	**Y2Q3**	**Y2Q4**
1	Alabama	0.970	0.978	0.980	0.985	0.989	0.991	0.996	1.000
2	Alaska	0.987	0.991	0.992	0.995	0.997	0.997	0.998	1.000
3	Arizona	0.831	0.876	0.898	0.936	0.953	0.967	0.983	1.000
4	Arkansas	1.165	1.110	1.114	1.086	1.066	1.048	1.025	1.000
5	California	0.941	0.958	0.965	0.977	0.983	0.988	0.994	1.000
6	Colorado	0.806	0.855	0.881	0.917	0.938	0.956	0.978	1.000
7	Connecticut	1.001	1.001	1.001	1.001	1.000	1.000	1.000	1.000
8	Delaware	1.127	1.099	1.097	1.075	1.057	1.041	1.020	1.000
9	District of Columbia	1.192	1.154	1.132	1.095	1.071	1.049	1.026	1.000
10	Florida	0.919	0.937	0.951	0.973	0.981	0.987	0.993	1.000
11	Georgia	0.947	0.960	0.964	0.975	0.980	0.986	0.993	1.000
12	Hawaii	1.154	1.135	1.103	1.049	1.024	1.017	1.007	1.000
13	Idaho	0.956	0.969	0.971	0.980	0.984	0.989	0.994	1.000
14	Illinois	0.930	0.946	0.951	0.963	0.972	0.981	0.989	1.000
15	Indiana	0.818	0.854	0.871	0.899	0.922	0.945	0.970	1.000
16	Iowa	0.977	0.985	0.985	0.988	0.991	0.994	0.996	1.000
17	Kansas	1.081	1.052	1.054	1.040	1.032	1.024	1.012	1.000
18	Kentucky	1.043	1.033	1.030	1.022	1.017	1.013	1.006	1.000
19	Louisiana	0.864	0.885	0.904	0.926	0.945	0.962	0.981	1.000
20	Maine	1.242	1.172	1.165	1.111	1.082	1.059	1.032	1.000
21	Maryland	1.166	1.127	1.118	1.090	1.067	1.047	1.023	1.000
22	Massachusetts	1.028	1.024	1.021	1.017	1.013	1.009	1.005	1.000
23	Michigan	0.969	0.974	0.978	0.982	0.986	0.991	0.995	1.000
24	Minnesota	0.955	0.969	0.969	0.976	0.983	0.987	0.993	1.000
25	Mississippi	0.965	0.972	0.978	0.983	0.986	0.990	0.996	1.000
26	Missouri	0.927	0.946	0.953	0.965	0.973	0.980	0.989	1.000
27	Montana	1.248	1.157	1.156	1.098	1.075	1.054	1.030	1.000
28	Nebraska	1.035	1.021	1.023	1.017	1.014	1.010	1.006	1.000
29	Nevada	0.855	0.878	0.915	0.959	0.972	0.981	0.991	1.000
30	New Hampshire	1.020	1.014	1.014	1.010	1.008	1.006	1.003	1.000
31	New Jersey	0.992	0.993	0.994	0.995	0.997	0.997	0.998	1.000
32	New Mexico	1.052	1.037	1.033	1.023	1.018	1.013	1.008	1.000
33	New York	1.079	1.068	1.061	1.047	1.035	1.025	1.012	1.000
34	North Carolina	1.165	1.121	1.115	1.085	1.064	1.045	1.025	1.000
35	North Dakota	1.316	1.178	1.219	1.150	1.113	1.081	1.044	1.000
36	Ohio	0.974	0.981	0.982	0.986	0.990	0.992	0.996	1.000
37	Oklahoma	1.052	1.035	1.033	1.024	1.018	1.013	1.007	1.000
38	Oregon	0.879	0.919	0.925	0.948	0.960	0.972	0.985	1.000
39	Pennsylvania	1.043	1.035	1.033	1.026	1.019	1.014	1.007	1.000
40	Rhode Island	1.183	1.156	1.141	1.110	1.082	1.056	1.029	1.000
41	South Carolina	0.929	0.945	0.954	0.969	0.975	0.983	0.992	1.000
42	South Dakota	1.166	1.106	1.114	1.081	1.062	1.045	1.024	1.000
43	Tennessee	0.913	0.936	0.942	0.958	0.967	0.975	0.987	1.000
44	Texas	0.954	0.968	0.972	0.981	0.985	0.990	0.995	1.000
45	Utah	0.786	0.843	0.870	0.912	0.933	0.953	0.975	1.000
46	Vermont	1.099	1.081	1.069	1.048	1.035	1.025	1.013	1.000
47	Virginia	1.076	1.055	1.050	1.037	1.028	1.019	1.010	1.000
48	Washington	0.981	0.986	0.988	0.991	0.994	0.996	0.997	1.000
49	West Virginia	1.439	1.276	1.308	1.227	1.175	1.127	1.069	1.000
50	Wisconsin	0.950	0.965	0.967	0.976	0.981	0.987	0.993	1.000
51	Wyoming	0.774	0.836	0.876	0.927	0.947	0.961	0.978	1.000

Appendix 2. Detailed description of the shocks used to represent the COVID-19 scenario adopted in this paper

Table A2.1 sets out COVID-19 shutdown and other COVID-related shocks to the economy, and Table A2.2 shows our representation in the model of the main fiscal response, the CARES Act. Together the set of shocks in Table A2.1 and the fiscal responses in Table A2.2 define the particular scenario analyzed in this paper. It should be emphasized that this scenario is just one of many possibilities. Our model could be used to investigate the effects of other scenarios. As the pandemic evolves, it will become apparent that some scenarios are more likely than others.

