The Potential Global Health, Environmental and Economic Impact of COVID-19

Badri Narayanan Gopalakrishnan*

Department of Environmental and Forest Sciences, University of Washington Seattle, Washington, USA.

Corresponding Author*

Badri Narayanan Gopalakrishnan
Department of Environmental and Forest Sciences
University of Washington Seattle
Washington
USA
E-mail: badri_gopalakrishnan@mckinsey.com

Abstract

Covid-19 has had a wide range of global impacts. We focus on the economic impact of this ongoing crisis through consumption, investment, tourism, trade and other channels, based on a comprehensive economic model that captures the global value chains, trade, production and consumption linkages, health economic impact, etc. Our results suggest a reduction in global GDP by 5.8-8.8 trillion USD, disproportionately affecting the poor. They also suggest a healthcare implication, because many patients suffering from non-Covid diseases have to wait for Covid patients who are higher priority. This means an increase in the Disability Adjusted Life Years (DALY) lost affecting the productivity and demand in the economies further. We also note that policy measures can help mitigate the negative impact of Covid-19, by ensuring better healthcare system, measures to foster physical distancing and supporting the poeple and companies alike to tide through these difficult times.
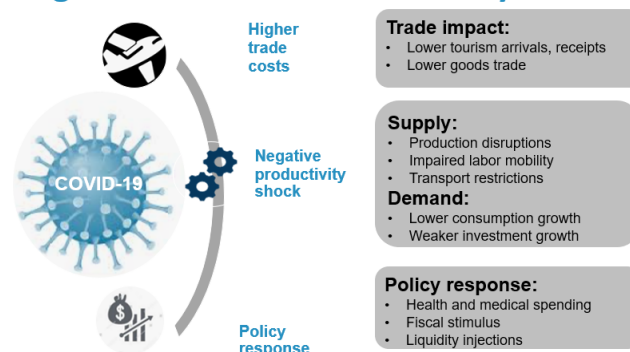
Introduction

On 31 December 2019, a series of pneumonia cases of unknown cause occurred in Wuhan, Hubei, People's Rep. of China (PRC). These cases were subsequently analyzed and named as the 2019 novel coronavirus (2019-nCoV). On 13 January 2020, the first COVID-19 case outside of the PRC was recorded in Thailand. In the next weeks, COVID-19 cases were also reported in Japan, South Korea, the US, France, Canada, Australia, Malaysia, and Germany. Then, on 30 January, the World Health Organization (WHO) declared the corona virus outbreak as an "international public health emergency" as more than 9,000 cases were reported in 18 countries outside of the PRC. Two days after, the first death from COVID-19 outside of the PRC was recorded in the Philippines. By 9 February, the death toll in the PRC surpassed that of the 2002-03 SARS epidemic, which killed 994 people globally. On 12 February, the number of COVID-19 cases started to spike in South Korea. By 21 February, the number of COVID-19 cases also spiked in Italy, signaling the rapid spread of the virus in Europe. By 9 March, Italy placed 60 million of its residents in lockdown. Two days after, the WHO declared COVID-19 a global pandemic. Presently, the virus has spread to 183 countries, infecting 1,425,032 people and claiming 81,932 lives; and the situation in the US and Europe is spreading out of control.

To suppress the spread of COVID-19, many affected countries have restricted the movement of their people. The first to impose this restriction was the PRC, which locked down Wuhan, which has a population of around 11 million, and restricted the movement of people in all cities in Hubei province which has a population of more than 57 million. Italy followed, imposing a quarantined red zone covering 11 towns and villages in the Lombardy and Veneto regions, home to more than 50,000 people. Later, the lockdown was imposed on the entire country. The US also imposed travel bans to and from South Korea and Italy, while South Korea announced a level 4 "do not travel to" advisory for Daegu which has a population of 2.5 million. To date, IATA data suggest that over 148 countries have imposed some form of travel restriction, either via denial of entry to passengers, visa restrictions, or mandatory quarantines, among others. Several countries have also closed their borders, including Egypt, Germany, Canada, the US, Australia, and New Zealand.

These control measures such as restrictions to transport, labor mobility, and closure of workplaces acted as supply shocks to the economy. Initially, these restrictions on transport and the movement of labor impaired the economy's production capacity, disrupting supplies. In turn, it spilt over to the demand side as workers were laid-off and lost their income. Air travel restrictions and border closures restricted not only the movement of people but the movement of goods across borders. In response, governments immediately ramped up outlay on medical supplies such as masks, personal protective equipment, and viral medicines. Later, governments announced various macroeconomic stimuli to support payroll and keep jobs, provide cash transfers and food supplies to poor people, and extend loans and tax assistance to businesses.