Shutdown shocks

Rows 1 to 10 of Table A2.1 show our assumptions concerning household consumption of commodities directly impacted by COVID-related shutdown restrictions operating in the U.S. For example, row 1 of Table A2.1 shows that for Y1Q1 we assume a reduction of 75 percent in household consumption of Durables (commodities 21 to 39, see Table A2.3 for a complete list of USAGE-Q commodities). This is a 75 percent reduction from the baseline Y1Q1 level of consumption.

The Y1Q1 values in rows 1 to 8 of Table A2.1 were guided by Walmsley *et al.* (2020) who estimated shutdown fractions for mandatory closures put in place up to April 7, 2020. In making their judgements, Walmsley *et al.* considered how much of the activity in each affected industry can be accommodated by "working at home." For consumption of vacations (rows 9 and 10) we assumed almost a complete shutdown in Y1Q1. For Y1Q2 we assume that restrictions will ease. We represent this by halving the negative deviations from Y1Q1 for most of the commodity groups in rows 1 to 10. However, we assume that through Y1Q2 Foreign vacation travel (row 10) will remain severely restricted, at its Y1Q1 levels. Beyond Y1Q2, we assume that consumption of commodities in rows 1 to 8 will return to their normal income/price-determined levels. Potentially these levels differ from the baseline levels because incomes and prices differ from their baseline levels. In the cases of Domestic and Foreign vacation travel (rows 9 and 10), we assume that formal restrictions and preference changes will leave consumption of these services well below baseline levels throughout the two-year simulation period.

Other shocks

Just as we expect Foreign vacation expenditure by U.S. residents to be sharply curtailed by COVID-19, we expect vacation expenditure in the U.S. by foreigners (Export tourism, row 11 in Table A2.1) to be sharply curtailed.

Table A2.1. Shocks representing COVID-related restrictions on economic activities in USAGE-Q: percent deviations from baseline

		Year 1 (Mar 1, 2020 to Feb 28, 2021)				**Year 2** (Mar 1, 2021 to Feb 28, 2022)			
No	**Variable**	**Y1Q1**	**Y1Q2**	**Y1Q3**	**Y1Q4**	**Y2Q1**	**Y2Q2**	**Y2Q3**	**Y2Q4**
Shutdown shocks: direct household consumption of									
1	Durables (coms 21-39)	-75	-37.5						
2	Non-durables other than food (coms 42-48)	-25	-12.5						
3	Wholesale & retail trade (coms 49-50)	-40.7	-20.35						
4	Other services (coms 59-70, 79, 82-84)	-15	-4.38						
5	Education (com 71)	-73.4	-36.7						
6	Entertainment & recreation (com 76)	-90.3	-45.15						
7	Hotels & restaurants (coms 77-78)	-72.7	-36.35						
8	Government services (coms 80-81)	-23.61	-11.81						
9	Domestic vacation (com 85) [1]	-95	-47.5	-25	-10	-10	-10	-10	-10
10	Foreign vacation (com 86) [1]	-95	-95	-50	-25	-10	-10	-10	-10
Other shocks									
11	Export tourism (com 87) [1], demand shift [2]	-95	-95	-50	-25	-10	-10	-10	-10
12	Export education (com 88) [1], demand shift [2]	-50	-50	-50	-25	-10	-10	-10	-10
13	Other non-residential expend. (com 89) [1], demand shift [2]	-25	-25	-25	-10	-10	-10	-10	-10
14	Investment (real)	-40	-30	*-32.69*	*-30.15*	*-28.27*	*-26.46*	*-24.71*	*-23.47*
15	Average propensity to consume	*-26.75*	*-12.41*	*-1.03*	*-0.20*	*-0.09*	*-0.11*	*-0.12*	*-0.14*
16	Domestic business travel, demand shift [2]	-50	-50	-25	-10	-10	-10	-10	-10
17	International business travel, demand shift [2]	-95	-95	-50	-25	-25	-25	-25	-25
18	Demand for U.S. exports, demand shift [2]	-15	-15	-15	-15	-15	-15	-15	-15
19	Labor supply	-0.399	-0.283	-0.158	-0.011	0.000	0.000	0.000	0.000

[1] Commodities 85 to 89 are packages of purchases by U.S. residents when they travel in the U.S. or abroad and packages of goods and services purchased by foreigners when they visit the U.S. The composition of these packages was estimated by Dixon *et al.* (2017) using data from the U.S Travel and Tourism Satellite Accounts published by BEA, see Hobbs (2015).

Domestic vacation. This is the package of services purchased by U.S. residents vacationing or undertaking business travel in the U.S. These services include travel, hotels and restaurants, entertainment, shopping etc.

Foreign vacation. This is the package of services purchased by U.S. residents vacationing or undertaking business travel abroad. The main items in the package are airline tickets purchased from both domestic and foreign suppliers, and Non-comparable imports (e.g. hotel services in foreign countries).

Export tourism. This is the package of services purchased by foreigners visiting the U.S. for tourism or business. These services include airline tickets purchased from U.S suppliers, and travel, hotels and restaurants, entertainment, shopping etc purchased inside the U.S.

Export education and **Other non-residential expenditure** are packages of services purchased by foreign students studying in the U.S. and by foreign embassy officials and workers at international organizations in the U.S., see Dixon *et al.* (2017).