This paper explores the potential economic impacts of the COVID-19 outbreak—using a standard, multi-regional, comparative static, with short-run closure, GTAP-computable general equilibrium model—based on three measurable channels, namely: 1) a negative productivity shock that cuts consumption and investment, but raises medical expenditures; 2) an increase in trade costs that affects the movement of people and inbound tourism, as well as industries that are linked to global supply chains; and 3) fiscal stimulus and liquidity injections through various macroeconomic policy instruments (Figure 1).

Fig 1. How it affects the economy

Higher trade costs

Negative productivity shock

Policy response

Trade impact:
- Lower tourism arrivals, receipts
- Lower goods trade

Supply:
- Production disruptions
- Impaired labor mobility
- Transport restrictions

Demand:
- Lower consumption growth
- Weaker investment growth

Policy response:
- Health and medical spending
- Fiscal stimulus
- Liquidity injections

The analysis in this paper revolves around two scenarios: the quick containment and the long containment scenarios. In the quick containment scenario, we assume that the outbreak is controlled within 3 to 6 months, and in the long containment scenario, we assume the outbreak lasts from six months to one year. The calibration of the shocks to productivity, trade costs, and government stimulus are explained below (Table 1):

	Baseline data	Short Containment Scenario	Long Containment Scenario
1.1 Productivity shifter calibrated to cut consumption by	PRC: $5.6 trillion	5% ($280 billion)	5% ($280 billion)
	ROW1: $33.6 trillion+	2% ($672.3 billion+)	5% (1.7 trillion+)
1.2 Productivity shifter calibrated to cut investment by	$6.5 trillion	5% ($324 billion)	6.25% ($405.4billion)
	$11 trillion	2% ($220 billion)	6.25% ($540.6 billion)
1.3 Productivity shifter calibrated to reduce tourism receipts by	$186.5 billion	11.4% ($21.397 billion)	22.9% ($42.4 billion)
	$4,516 billion	4.4% ($268.4 billion)	8.9% ($536.78 billion)
Trade costs		1%	2%
3.1 Productivity shifter calibrated to raise health sector output by		$10,000 per case for developing countries; $20,000 per case for developed countries	Double the expenditure
3.2 Fiscal stimulus and liquidity injections was split as subsidy to labor and capital (50/50)		See Appendix 1	Double the shock in the moderate case + 10% liquidity injection

Table 1: Assumptions

GTAP Model and Database

Forty-two countries/regions and 52 subsectors were analyzed using version 10 of the GTAP computable general equilibrium (CGE) model. As the GTAP model is a multi-regional, comparative static, CGE model of world trade and investment, it provides a comprehensive representation of the economy as a complete system of interdependent components: industries, households, investors, governments, importers and exporters, capturing the economic interactions of each country and/or region with detailed inter-industry links. It also represents markets as perfectly competitive, industry technologies as linearly homogeneous, and traded goods as imperfectly substitutable. Flow-on effects to other countries are also captured in the model via bilateral trade relations from/to all countries/regions in the world. For this exercise, the GTAP database was calibrated using 2018 data from the International Monetary Fund and the Asian Development Bank.

Results

Comparison with the ADO 2020 results: based on the GTAP analysis, global output will decline by between 2.8% to 5.4%. For the People's Rep. of China (PRC), GDP will also fall by between 5.4% to 6.3%. Broadly, the GTAP estimates are about 5% to 20% higher than the ADO estimates, except for Asia ex-PRC where the differences are huge.

	Short Containment		Long Containment	
	ADO 2020	**GTAP**	ADO 2020	**GTAP**
Global	-2.3	**-2.8**	-4.8	**-5.4**
Asia ex-PRC	-1	**-2.3**	-2.2	**-5.4**
PRC	-4.6	**-5.4**	-5.1	**-6.3**
ROW	-2	**-2.3**	-5.1	**-5.4**

Source: ADO 2020 and Staff Estimates

Table 1. Comparative Results: MRIOTADO 2020 and GTAP

A key difference between the ADO and the GTAP run is the presence of trade shock GTAP. This shock accounts for $330 billion or 0.36 percentage point of the global GDP decline in the short containment scenario and $658 billion or 0.72 percentage point in the long containment scenario. The effect on the PRC GDP is $49 billion or 0.34 percentage point in the short containment scenario and $100 billion or 0.69 percentage point in the long containment.

Aside from this extra shock in GTAP, the other differences could be explained by the following factors, namely: 1) the use of fixed shares in the ADO analysis and behavioral equations in GTAP, thus generating stronger interaction effects between demand and supply shocks as well as spillover effects across countries; 2) greater interaction within supply and demand components in GTAP compared to the ADO analysis; 3) the use of productivity shock in GTAP to bring down consumption and investment levels, which also brings down production on the supply side; 4) presence of price and unemployment effects in GTAP which is not present in the ADO analysis; and 5) the general equilibrium nature of GTAP where the 2nd, 3rd, and nth round effects are incorporated.

GDP impact

Under the short containment scenario, GDP growth in the PRC will fall by 5.4%, compared to a world without COVID-19. GDP growth in Asia and the world will also fall by 3.7% and 2.8% respectively, with Asia accounting for about 48% of the overall decline in global output.

Under the long containment scenario, where the outbreak lasts from 6-12 months, output in the PRC will contract by 6.3%, compared to a world without COVID-19. GDP growth in Asia and the world will also fall by 5.8% and 5.4% respectively, with Asia accounting for 38% of the overall decline in global output.

	Short containment	Long Containment	Short containment	Long Containment
Global	-25,34,687	-49,35,014	-2.8	-5.4
Asia	-12,05,122	-18,87,949	-3.7	-5.8
Central Asia	-11,900	-24,697	-2	-4.1

East Asia ex PRC	-1,78,628	-4,05,843	-2.2	-4.9
PRC	-7,82,395	-9,08,405	-5.4	-6.3
Southeast Asia	-99,893	-2,34,074	-2.8	-6.6
South Asia	-81,184	-1,95,198	-2.2	-5.4
Oceania	-49,994	-1,17,719	-2.5	-5.9
Pacific	-1,128	-2,013	-1.6	-2.8
US	-4,22,690	-9,80,254	-2	-4.7
EU+UK	-5,52,965	-12,26,614	-2.5	-5.5

Source: Staff Estimates

Table 2: GDP Impact (Deviation from World without COVID-19)

Sub-regional impacts: Under the 2 scenarios, GDP growth will fall between 2.2% to 4.9% in East Asia excluding the PRC and between 2.8% to 6.6% in Southeast Asia. The greater effects are due to their larger trade and tourism shares relative to GDP. GDP growth in Central Asia will also fall by between 2.0% 4.1% and in the Pacific by between 1.6% to 2.8%.

Euro+UK and US impacts: GDP growth in the Euro areas and UK will contract between 2.5% to 5.5%, while output growth in the US will fall between 2.0% to 4.7%. The combined output decline in the US and Euro+UK is approximately 38% to 45% % of the total output decline in the 2 scenarios.

Effects on trade: The COVID-19 outbreak will also cut global exports by between $451 billion $1,039 billion in the 2 scenarios. Similarly, global imports will also fall by between $454 billion $1,056 billion. In total, global trade could contract by between $905 billion–$2,095 billion in the 2 scenarios.

	Short containment	Long Containment	Short containment	Long Containment
Global	-4,53,946	-10,56,145	-4,51,462	-10,38,792
Asia	-2,27,989	-4,16,390	28,995	-55,889
Central Asia	-56	-1,898	-1,668	3,119
East Asia ex PRC	-30,522	-71,579	-1,00,145	-2,19,598
PRC	-1,61,257	-2,24,055	1,50,730	1,14,656
Southeast Asia	-22,762	-65,289	-15,483	7,927
South Asia	-8,139	-33,953	6,057	51,444
Oceania	-5,123	-19,312	-10,367	-13,258
Pacific	-129	-304	-129	-180
US	-1,10,623	-3,34,522	928	1,24,932
EU+UK	-1,38,218	-2,99,922	-3,32,954	-8,35,733

Source: Staff Estimates

Table 3: Trade Impact (Deviation from World without COVID-19)

Export opportunities: There are export opportunities that emerge in the modelling scenario and this stem from trade redirections that are happening as well as the sharp decline in consumption which also releases goods for exports.

Employment impacts: Globally, employment will fall by between 106 million to 195 million in the 2 scenarios. For Asia, the employment fall will be by between 77 million to 129 million or 66% 72% of the total employment fall. For the PRC, employment will fall by between 45 million to 53 million. The job losses in the short containment scenario is almost five times the observed fall in employment during the 2008 09 global financial crisis, which reduced employment by about 22 million (ILO report).

	Employment ($ million)		Employment (%)	
	Short containment	Long Containment	Short containment	Long Containment
Global	-106.1	-195.3	-4	-7.4
Asia	-76.8	-129.4	-4.8	-8
Central Asia	-1.3	-2.8	-4.7	-9.9
East Asia ex PRC	-2.1	-4.5	-2.8	-6
PRC	-44.5	-53.2	-6.6	-7.9
Southeast Asia	-9.9	-22.8	-3.6	-8.3
South Asia	-18.7	-45.5	-3.4	-8.2
Oceania	-0.3	-0.6	-3.1	-7.4
Pacific	-0.1	-0.1	-2.4	-4.4

US	-2.4	-5.6	-2.7	-6.5
EU+UK	-5	-10.4	-3.4	-7

Source: Staff Estimates

Table 5: Employment Impact (Deviation from World without COVID-19)

Impacts on wage incomes: Wage income will reduce globally, especially for the US, EU, and the UK. Globally, labor income will fall between $535 billion to $1,053 billion. For Asia, the decline in wage income will range from $255 billion to $395 billion or about 38% of the total wage income fall in the 2 scenarios. For the US, EU, and the UK the combined fall in labor income ranges from $191 billion to $448 billion.