[2] USAGE-Q contains a demand function for Export tourism, relating foreign demand for vacations in the U.S. to the cost to foreigners of these vacations. Rather than assuming direct reductions in Export tourism, we assume movements in the demand function. For example, in Y1Q1 we assume that for any given cost for Export tourism, COVID-19 causes a 95 percent reduction in demand (a -95 percent shock to the demand-shift variable). Similar comments apply in rows 12, 13 and 16-19.

Table A2.2. Representing the fiscal stimulus package, CARES Act, in USAGE-Q ($billion)

	Year 1				Year 1	Year 2				Year 2
	Y1Q1	**Y1Q2**	**Y1Q3**	**Y1Q4**	**Total**	**Y2Q1**	**Y2Q2**	**Y2Q3**	**Y4Q4**	**Total**
Expenditures										
Transfers	487.00	243.50	15.25	15.25	**761**	15.25	15.25	15.25	15.25	**61**
Purchases of goods & services	114.67	57.33	3.00	3.00	**178**	3.00	3.00	3.00	3.00	**12**
Revenue reduction	299.67	149.83	60.75	60.75	**571**	60.75	60.75	60.75	60.75	**243**
Total	901.34	450.66	79.00	79.00	**1,510**	79.00	79.00	79.00	79.00	**316**

Table A2.3. **Description of commodities/industries in USAGE-Q**

No.	Commodity	Description	No.	Commodity	Description
1	OilSeedFarm	Oil seed farming	31	ElectricProd	Electrical products
2	GrainFarm	Grain farming	32	MotorVeh	Motor vehicles
3	VegMelonFarm	Vegetable & melon farming	33	OthAerospace	Aircraft & space vehicles
4	FruitNutFarm	Fruit & nut farming	34	MissileParts	Missile parts
5	GreenNursPrd	Greenhouse & nursery products	35	OthTranEquip	Other transport equipment
6	OthCropFarm	Other crop farming	36	ArmyTanks	Army tanks
7	CattRancFarm	Cattle ranching	37	Furniture	Furniture
8	DairCattProd	Dairy & milk production	38	MedEquiSup	Medical equipment & supplies
9	OtherAnimal	Other animal farming	39	OthMiscMan	Other miscellaneous manufacturing
10	PoultryEgg	Poultry & eggs	40	FoodManuf	Food manufacturing
11	ForestLog	Forestry & logging	41	BeverageTob	Beverages & tobacco
12	FishHuntTrap	Fishing, hunting & trapping	42	ClothTextile	Clothing & textiles
13	AggForSupp	Agricultural & forestry support	43	PaperPrintin	Paper products & Printing
14	CoalOilGas	Coal oil & gas mining	44	PetrolRefine	Petroleum refining
15	OtherMining	Other mining	45	OthPetroCoal	Other petroleum & coal products
16	MiningServ	Mining services	46	OthChemProd	Other chemical products
17	PowerGener	Power generation	47	Pharmaceut	Pharmaceuticals
18	GasWatSewage	Gas, water & sewage services	48	PlasticRubb	Plastic & rubber products
19	NonResCons	Non-residential construction	49	WholesaleTr	Wholesale trade
20	ResConst	Residential construction	50	RetailTr	Retail trade
21	WoodProds	Wood products	51	AirTrans	Air transport
22	NonMetMinPro	Non-metalic mineral products	52	RailTrans	Rail transport
23	IronSteel	Iron & steel	53	WaterTrans	Water transport
24	NonFerMetPr	Non-ferrous metal products	54	TruckTrans	Truck transport
25	FabMetProd	Fabricated metal products	55	GrdPassTrans	Ground passenger transport
26	Ammunition	Ammunition	56	Pipeline	Pipelines
27	Machinery	Machinery	57	OthTransport	Other transportation services
28	Computers	Computers	58	Warehousing	Warehousing
29	OthElectroni	Other electronic equipment	59	PubMovieRec	Motion picture, video & sound recording
30	SemicElCompo	Semi-conductors & electronic components	60	BroadCTelco	Broadcasting, cable & other telecommunication services

Table A2.3 continues

… Table A2.3 continued

No.	Commodity	Description	No.	Commodity	Description
61	DatInterInfo	Data processing & other internet information services	77	Accomm	Accommodation
62	BankingFin	Banking & finance	78	Restaurant & hotels	Restaurant & hotels
63	Insurance	Insurance	79	Other services	Other services
64	Housing	Owner-occupier & tenant housing	80	Federal government	Federal government
65	OthRealEst	Other real estate	81	State & local government	State & local government
66	AssetLease	Rental & leasing services	82	Scrap	Scrap
67	LegalSvces	Legal services	83	Used2HndGds	Used & 2nd hand goods
68	ProfSciTech	Professional, scientific & technical services	84	NoncompImprt	Non-comparable imports
69	ResDevelSvc	Research & development services	85	Domestic vacation	Domestic vacation
70	WasteMgmt	Waste management	86	Foreign vacation	Foreign vacation
71	Education	Education	87	Export tourism	Export tourism
72	AmbulHealth	Ambulatory health services	88	Export education	Export education
73	Hospitals	Hospitals	89	Other non-resident spending	Other non-resident spending
74	NursingRes	Nursing & residential mental health	90	Air transport international	Air transport international
75	SocialAssist	Social assistance	91	Water transport international	Water transport international
76	ArtsEntRec	Arts, entertainment & recreation			

In row 12, we assume 50 percent reductions in foreign student expenditure (Export education) in the U.S. in Y1Q1 toY1Q3, followed by a gradual, although not complete recovery.

In row 13, we assume a relatively mild reduction in expenditure by foreign officials working in the U.S. at embassies and international organizations.

In row 14, we assume a 40 percent reduction in aggregate investment in Y1Q1. This assumption was guided by Walmsely *et al.* (2020) who assumed a shutdown in all private sector construction except emergency repair or maintenance. Under this assumption there would be approximately a 50 percent shutdown in private construction activities. We assume no reduction in public-sector investment activities. Our assumptions for private and public sector investment together imply a reduction in aggregate investment of about 40 percent. After Y1Q1 we assume that construction (and hence investment) will recover slowly. Whereas the -40 and -30 percent deviations in investment in Y1Q1 and Y1Q2 are imposed directly on the model, the investment deviations in Y1Q3 through Y2Q4 are generated endogenously (indicated by unshaded italics). For these quarters, we allowed the model to project investment under the assumption that there is a persisting loss of confidence requiring higher expected rates of return to support any given level of investment. Numerically, we set the loss of confidence variable for quarters 3 to 8 at a level consistent with the investment assumption (deviation of -30 percent) we made for quarter 2.

Row 15 shows our assumptions for the COVID-induced deviations in the average propensity to consume (the ratio of household consumption to household disposable income). As indicated by the unshaded italics, these assumptions were generated endogenously. Our underlying assumption is that only a low percentage, 25 percent, of saved shutdown expenditures is redirected by households to expenditure on other commodities. Under this assumption, the entries in rows 1 to 10, lead to the entries in row 15.

Rows 16 and 17 show our assumptions concerning domestic and foreign business travel. In imposing these assumptions, we assume cost neutrality, that is, we assume that reduced inputs of business travel to industries are replaced by other inputs. By making this assumption, we avoid the implication that reductions in inputs of business travel represent an improvement in technology.

In row 18, we introduce general contractions in world demand for U.S. exports. The magnitudes assumed are broadly consistent with the slowdown in the world trade projected by the World Trade Organization in their press release of April 7, see WTO (2020).

The shocks in row 19 are based on preliminary epidemiological modeling results provided by the U.S. Department of Health and Human Services. Details are in Appendix 3.

Fiscal stimulus, the CARES Act

The federal government's principal economic policy response to COVID-19 is the CARES Act of March 27, 2020. As documented by the Congressional Budget Office in a paper dated April 16, (CBO, 2020), CARES consists of a large number of expenditure and revenue reduction (mainly tax relief) programs. CBO estimates that these programs will increase the public sector deficit by $1.510 trillion in 2020 and $0.316 trillion in 2021. While the CBO estimates refer to calendar years, for modeling convenience in Table A2.2 we have adopted them as though they refer to years starting March 1, 2020 and March 1, 2021.

We divided the CBO's deficit estimates into Transfers, Purchases of goods and services and Revenue reductions. Transfers are payments by the government to households and businesses that are made without requiring goods or services in return. In the CARES Act the main new transfers are various forms of wage replacement for workers who have lost their jobs. While some of these programs are a broadening of the eligibility for unemployment benefits and an increase in the payment rate of benefits, other programs are aimed to make it possible for businesses to maintain their workforce even without meaningful work being available. It is hoped that continuing the link between workers and their employers will facilitate a speedy economic recovery when the COVID health crisis eases.

Purchases included in the CARES Act are mainly medical related covering, among other things, acquisition by federal and state governments of medical equipment, vaccines and other pharmaceuticals, and upgrading of telehealth flexibilities.

Revenue reduction measures in the CARES Act include rebates of income taxes paid by individuals (the $1,200 scheme) and temporary suspension of payroll taxes. These measures are aimed at increasing household demand and improving the viability of businesses.

CBO does not show how CARES expenditures and revenue reductions are spread across quarters within years 2020 and 2021. As can be seen from Table A2.2, we assume that the bulk of the CARES package will be delivered in the period March 1, 2020 to August 31, 2020, that is Y1Q1 and Y1Q2. Press reports, e.g. Forbes (2020) indicate that the package is

being rolled out quickly. On this basis we have assumed that expenditures and revenue reductions will be large in Y1Q1 relative to Y1Q2.

Apart from the items in Table A2.2, the CARES package includes facilities for about $0.5 trillions of loans to the Airline industry. Since these loans must be paid back, the CBO estimates that they have only minor budgetary implications. In line with CBO, we have not included the loans directly in our simulations. We have included them indirectly by assuming that the recovery of critical industries after the medical crisis is not impeded by insolvencies suffered during the crisis.

Appendix 3. Calculating labor supply effects from epidemiological modeling

To assist this project, Tony Cheesebrough (Chief Economist at CISA) supplied us with epidemiological modeling produced on March 30 and April 1, 2020 by the U.S. Department of Health and Human Services (HHS). From the HHS modeling results we extracted the numbers in Tables A3.1 and A3.2.

Table A3.1. Best-guess scenario for COVID-19 infections over the course of the disease in the U.S. differentiated by age group and treatment type: no mitigation

Age bracket	No treatment sought	Treat but not hospitalized	Hospitalize but not in ICU	ICU but no ventilation	Receive ventilation	Total
0-4	4,721,170	8,373,333	355,099	15,782	23,673	13,489,057
5-17	17,235,575	31,579,293	176,666	8,175	11,739	49,011,448
18-49	26,384,586	47,284,947	1,543,498	68,600	102,900	75,384,531
50-64	11,254,144	19,437,514	1,170,431	73,152	219,456	32,154,697
65+	7,755,077	12,962,056	1,008,160	108,017	324,051	22,157,361
Total	67,350,552	119,637,143	4,253,854	273,726	681,819	192,197,094

Table A3.2. Proportion of COVID-19 infections occurring in each quarter under three public health responses