	Wage Income ($ million)		Wage Income (%)	
	Short containment	Long Containment	Short containment	Long Containment
Global	-5,35,314	-10,53,262	-2.9	-5.8
Asia	-2,54,763	-3,95,138	-4	-6.2
Central Asia	-2,002	-4,442	-2.2	-5
East Asia ex PRC	-33,736	-78,325	-2.2	-5.2
PRC	-1,77,715	-2,09,488	-5.5	-6.5
Southeast Asia	-16,899	-41,276	-2.9	-7.2
South Asia	-16,090	-40,540	-2.5	-6.2
Oceania	-8,197	-20,836	-2.4	-6.1
Pacific	-124	-232	-1.6	-3
US	-1,02,755	-2,53,481	-2.1	-5.2
EU+UK	-87,797	-1,94,711	-2.6	-5.8

Source: Staff Estimates

Table 6: Wage Income Impact (Deviation from World without COVID-19)

Impacts on poverty and inequality: In general, the fall in employment and wage income will translate to the lower consumption of goods and services and an increase in poverty. Based on poverty growth elasticity (0.5) estimated by Ram (2013) and the estimated 434 million in Asia defined as $1.9/day, the number of poor people could increase by 8 million to 12.6 million[1]. This is close to the ILO estimate of 8.8 million increases in the number of working poor. Inequality could also become more severe as the geographical and sectorial impact of job losses vary. Due to the more significant health impact of COVID-19 on older workers, they will likely suffer more than prime-age workers. Women will also likely to be more affected, as a larger proportion of employment in services is attributed to women (58.6%). Casual employees, gig workers, those employed in the informal sector, and migrant workers, will also are hard hit. Urban centers where the quarantine or lockdowns are in place will be hardest hit.

Impacts of medical expenditures: spending on medical equipment will have small economic impact, ranging from between 0.05% to 0.08%. However, these expenditures are important to control and contain the disease, protect the frontline workers, and save lives.

GDP Results	GDP ($ million)		GDP (%)	
	Short containment	Long Containment	Short containment	Long Containment
Global	46,603	69,905	0.05	0.08
Asia	4,707	7,061	0.01	0.02
Central Asia	32	48	0.01	0.01
E-Asia ex PRC	848	1,272	0.01	0.02
PRC	2,885	4,327	0.02	0.03
Southeast Asia	411	617	0.01	0.02
South Asia	157	236	0	0.01
Oceania	370	556	0.02	0.03
Pacific	4	6	0.01	0.01
US	16,568	24,852	0.08	0.12
EU+UK	23,645	35,469	0.11	0.16

Source: Staff Estimates

Table 7: Impact of Medical Spending (Deviation from World without COVID-19)

Effects of fiscal stimulus: Governments from all over the world have implemented numerous macroeconomic stimulus packages such as tax cuts, support to purchase masks and other medical equipment, cash hand-outs, support to businesses, and liquidity injections through reverse repurchase, expanded quantitative easing, and purchase of treasury bonds

or mortgage-backed securities. These macroeconomic stimuli will potentially raise GDP growth by between 0.6% to 1.6% globally. For Asia, these could also add by between 0.4% to 1.0% to the region's

growth. For the PRC, they could add from 0.3% to 1.0% of its growth. For the EU+UK and the US they could raise growth from: 1.1% to 2.9%, to 0.8% to 2.1%, respectively.

GDP Results	GDP ($ million)		GDP (%)	
	Short containment	Long Containment	Short containment	Long Containment
Global	5,49,035	14,54,370	0.6	1.6
Asia	1,26,746	3,38,030	0.4	1
Central Asia	196	499	0	0.1
E-Asia ex PRC	43,461	98,518	0.5	1.2
PRC	47,594	1,38,304	0.3	1
Southeast Asia	10,906	22,208	0.3	0.6
South Asia	9,685	48,229	0.3	1.3
Oceania	14,863	30,132	0.7	1.5
Pacific	41	140	0.1	0.2
US	1,71,044	4,37,452	0.8	2.1
EU+UK	2,36,210	6,45,538	1.1	2.9

Source: Staff Estimates

Table 8. Impact of Fiscal Stimulus (Deviation from World without COVID-19)

GDP Impact with Government Policy Response: Incorporating the effects of the government's health and macroeconomic policy responses, the net effect of COVID-19 on output growth is more modest. In the short containment scenario, global output will fall by over $1.9 trillion or 2.1% with output in the Asia falling by $1.1 trillion or 3.3%. In the long

containment, global output will fall by about $3.4 trillion or 3.8% with output in the Asia falling by $1.5 trillion or 2.9%. The higher net effect on output growth in Asia relative to the world (in the short containment scenario) is due to the smaller size of government health and macroeconomic policy responses in the region.

	GDP ($ million)		GDP (%)	
	Short containment	Long Containment	Short containment	Long Containment
Global	-19,39,049	-34,10,739	-2.1	-3.8
Asia	-10,73,669	-15,42,858	-3.3	-4.7
Central Asia	-11,672	-24,150	-2	-4
East Asia ex PRC	-1,34,319	-3,06,053	-1.6	-3.7
PRC	-7,31,916	-7,65,774	-5.1	-5.3
Southeast Asia	-88,576	-2,11,249	-2.5	-6
South Asia	-71,342	-1,46,733	-2	-4.1
Oceania	-34,761	-87,031	-1.8	-4.4
Pacific	-1,083	-1,867	-1.5	-2.6
US	-2,35,078	-5,17,950	-1.1	-2.5
EU+UK	-2,93,110	-5,45,607	-1.3	-2.5

Source: Staff Estimates

Table 9: GDP Impact with Health and Macro Policy Response

Policy Implications:

Avoid the occurrence of worst-case scenario by any means necessary: Policymakers should do everything to avoid the worst-case scenario where output losses could reach $4.7 trillion, job losses 128.6 million, and foregone labor income of about $960 billion. These losses are large and will be difficult to recoup. For instance, to recoup these losses in 2 years, output, and growth should be 2.8% higher than potential growth.

It is also likely that a worst-case scenario will trigger a financial crisis which could further deepen the crisis and cause permanent economic scarring arising from more permanent impact on health, education, labor participation, and entrepreneurship. And there are a number of mitigation measures that can help.

Double or triple the size of the current macroeconomic stimulus: In particular, fiscal stimulus appears to be an effective way to counteract the effect of the COVID-19 outbreak. However, presently, the size of the

macroeconomic stimulus is still small relative to the potential impact of the COVID-19 outbreak.

Adopt measures to keep the transport and supply chain open: Based on decomposition, tourism and consumption are the key drag to growth. While we cannot do anything about tourism, we can manage the impact of travel restrictions and quarantine on consumption. One way is to differentiate restrictions on transport of goods, as against restriction on transport of people. Another way is to support e-commerce and online deliveries of goods or food, to keep consumption disruptions to the minimum.

Move supply chains to safe areas: Either in rural areas or countries with low infection rates. As the COVID-19 infections are usually geographically concentrated to urban centers, it is a good idea to move the supply chain to rural areas within a country; or to countries with low infection within the region. This way, the flow of goods and services will not be unduly affected by lockdown policies.

Promote strong income and employment protection program: A key driver of the drop in consumption comes from the huge employment losses globally and in the region. Therefore, governments should support

temporary cash transfers, unemployment subsidy, and the distribution of essential commodities, particularly food to ensure that consumption will not fall sharply. Help should also be targeted to those who are most affected such as older workers, women, unskilled, and informal-sector workers; and workers in urban areas where community lockdowns are in place.

Increase health expenditure to save lives and contain the spread of the virus: While economic effects of health expenditures are miniscule relative to GDP, their impact on human lives, and in controlling and containing the spread of the virus are critical.

Appendix 1: Technical details of our model

Shock 1: Tourism

In the Global Trade Analysis Project (GTAP) dataset, travelers' expenditure is merged with the other cross-border trade flows in both goods and services, based on their shares as described in the GTAP Data Base Documentation.

"Travelers' expenditures" includes spending abroad by tourists, people working overseas for short periods, and the like. The balance of payments statistics treat these expenditures as a single services commodity. But to fit in with the I-O [Input-Output] accounting framework in the GTAP Data Base, we need to resolve them into the standard GTAP commodities; so if a traveler abroad buys a T-shirt or a train ticket, we treat the expenditure as trade in apparel or in "other transport", not in "travelers' expenditures".

Therefore, we use the magnitude of tourism expenditure losses by country and divide each by the total production value of all sectors in GTAP. These are the shocks then given to the output of this sector in every country. We introduced a new variable, qor(REG) in the model, which is the aggregate output across all sectors. This is endogenous by default, and therefore needs to be swapped by an exogenous variable of the same dimension. We choose the technological change or total factor productivity (TFP) variable aoreg(REG) for this swap, because this implies that the tourism shock happened due to factors that are neither policy-driven nor industry-driven, but totally outside the economic system.