	Year 1				Year 2		
	Y1Q1	Y1Q2	Y1Q3	Y1Q4	Y2Q1	Y2Q2	total
No mitigation	0.9800	0.0170	0.0030	0.0000	0.0000	0.0000	1
Steady state	0.2532	0.5295	0.1835	0.0323	0.0014	0.0001	1
Steady state plus	0.0729	0.5147	0.4029	0.0095	0.0001	0.0000	1

Table A3.1 shows that HHS's "best guess" is that if the COVID-19 epidemic in the U.S. ran its course with no effective public health response (HHS's *No mitigation* case), then about 60 percent of the U.S. population (192,197,094 people) would suffer infection. Of these 67,350,552 would have only mild symptoms and seek no treatment; 119,637,143 would be treated but not be hospitalized, etc. HHS also provides modeling for 13 states which contain results for two other public-health-response scenarios that they label *Steady state* and *Steady state plus*. We deduced that under Steady state, the total number of infections would be 81 percent of those under *No mitigation*, that is, 155,679,646. Under Steady state plus, the total number of infections would be 85 percent of those under *No mitigation*, that is, 163,367,530. The distributions of infection through time in HHS's 13-state study are shown in Table A3.2.

We used the HHS modeling results together with data from other sources to calculate work-days lost and consequent effects on labor supply under the 3 public-health-response scenarios.

Following the assumptions in Ferguson *et al.* (2020), we assumed that a hospitalization requires 8 non-work days for the patient. Sixteen non-work days are required for ICU and medical ventilation patients. Following Dixon *et al.* (2010), we assumed that non-hospitalized patients require 0.5 days non-work days. Next, we used labor-force statistics from BLS (2020a) and U.S. Census Bureau (2019) to derive workforce participation rates by age: 0 percent for people aged 0 to 4; 2 percent for people aged 5 to 17; 76 percent for people aged 18 to 49; 68 percent for people aged 50 to 64; and 20 percent for people aged 65 plus.

From here we calculated Table A3.3. For example, the total labor force days lost through illness for the 18-49 group who require ventilation is 0.76*16*102,900 = 1,251,264. In total, the labor force days lost through illness is 65,040,388.

Table A3.3. Work days lost through illness under best-guess scenario for COVID-19 infections with no mitigation

Age bracket	No treatment sought	Treat but not hospitalized	Hospitalize but not in ICU	ICU but no ventilation	Receive ventilation	Total
0-4	0	0	0	0	0	0
5-17	172,356	315,793	28,267	2,616	3,756	522,788
18-49	10,026,143	17,968,280	9,384,468	834,176	1,251,264	39,464,330
50-64	3,826,409	6,608,755	6,367,145	795,894	2,387,681	19,985,883
65+	775,508	1,296,206	1,613,056	345,654	1,036,963	5,067,387
Total	14,800,415	26,189,033	17,392,935	1,978,340	4,679,665	65,040,388

There are also days lost for caregiving in addition to days lost due to illness. It is assumed that a caregiver is required for COVID-19-infected children, aged 0 to 17. Following Dixon *et al.* (2010), we assumed that 0.5 caregiving days are removed from work days for each non-hospitalized infected child, and 0.35 days are lost from work for each day a child spends in hospital. On the basis of the numbers in Table A3.1, we find that caregiving days lost from work are 32,776, 094.

The sum of caregiving work-days lost and days lost to illness in the no mitigation case is 97,816,486 days (=65,040,388+32,776,094). In the Steady state scenario work days lost is 79,231,354 (= 0.81*97,816,486) and in the Steady state plus scenario work days lost is 83,144,013 (= 0.85*97,816,486). For each of the 3 public-health scenarios we used the distribution in Table A3.2 to distribute the lost work days across quarters. Finally, assuming 65.25 work days per quarter and baseline employment of 156 million, we arrived at the labor supply percentage reductions in Table A3.4. These reductions do not include COVID-related deaths. But with deaths being concentrated in upper age groups their effects on labor supply are negligible.

The percentage reductions in labor supply in Table A3.4 are small relative to the percentage reductions in employment in each quarter (compare Table A3.4 with Figure 2). Consequently, the choice between the 3 public-health responses is not important for our simulation results. We adopted the average effect, last row of Table A3.4. Adopting any of the other rows would have had no discernible effect on our simulation results.

Table A3.4. Percentage reduction in labor supply caused by COVID-19 illness of workers and caregiving for COVID-19 infected children under three public health responses

	Year 1				Year 2	
	Y1Q1	**Y1Q2**	**Y1Q3**	**Y1Q4**	**Y2Q1**	**Y2Q2**
No mitigation	0.942	0.016	0.003	0.000	0.000	0.000
Steady state	0.197	0.412	0.143	0.025	0.001	0.000
Steady state plus	0.060	0.420	0.329	0.008	0.000	0.000
Average	0.399	0.283	0.158	0.011	0.000	0.000

Appendix 4. National Critical Function Capability Indicators and directions for future research

We translate movements in USAGE-Q industry outputs to movements in indicators of National Critical Function (NCF) capability, z_k, via equation (A4.1). The rationale behind (A4.1) is that adverse COVID-19 impacts on USAGE-Q industry j weaken the ability of industry j to service those NCF categories that are reliant on its output.

$$z_k = \sum_{j \in IND} \left(\frac{M_{j,k} \cdot Q_j}{\sum_t M_{t,k} \cdot Q_t} \right) \cdot x_j \quad k \in NCF \qquad \text{(A4.1)}$$

where

IND is the set of USAGE-Q industries;

NCF is the set of NCF categories;

$M_{j,k}$ is a mapping matrix, with values of 1 where industry j is relevant to NCF capability k, or 0 otherwise;

Q_j is the level of output of USAGE-Q industry j, measured by value added;

x_j is the COVID-related percentage deviation in the output of USAGE-Q industry j; and

z_k is the COVID-related percentage deviation in the capability indicator for NCF category k, defined as the share-weighted sum of the percentage deviations in the outputs of USAGE-Q industries classified as relevant (via the values assigned to $M_{j,k}$) to the determination of NCF capability k. The weights are in Table A4.1.