The variable qor is simply a weighted aggregation of percent changes in output (qo). The sequence of equations that connect qo with aoreg is as follows:

1. Market clearing equation ensures output equals domestic consumption qds and exports qxs:

$qo(i,r)$

    $= SHRDM(i,r) * qds(i,r)$

    $+ sum(s,REG, SHRXMD(i,r,s) * qxs(i,r,s))$

    $+ tradslack(i,r);$

2. Domestic consumption is a sum of consumption by firms (qfd), households (qpd), and government (qgd):

$qds(i,r)$

$= sum(j,PROD\_COMM, SHRDFM(i,j,r) * qfd(i,j,r))$

$+ SHRDPM(i,r) * qpd(i,r)$

    $+ SHRDGM(i,r) * qgd(i,r);$

3. Each type of consumption above has a CES nest, with an elasticity of substitution between domestic and imports (Armington) dictating the extent of pass through from prices to demand for domestic consumption by each agent. The following is the example equation for domestic private consumption being a function of total private consumption (qp), and private consumption prices – domestic (ppd) and aggregated (pp).

$qpd(i,s) = qp(i,s) + ESUBD(i) * [pp(i,s) - ppd(i,s)];$

4. Each of the prices in the equations like the above are linked to the market prices (pm) – the following shows the example of the private domestic consumption price:

$ppd(i,r) = atpd(i,r) + pm(i,r);$

5. *The following equation links the market price with the supply price, the only difference being the output tax (to), which remains unchanged in our simulations:*

$ps(i,r) = to(i,r) + pm(i,r);$

6. *The following equation links supply price with TFP, i.e. the variable ao, and other prices of intermediate inputs (pf), their associated productivity changes (af) as well as those of primary factors (pfe) and their associated productivity changes (afe and ava):*

$ps(j,r) + ao(j,r)$

$= sum(i,ENDW\_COMM, STC(i,j,r) * [pfe(i,j,r) - afe(i,j,r) - ava(j,r)])$

$+ sum(i,TRAD\_COMM, STC(i,j,r) * [pf(i,j,r) - af(i,j,r)])$

$+ profitslack(j,r)$

7. *Finally, the equation below shows how the total change in TFP may come from the sector-specific TFP aosec, region-specific TFP aoreg and TFP that is specific to a sector and region aoall, which is our swap variable for qo:*

$ao(j,r) = aosec(j) + aoreg(r) + aoall(j,r);$

Shock 2: Consumption

We assume the aggregate private consumption, captured by the private consumption utility variable up, to be shocked to different extents (0.7% and 2% in low and mid/high scenarios respectively), by swapping it with a technological shifter variable in the value-added part of the production "avareg". The link here is through the complex connections between consumption and production. Again, as in all our other shocks, we keep the consumption variable 'up' endogenous and shock the variable *avareg* based on our pre-simulation.

The following equation links nominal private consumption expenditure (yp) and private consumer price index (ppriv) with our variable of interest, up:

$yp(r) - pop(r) = ppriv(r) + UELASPRIV(r) * up(r);$

The following equation connects ppriv with each of the different commodity prices:

$ppriv(r) = sum(i,TRAD\_COMM, CONSHR(i,r) * pp(i,r));$

The following expresses each of these prices as the weighted sum of domestic (ppd) and imported prices (ppm):

$pp(i,s) = PMSHR(i,s) * ppm(i,s) + [1 - PMSHR(i,s)] * ppd(i,s);$

The following equation links the market price with the supply price, the only difference being the output tax (to), which remains unchanged in our simulations:

$ps(i,r) = to(i,r) + pm(i,r);$

The following equation links supply price with TFP, i.e. the variable ao, and other prices of intermediate inputs (pf), their associated productivity changes (af) as well as those of primary factors (pfe) and their associated productivity changes (afe and ava):

$ps(j,r) + ao(j,r)$
$= sum(i,ENDW\_COMM, STC(i,j,r) * [pfe(i,j,r) - afe(i,j,r) - ava(j,r)])$
$+ sum(i,TRAD\_COMM, STC(i,j,r) * [pf(i,j,r) - af(i,j,r)])$
$+ profitslack(j,r);$

Finally, the equation below shows how the total change in TFP may come from the sector-specific TFP aosec, TFP that is specific to a sector and region avall, and the region-specific TFP avareg, which is our swap variable for up:

$ava(j,r) = avasec(j) + avareg(r) + avaall(j,r);$

Shock 3: Investment

Investment slack (qcgdslack) is exogenous in this model. We swap it with investment (qcgds) and shock the latter in the long containment scenario by 6.25% for the People's Republic of China. This means that there will be more or less investment, relative to savings.

Shock 4: Fiscal Stimulus

We take all fiscal stimulus numbers and equally divide them as subsidies for consumption and those for labor (inputs to production).

Appendix 2. Comparison of GDP Impact Estimates between the ADO 2020 (MRIOT) and the GTAP Modeling Results

Economy	"Pre-COVID-19" GDP growth forecasts for 2020 (%)a	ADO 2020 Analysis COVID-19 Impact (% of GDP)		GTAP Analysis COVID-19 Impact (% of GDP)	
		Short containment	Long containment	Short containment	Long containment
People's Republic of China	5.8	-4.60	-5.1	-7.5	-11.2
Bangladesh	8.0	-1.8	-4.9	-4.3	-6.6
Brunei Darussalam	3.0	-1.8	-4.7	-2.7	-4.8
Cambodia	6.8	-4.9	-10.7	-4.9	-7.4
Fiji	2.5	-5.2	-11.6	-2.6	-4.6
Hong Kong, China	0.3	-2.5	-5.7	-4.5	-7.9
India	6.5	-1.9	-5.1	-3.9	-6.0
Indonesia	5.2	-2.1	-5.4	-4.6	-7.1
Kazakhstan	3.8	-2.3	-5.6	-1.6	-3.0
Kyrgyz Republic	4.4	-2.6	-6.5	-2.5	-4.6
Lao PDR	6.2	-2.3	-5.5	-4.9	-7.5
Malaysia	4.7	-2.2	-5.1	-4.0	-6.3
Mongolia	5.5	-3.0	-5.5	-3.9	-6.6
Nepal	6.3	-2.2	-5.7	-7.9	-13.6
Pakistan	2.8	-2.1	-5.5	-3.3	-5.1
Philippines	6.2	-2.3	-5.8	-3.9	-6.0
Republic of Korea	2.3	-2.2	-5.4	-7.7	-11.7
Singapore	1.2	-2.1	-4.9	-6.7	-10.5
Sri Lanka	3.5	-3.4	-8.2	-3.8	-6.0
Taipei,China	2.0	-2.6	-5.6	-2.3	-3.9
Thailand	3.0	-3.5	-7.8	-5.4	-8.1
Viet Nam	6.8	-2.5	-5.8	-2.9	-5.0

ADO = Asian Development Outlook, GDP = gross domestic product, GTAP = Global Trade Analysis Project, Lao PDR = Lao People's Democratic Republic, MRIOT = Multi-Regional Input-Output Table.

aFrom ADB. 2019. ADO Supplement December 2019. Manila.

Source: ADB staff estimates.

Appendix 3. Comparison between the MRIOT Model and the GTAP Model

	ADB's 2018 Multi-Regional Input-Output Table (MRIOT)	Global Trade Analysis Project (GTAP) v.10 Model
Type of model	Multiregional input-output trade model	Multiregional, comparative-static, computable general equilibrium (CGE) model of world trade and investment.
Countries/sector	Aggregated to 62 economies (covering 95% of global GDP), and 35 sectors	Aggregated to 42 countries/regions and 52 subsectors.
Model features	• Shocks to final demand—in this case, tourism demand and domestic consumption—are transmitted across sectors and borders via trade and production linkages • Key element is the Leontief Inverse (see appendix for details)	• Standard features of the model such as the behavior of private individuals, firms, and governments, along with their responses to changing resource and market conditions. • Consumers maximize welfare, subject to their budget limitations, with a relatively sophisticated representation of consumer

	• Sectoral input-output analysis can also incorporate supply shocks (e.g., production disruptions due to forced closures)	demand, allowing for regional differences in the price and income elasticities of demand. • Firms maximize profits using the limited resources available in the economy. Five primary factors of production (land, natural resources, physical capital, and skilled and unskilled labor) are combined with intermediate inputs, including imports, to produce the final output.
Impacts being measured	• Impact on in domestic consumption in the PRC and outbreak-affected economies • Decline in tourism arrivals and receipts (also business travel) • Spillovers via trade and production linkages	• Impact on in domestic consumption in the PRC and outbreak-affected economies • Impact on trade: Production/supply chain disruptions due to forced closures (decline in imports/exports) • Decline in tourism receipts (global) • Impact on employment and wage Income (millions) • Impact of fiscal stimulus (% GDP)
Scenario Settings:		
Consumption	**Short containment, smaller demand shocks:** Growth in domestic consumption in the PRC slows by: - 5 pp; growth in domestic consumption in out-break-affected economies excluding the People's Republic of China (PRC) declines by: -2 pp;	**Short containment:** Decrease in productivity cuts consumption growth by: -6.7 pp in PRC -8.1 pp in the US -7.1 pp in EU -6.6 pp in Japan -6.5 pp in other outbreak-affected advanced economies -3.5 pp in other outbreak-affected ADB developing member countries (DMCs)
	Long containment, higher demand shocks: Growth in domestic consumption in outbreak-affected economies decline by 5 pp;	**Long containment, higher demand shocks:** Decrease in productivity cuts consumption growth by: -10.1 pp in PRC -12.2 pp in the US -10.7 pp in EU -9.9 pp in Japan -9.75 pp in other outbreak-affected advanced economies -5.3pp in other outbreak-affected DMCs
Investment	**Short containment, smaller demand shocks:** Growth in domestic investment in the PRC declines by 6.25 pp; Growth in domestic investment in outbreak-affected economies excluding the PRC declines by 2 pp.	**Short containment:** Decrease productivity cuts investment growth by: -5.4 pp in PRC -8.2 pp in the US -10.0 pp in EU -7.3 pp in Japan -9.2 pp in other outbreak-affected advanced economies -4.4pp in other outbreak-affected DMCs
	Long containment, higher demand shocks: Growth in domestic investment in outbreak-affected economies declines by 6.25 percentage points.	**Long containment:** Decrease productivity cuts investment growth by: -8.1 pp in PRC -12.3 pp in the US -15 pp in EU