Directions for further development of NCF analysis in a USAGE framework

The investigation of impacts on NCF categories could be extended in a number of ways in future work.

First, we note that the weights in equation (A4.1), which calculates movements in the NCF capability indicator, are assigned in two steps. Industries are deemed to be either relevant or irrelevant to the capability of each NCF, via the assignment of values of 1 or 0 to the elements of $M_{j,k}$. Then, each industry relevant to the capability of a particular NCF is assigned a weight equal to the value of its output (measured by value added). With input from CISA, these weights could be developed in future work. In particular, CISA might have

insights into which industries are relevant to each NCF category, and on appropriate weights to be assigned to each industry in the determination of each NCF's capability index. These insights may be informed by the independent verification and validation of the NAICS to NCF mapping being conducted by the Carnegie Mellon University.

Second, USAGE-Q could be further disaggregated in the industry/commodity dimension to provide more granularity in the inputs to the NCF capability calculation. The full USAGE database contains approximately 400 industries/commodities. For example, rather than assuming as in Table A4.1 that NCF 31 (*Provide and maintain infrastructure*) is 92 percent dependent on the USAGE-Q industry 19 (Non-residential construction), using the full 400-order database it would be possible to split this dependence between 9 USAGE industries: Non-residential maintenance & repair; Residential maintenance & repair; Health care structures; Manufacturing structures; Power & communication structures; Educational & vocational structures; Highway & street construction; Office & commercial structures; and Other non-residential structures. Not only would this support the first line of further development noted above by providing more finely-defined commodity and industry detail against which NCF-specific weights could be assigned, but it would also facilitate selected deeper investigations into particular inputs. With finer commodity and industry detail, it might be possible to undertake case studies into particular NCF categories and their associated inputs, with the aim of investigating whether impairment of particular domestic or imported inputs might be particularly damaging to certain NCF categories.

Third, we could explore whether certain NCF categories can be defined as industries in their own right within the core USAGE model. This might not be suitable for some of the more abstract NCF categories (such as 29 *Preserve constitutional rights*), for which the current methodology (i.e. identifying relevant inputs to the NCF category) will likely remain the preferred approach. However, many of the NCF categories have strong overlaps with particular industrial functions and commodity supplies within USAGE. For example, NCF categories 10, 12, 13-18, 21, 24-26, and 31-55 appear to have strong correspondences with the concept of what constitutes an industry and its activity within USAGE. Not only would explicit disaggregation and identification of these activities within USAGE support some of the ideas for future work outlined above, it would also facilitate, if required, the introduction of NCF-specific production functions (allowing, for example, more or less commodity- and source-specific substitutability than given by the default USAGE theory).

Fourth, we could explore, in a quantitative manner, the interactions and dependencies between NCF categories. This idea is introduced in the *National Critical Functions COVID-19 Dashboard* document (see HSOAC, 2020), which contains, for each NCF category, a "Function Interdependencies" table. These tables describe the various NCF categories that each particular NCF category relies upon or supports. For example, the Function Interdependencies table for NCF category *Fuel Refining and Processing Fuels* notes that it relies upon *Exploration and Extraction of Fuels*, and supports *Transport Cargo and Passengers by Air*. In essence, these tables are describing, in narrative form, input-output relationships between NCF categories. These relationships could be quantified and modeled by explicitly recognizing, where appropriate, NCF activities within the core of the economic model. This would facilitate simulations exploring how impairment of particular economic activities or NCF functions affect downstream NCF categories.

Table A4.1. Weighting schemes for calculations of capability indicator for National Critical Functions

National Critical Function / Industry	1. Operate core network	2. Provide cable access network services	3. Provide internet based content, information, etc	4. Provide internet routing, access, and connection services	5. Provide positioning, navigation and timing services	6. Provide radio broadcast access network services	7. Provide satellite access network services	8. Provide wireless access network services	9. Provide wireline access network services	10. Distribute electricity	11. Maintain supply chains	12. Transmit electricity	13. Transport cargo and passengers by air	14. Transport cargo and passengers by rail	15. Transport cargo and passengers by road	16. Transport cargo and passengers by vessel	17. Transport materials by pipeline	18. Transport passengers by mass transit	19. Conduct elections	20. Develop and maintain public works and services
1 Oil seed farming																				
2 Grain farming																				
3 Vegetable & melon farm																				
4 Fruit & nut farming																				
5 Greenhouse nursery prods																				
6 Other crop farming																				
7 Cattle ranching																				
8 Dairy & milk production																				
9 Other animal farming																				
10 Poultry & eggs																				
14 Coal oil & gas mining																				
15 Other mining																				
16 Mining services																				
17 Power generation										1		1								0.18
18 Gas, water & sewage																	0.76			0.07
19 Non-residential construct																				0.75
20 Residential construction																				
21 Wood products																				
22 Non-metal min products																				
23 Iron & steel																				
24 Non-ferrous metal prods																				
25 Fabricated metal products																				
26 Ammunition																				
27 Machinery																				
28 Computers																				
29 Other electronic equip																				