		-10.95 pp in Japan
		-13.8 pp in other outbreak-affected advanced economies
		-6.6pp in other outbreak-affected DMCs
Tourism	**Short containment, smaller demand shocks:** Outbound PRC tourism drops by 55% for 3 months (WTO 2019); Economies that impose travel bans on visitors from outbreak-affected economies earn no tourism receipts for 3 months.	**Short containment, smaller demand shocks:** Increase in trade costs bring down tourism receipts by 55% for 3 months for the PRC;
		To zero for 3 months, for economies that impose travel bans on visitors from outbreak-affected economies
	Inbound tourism to outbreak-affected economies falls by 80% for 3 months; Inbound tourism to Asia excluding the PRC, the ROK, and Japan falls by 40% for 3 months; Inbound tourism to Europe excluding the European Union, Norway, Switzerland, and the United Kingdom falls by 30% for 3 months.	By 80% for 3 months, for outbreak-affected economies
		By 40% for 3 months, for Asia excluding the PRC, the ROK, and Japan
		By 30% for 3 months, for Europe excluding the European Union, Norway, Switzerland, and the United Kingdom falls
	Long containment, higher demand shocks: Outbound PRC tourism drops by 55% for 6 months; Economies that impose travel bans on visitors from outbreak-affected economies earn no tourism receipts for 6 months;	**Long containment,** increase in trade costs bring down tourism receipts by 55% for 3 months for the PRC;
		By 55% for 6 months for the PRC
	Inbound tourism to outbreak-affected economies falls by 80% for 6 months; Inbound tourism to Asia excluding the PRC, the ROK, Japan falls by 40% for 6 months; Inbound tourism to Europe excluding the European Union, Norway, Switzerland, and the United Kingdom falls by 30% for 6 months.	To zero for 6 months, for economies that impose travel bans on visitors from outbreak-affected economies
		By 80% for 6 months, for outbreak-affected economies
		By 40% for 6 months, for Asia excluding the PRC, the ROK, and Japan
		By 30% for 6 months, for Europe excluding the European Union, Norway, Switzerland, and the United Kingdom falls
Global supply chain	None	Iceberg costs of industries linked to global supply chain:
		Short containment: Increases by 1%
		Long containment: Increases by 2%
Macroeconomic Stimulus	None	**Short containment:** Half of the announced direct intervention to income and revenues enter as subsidy to consumers and producers
		Long containment: The full amount of the announced direct intervention to income and revenues enter as subsidy to consumers and producers
Data Sources:		
Main database	ADB Multiregional Input-Output	The latest GTAP v.10 database was used and calibrated using 2018 data from the International Monetary Fund and the ADB Multiregional Input-Output Table.
Employment	n/a	GTAP database

Fiscal Stimulus	n/a	Felipe, J. et al. 2020. ADB COVID-19 Policy Database (Version 1, 20 April 2020). Manila: ADB.
Tourism data	IATA. 2020. *COVID-19 Updated impact* assessment of the novel Coronavirus*. 5 March. https://www.iata.org/en/iata-repository/publications/economic-reports/coronavirus-updated-impact-assessment/ World Tourism Organization (WTO). 2020. *Impact assessment of the COVID-19 outbreak on international tourism*. 5 March. https://webunwto.s3.eu-west-1.amazonaws.com/s3fs-public/2020-03/UNWTO-Impact-Assessment-COVID19.pdf WTO. 2019. *Guidelines for the Success in the Chinese Outbound Tourism Market*. Madrid: International Air Transport Association. https://doi.org/10.18111/9789284421138	

%= percentage, $= US dollars, N/A= not applicable, ADB= Asian Development Bank, DMC= developing member countries, EU= European Union, GDP= gross domestic product, IATA= International Air Transport Association, IMF= International Monetary Fund, pp= percentage points, PRC= People's Republic of China, ROK= Republic of Korea, SARS= Severe Acute Respiratory Syndrome, UNWTO= World Tourism Organization.

Source: Asian Development bank.