Table A4.1 continues …

... Table A4.1 continued

Industry \ National Critical Function	1. Operate core network	2. Provide cable access network services	3. Provide internet based content, information, etc	4. Provide internet routing, access, and connection services	5. Provide positioning, navigation and timing services	6. Provide radio broadcast access network services	7. Provide satellite access network services	8. Provide wireless access network services	9. Provide wireline access network services	10. Distribute electricity	11. Maintain supply chains	12. Transmit electricity	13. Transport cargo and passengers by air	14. Transport cargo and passengers by rail	15. Transport cargo and passengers by road	16. Transport cargo and passengers by vessel	17. Transport materials by pipeline	18. Transport passengers by mass transit	19. Conduct elections	20. Develop and maintain public works and services
30 Semi-cond & electronics																				
31 Electrical products																				
32 Motor vehicles															0.36					
33 Aircraft & space vehicles													0.32							
34 Missile parts																				
35 Other transport equip														0.11		0.13				
36 Army tanks																				
38 Medical equip & supply																				
40 Food manufacturing																				
41 Beverages & tobacco																				
44 Petroleum refining													0.45	0.69	0.29	0.76				
46 Other chemical products																				
47 Pharmaceuticals																				
49 Wholesale trade											0.43									
50 Retail trade											0.48									
51 Air transport													0.12							
52 Rail transport														0.2				0.58		
53 Water transport																0.07				
54 Truck transport															0.30					
55 Ground passing transport															0.06			0.42		
56 Pipelines																	0.24			
57 Other transport											0.06									
58 Warehousing											0.04									
59 Publishing			0.33																	
60 Broadcasting & telecom	0.79	1	0.53	1	1	1	1	1	1											
61 Data proc & internet info	0.21		0.14																	
62 Banking & finance																				

Table A4.1 continues ...

... Table A4.1 continued

National Critical Function / Industry	1. Operate core network	2. Provide cable access network services	3. Provide internet based content, information, etc	4. Provide internet routing, access, and connection services	5. Provide positioning, navigation and timing services	6. Provide radio broadcast access network services	7. Provide satellite access network services	8. Provide wireless access network services	9. Provide wireline access network services	10. Distribute electricity	11. Maintain supply chains	12. Transmit electricity	13. Transport cargo and passengers by air	14. Transport cargo and passengers by rail	15. Transport cargo and passengers by road	16. Transport cargo and passengers by vessel	17. Transport materials by pipeline	18. Transport passengers by mass transit	19. Conduct elections	20. Develop and maintain public works and services
63 Insurance																				
64 Owner & tenant housing																				
67 Legal services																				
68 Prof, science & tech serv																				
69 Research & develop serv																				
70 Waste management																				
71 Education																				
72 Ambulatory health serv																				
73 Hospitals																				
74 Nursing & resid. health																				
75 Social assistance																				
80 Federal government																			0.29	
81 State & local govern																			0.71	
90 Air transport internat													0.11							
91 Water transport internat																0.05				
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table A4.1 continues ...

... Table A4.1 continued

National Critical Function / Industry	21. Educate and train	22. Enforce law	23. Maintain access to medical records	24. Manage hazardous materials	25. Manage wastewater	26. Operate government	27. Perform cyber incident management capabilities	28. Prepare for and manage emergencies	29. Preserve constitutional rights	30. Protect sensitive information	31. Provide and maintain infrastructure	32. Provide capital markets and investment activities	33. Provide consumer and commercial banking services	34. Provide funding and liquidity services	35. Provide identity management and support	36. Provide insurance services	37. Provide medical care	38. Provide payment, clearing and settlement services	39. Provide public safety	40. Provide wholesale funding
1 Oil seed farming																				
2 Grain farming																				
3 Vegetable & melon farm																				
4 Fruit & nut farming																				
5 Greenhouse nursery prods																				
6 Other crop farming																				
7 Cattle ranching																				
8 Dairy & milk production																				
9 Other animal farming																				
10 Poultry & eggs																				
14 Coal oil & gas mining																				
15 Other mining																				
16 Mining services																				
17 Power generation											0.10									
18 Gas, water & sewage					1						0.04									
19 Non-residential construct											0.41									
20 Residential construction																				
21 Wood products																				
22 Non-metal min products																				
23 Iron & steel																				
24 Non-ferrous metal prods																				
25 Fabricated metal products																				
26 Ammunition																				
27 Machinery																				
28 Computers																				
29 Other electronic equip																	0.07			

Table A4.1 continues ...

... Table A4.1 continued

National Critical Function / Industry	21. Educate and train	22. Enforce law	23. Maintain access to medical records	24. Manage hazardous materials	25. Manage wastewater	26. Operate government	27. Perform cyber incident management capabilities	28. Prepare for and manage emergencies	29. Preserve constitutional rights	30. Protect sensitive information	31. Provide and maintain infrastructure	32. Provide capital markets and investment activities	33. Provide consumer and commercial banking services	34. Provide funding and liquidity services	35. Provide identity management and support	36. Provide insurance services	37. Provide medical care	38. Provide payment, clearing and settlement services	39. Provide public safety	40. Provide wholesale funding
30 Semi-cond & electronics																				
31 Electrical products																				
32 Motor vehicles																				
33 Aircraft & space vehicles																				
34 Missile parts																				
35 Other transport equip																				
36 Army tanks																				
38 Medical equip & supply																				
40 Food manufacturing																				
41 Beverages & tobacco																				
44 Petroleum refining																				
46 Other chemical products																				
47 Pharmaceuticals																	0.08			
49 Wholesale trade																				
50 Retail trade																				
51 Air transport																				
52 Rail transport																				
53 Water transport																				
54 Truck transport																				
55 Ground passing transport																				
56 Pipelines																				
57 Other transport																				
58 Warehousing																				
59 Publishing																				
60 Broadcasting & telecom											0.45									
61 Data proc & internet info			0.04							0.05					0.06					
62 Banking & finance												1	1	1				1		1

Table A4.1 continues

... Table A4.1 continued

National Critical Function / Industry	21. Educate and train	22. Enforce law	23. Maintain access to medical records	24. Manage hazardous materials	25. Manage wastewater	26. Operate government	27. Perform cyber incident management capabilities	28. Prepare for and manage emergencies	29. Preserve constitutional rights	30. Protect sensitive information	31. Provide and maintain infrastructure	32. Provide capital markets and investment activities	33. Provide consumer and commercial banking services	34. Provide funding and liquidity services	35. Provide identity management and support	36. Provide insurance services	37. Provide medical care	38. Provide payment, clearing and settlement services	39. Provide public safety	40. Provide wholesale funding
63 Insurance																1				
64 Owner & tenant housing																				
67 Legal services									0.07											
68 Prof, science & tech serv							0.73			0.70					0.94					
69 Research & develop serv																				
70 Waste management				1																
71 Education	1																			
72 Ambulatory health serv			0.20														0.34			
73 Hospitals			0.23														0.38		0.23	
74 Nursing & resid. health			0.05														0.08			
75 Social assistance																	0.06		0.03	
80 Federal government		0.29				0.29	0.27	0.29	0.27	0.26									0.23	
81 State & local govern		0.71	0.49			0.71		0.71	0.66										0.50	
90 Air transport internat																				
91 Water transport internat																				
total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table A4.1 continues

... Table A4.1 continued

National Critical Function / Industry	41. Store fuel and maintain reserves	42. Support community health	43. Exploration and extraction of fuels	44. Fuel refining and processing fuels	45. Generate electricity	46. Manufacture equipment	47. Produce & provide agricultural products/services	48. Produce and provide human & animal food products/service	49. Produce chemicals	50. Provide metals and materials	51. Provide housing	52. Provide information technology products/services	53. Provide materiel and operational support in defence	54. Research and development	55. Supply water
1 Oil seed farming							0.11								
2 Grain farming							0.06								
3 Vegetable & melon farm							0.11								
4 Fruit & nut farming							0.13								
5 Greenhouse nursery prods							0.08								
6 Other crop farming							0.08								
7 Cattle ranching							0.12								
8 Dairy & milk production							0.08								
9 Other animal farming							0.14								
10 Poultry & eggs							0.09								
14 Coal oil & gas mining			0.85							0.46					
15 Other mining										0.05					
16 Mining services			0.15												
17 Power generation					1										
18 Gas, water & sewage															1
19 Non-residential construct															
20 Residential construction											0.14				
21 Wood products										0.05					
22 Non-metal min products										0.07					
23 Iron & steel										0.05					
24 Non-ferrous metal prods										0.08					
25 Fabricated metal products										0.24					
26 Ammunition													0.01		
27 Machinery						0.22									
28 Computers						0.07						0.02			
29 Other electronic equip		0.09				0.21									

Table A4.1 continues ...

... Table A4.1 continued

National Critical Function / Industry	41. Store fuel and maintain reserves	42. Support community health	43. Exploration and extraction of fuels	44. Fuel refining and processing fuels	45. Generate electricity	46. Manufacture equipment	47. Produce & provide agricultural products/services	48. Produce and provide human & animal food products/service	49. Produce chemicals	50. Provide metals and materials	51. Provide housing	52. Provide information technology products/services	53. Provide materiel and operational support in defence	54. Research and development	55. Supply water
30 Semi-cond & electronics						0.09						0.03			
31 Electrical products						0.07									
32 Motor vehicles						0.26									
33 Aircraft & space vehicles													0.12		
34 Missile parts													0.02		
35 Other transport equip															
36 Army tanks													0.01		
38 Medical equip & supply		0.04				0.08									
40 Food manufacturing								0.74							
41 Beverages & tobacco								0.26							
44 Petroleum refining	0.15			1											
46 Other chemical products									0.52						
47 Pharmaceuticals									0.48						
49 Wholesale trade	0.85														
50 Retail trade															
51 Air transport															
52 Rail transport															
53 Water transport															
54 Truck transport															
55 Ground passing transport															
56 Pipelines															
57 Other transport															
58 Warehousing															
59 Publishing															
60 Broadcasting & telecom															
61 Data proc & internet info															
62 Banking & finance															

Table A4.1 continues …

... Table A4.1 continued

National Critical Function / Industry	41. Store fuel and maintain reserves	42. Support community health	43. Exploration and extraction of fuels	44. Fuel refining and processing fuels	45. Generate electricity	46. Manufacture equipment	47. Produce & provide agricultural products/services	48. Produce and provide human & animal food products/service	49. Produce chemicals	50. Provide metals and materials	51. Provide housing	52. Provide information technology products/services	53. Provide materiel and operational support in defence	54. Research and development	55. Supply water
63 Insurance															
64 Owner & tenant housing											0.87				
67 Legal services															
68 Prof, science & tech serv												0.95			
69 Research & develop serv														1	
70 Waste management															
71 Education															
72 Ambulatory health serv		0.40													
73 Hospitals		0.32													
74 Nursing & resid. health		0.09													
75 Social assistance		0.07													
80 Federal government													0.86		
81 State & local govern															
90 Air transport internat															
91 Water transport internat															
total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

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